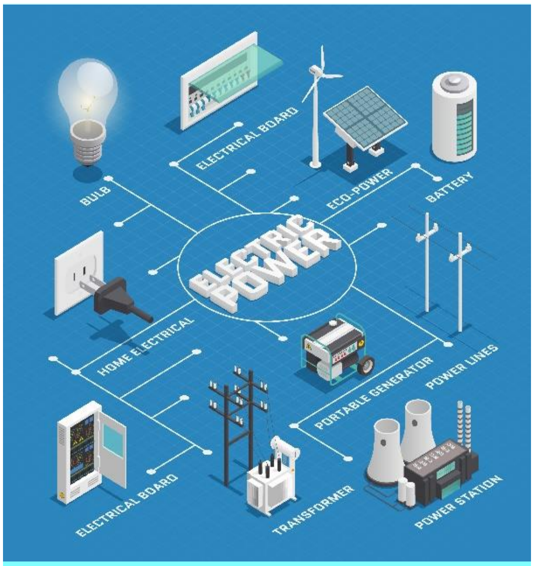

Techno-Economic Feasibility Study on Demand Response Opportunities in Sri Lanka

Final Report

July 2022

Public Utilities Commission of Sri Lanka

ABSTRACT

This report includes a techno-economic feasibility study on Demand Response (DR) opportunities in Sri Lanka conducted by a research group of the University of Moratuwa in collaboration with the Public Utilities Commission of Sri Lanka (PUCSL). Demand Response was developed by electric utilities to increase flexibility on the demand side by temporarily shifting or reducing the peak energy demand, thereby avoiding costly energy procurements and capacity investments for a small number of hours of need. Although DR resources can provide numerous benefits to the power system, particularly those seeking to integrate a large fraction of renewable generation, DR is a challenging area for utilities and grid managers. Use of DR resources as equivalents to traditional generation resources to ensure sufficient capacity during peak-load hours, formulation of DR programs that act as spinning and non-spinning reserves to provide resources during system emergencies, provision of energy services through DR programs that primarily enhance efficient price formation and reliable operation of the system, and analysis of the flexibility of DR programs to accommodate higher penetrations of renewable resources such as wind and solar into the power system are the main objectives discussed in this report.

Further, the study proposes possible cost-effective DR and DSM programs for the existing utility and analyses the opportunities and challenges for the implementation of such programs in Sri Lanka. The industry and customer perspectives in this regard along with the motivational factors were identified through surveys. Moreover, a workshop and a discussion were conducted as a part of this study with the participation of academia and industry experts from the PUCSL, CEB, LECO, DIMO and SEA to incorporate their views on the proposed programs. Necessary policies and regulatory framework to govern the future implementation of DR programs in Sri Lanka and enable it to be compensated in a manner comparable to generation resources have also been identified. In conclusion, this study presents the recommendations for facilitating DR programs in Sri Lanka.

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List of Abbreviations

BESS	-	Battery Energy Storage Systems
CEB	-	Ceylon Electricity Board
CHP	-	Combined Heat and Power
CPP	-	Critical Peak Pricing
DG	-	Diesel Generators
DIMO	-	Diesel and Motor Engineering PLC
DLC	-	Direst Load Control
DR	-	Demand Response
DSM	-	Demand Side Management
EV	-	Electric Vehicles
FC	-	Fixed Charge
FIT	-	Feed In Tariff
HAN	-	Home Area Network
IBP	-	Incentive-Based Programs
LECO	-	Lanka Electricity Company (Private) Limited
MG	-	Microgrids
NAN	-	Neighbor Area Network
PBP	-	Price Based Programs
PUCSL	-	Public Utilities Commission of Sri Lanka
PV	-	Photo-Voltaic
RE	-	Renewable Energy
RTP	-	Real Time Pricing
SEA	-	Sustainable energy Authority
TOS	-	Time of Supply Tariff
TOU	-	Time of Use Tariff
WAN	-	Wide Area Network

CHAPTER 1

1. Introduction

1.1. Introduction

The reliable operation of the power system is imperative in order to achieve a perfect balance between the demand and the supply. This has become a challenging task due to the rapid change in power usage and generation. The main causes for generation reduction are the outages caused in generation plants, and transmission and distribution lines. In terms of load, it could be suddenly changed due to the addition of new loads. In general, Demand-Side Management (DSM) or Demand Response (DR) programs are cheaper options that can be adapted in reducing the gap between the demand and supply benefiting both customers and utilities.

In conventional power systems, the required demand should be supplied by the utility while the proposed DR programs make the system more efficient by keeping the required demand at a minimum level. The DSM approaches are focused on lowering energy consumption costs, limiting peak demand, improving the peak to average demand ratio, reducing user discomfort by changing device operation patterns, and enhancing energy consumption from local generation sources. In general, there are two types of DSM methods.

1) Energy-saving techniques
2) Load-management techniques

Energy-saving methods include a wide range of appropriate measures for reducing power usage in various sectors. The main goal is to reduce total power consumption while maintaining user comfort by optimizing nonflexible load. In terms of load management techniques, they are activities taken on a network to regulate and control the load rather than the power supply in order to achieve a balance between electricity supply and demand.

To execute demand response programs in Sri Lanka, it is crucial to identify the potential technical and economic opportunities as well as constraints. Demand response programs have several obstacles, including raising customer awareness, developing bidirectional communication between utilities and customers, collecting real-time data, etc. The initial cost of the utility will be increased by control, monitoring, and communication systems. The participation of customers is the most important aspect of demand response. Customers may be reluctant to participate because they feel that these programs will solely benefit the utility. They also will be reluctant to waste time monitoring and controlling the load. Customers must be motivated by proper incentives by utilities. Customers who pay flat or block rates have even less responsibility to improve their consumption patterns.

The current market structures lack the appropriate market mechanism. Demand response planning done ahead of time raises doubts about whether it can be completed in real-time. To participate in demand response programs, smart meters, and smart thermostats and switched must be installed on residential customers' premises. Customers are hesitant to hand over their personal information and control to the utilities. Because of the high success and income associated with commercial and industrial customers, demand response programs focus more on them than on residential customers. Customers have less control over the monetary assets used by demand response programs. Further, funding and incentive policies for demand response programs may change from year to year, or they may be eliminated entirely.

This study focuses on highlighting technical and economic opportunities and challenges and giving recommendations for the proper implementation of DR programs. Moreover, customer motivation factors are analyzed by conducting surveys and all the results are discussed in this report. Finally, required policies and regulations are discussed to implement the proposed DR programs in the existing utility grid in Sri Lanka.

1.2. Problem Statement

Electricity demand varies significantly by time of day as well as by season. Historically, the balancing of electricity supply and demand was performed only by increasing or decreasing the electrical output of power plants, but this often requires large investments in capital-intensive facilities that are infrequently used or the dispatch of increasingly inefficient (and therefore expensive) generators. Demand Response (DR) was originally developed by electric utilities in order to increase flexibility on the demand side by temporarily shifting or reducing peak energy demand, thereby avoiding costly energy procurements and capacity investments for a small number of hours of need. Although DR resources can provide numerous benefits to power systems, particularly those seeking to integrate a large fraction of renewable generation.

DR is a challenging new area for most utilities and grid managers. Therefore, techno-economically feasible DR programs should be investigated to develop a better demand management system for the existing utilities in Sri Lanka. This study is mainly focused on researching and analysing the DR programs worldwide and finding solutions for the challenges and drawbacks when implementing such programs in Sri Lanka.

1.3. Project Objectives and Scope

1.3.1. Project Objectives

The main objective of this assignment is to develop a techno-economic feasibility study on demand response opportunities in Sri Lanka.

As specific objectives, it is aimed to,

- Use DR resources as equivalents to traditional generation resources to ensure sufficient capacity during peak-load hours.
- Formulate DR programs that act as spinning and non-spinning reserves to provide resources during system emergencies.
- DR to provide energy services that primarily enhance efficient price formation, but also enhance the reliable operation of the system.
- To attain environmental benefits, resulting from DR's ability to facilitate the integration of renewable resources, the flexibility of DR allows the power system to accommodate higher penetrations of variable resources such as wind and solar**.**

1.3.2. Scope

To conduct a techno-economic feasibility study on DR opportunities in Sri Lanka covering the following as a pilot project.

- Resources that can act as spinning and non-spinning reserves to provide support during system emergencies and their techno-economic feasibility.
- Resources providing ancillary services that include various reserve services, dynamic system regulation, and load-following capabilities that can deliver value to the grid during any hour of the year.
- Storage-type resources that can ramp in both directions to both reduce load and also absorb excess generation that has proven reliable for balancing services (regulation and load-following) at a small scale.
- DR to allow the power system to accommodate higher penetrations of variable resources such as wind and solar.

1.4. *Time Plan of the Research*

Methodology Weeks	1-4	4-8	8-12	12-16	16-20	20-24	24-28	28-32
Performing an extensive literature review on technical, social, and economic impacts of demand response programs. ▪ Assessment of types and technologies of demand response approaches. ▪ Demand response costs and benefits for participants and utilities. ▪ Environmental benefits of DR programs ▪ Researching on DR measurements (Evaluation Indices) ▪ Analysis of demand response-based ancillary services for the power system. ▪ Comparative analysis of available communication technologies for DR ▪ Qualitative analysis of the DR programs ▪ Quantitative analysis of the DR programs								
Performing a technical and economic feasibility study on demand response resources as spinning and non-spinning reserves.								
Identifying the technical and economic opportunities and challenges for the implementation of demand response programs in the Sri Lankan context. ▪ The problems and challenges of DR programs when implementing in the existing utility ▪ Analysis of the demand diversity in Sri Lanka. ▪ Discussion on the novel smart grid-based approaches for the implementation of demand response programs.								

Methodology Weeks	1-4	4-8	8-12	12-16	16-20	20-24	24-28	28-32
Performing a study on the current renewable penetration level in Sri Lanka. ▪ Identifying the positive impacts of demand response in promoting renewable integration								
Identifying the contribution of storage-type resources in balancing demand-supply variations in the power network.								
Conducting surveys in order to find the better DR program for the existing challenges in the Sri Lankan utility. ▪ Survey on TOU Tariff ▪ Survey on Electric Vehicles ▪ Survey on Microgrid ▪ Survey on Diesel Generators ▪ Survey on Net metering								
Evaluating the performance of demand response programs in catering to the peak load ▪ Collecting the load curve data of the existing Sri Lankan Utility ▪ Performance analysis based on the proposed DR programs								
Identifying the necessary policies and regulatory framework for the implementation of demand response programs in the Sri Lankan context.								
Presenting recommendations for the implementation of demand response programs in Sri Lanka.								

1.5. Report Outline

This report presents the fact-findings related to the demand response program implementation. Chapter 1 presents an introduction to the undertaken feasibility study on-demand response opportunities in Sri Lanka together with problem formation, objectives, and defined project scope. The findings from the literature review are included in Chapter 2. Existing demand response programs, costs and benefits of demand response programs from utility and consumer perceptions, opportunities and challenges in demand response program implementation, demand response for renewable energy integration encouragement, etc. are discussed under the literature review.

The challenges when implementing DR programs in the existing utility grid are discussed in Chapter 3 by categorizing them into technological, socio-economic, and miscellaneous challenges. Then, the available opportunities are discussed in Chapter 4 in order to increase the renewable integration level, storage type resources and spinning, and non-spinning reserves in Sri Lanka. Further, a detailed summary of challenges and opportunities is demonstrated in Chapter 5. The next chapter is used to present the outcomes and recommendations of each objective given by the PUCSL and all the outcomes are discussed in detail in the same chapter.

Based on the opportunities and challenges, six proposals are created for Time of Use tariffs, Electric vehicles, Diesel generators, Rooftop solar PV systems, Microgrid and HVAC by analysing customer behaviour and motivational factors by conducting surveys. Further, all proposals are discussed with experts in CEB, PUCSL, LECO, SEA and other service providers in Sri Lanka and based on their comments, each proposal is analysed with the cost calculations, savings, worldwide experiences and finally required policies and regulations are also discussed in the Chapter 7. Finally, the conclusion and all identified future opportunities by the expert views are discussed in Chapter 8.

CHAPTER 2

2. Literature Review

2.1. *Existing Demand Response Programs*

2.1.1. What is Demand Response?

"Changes in electric usage by end-use customers from their normal consumption patterns in response to changes in the price of electricity over time, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized [1]."

Demand Response (DR) is known as a process of changing the electricity usage from the usual consumption patterns by the end-use customers in order to reduce the electricity cost and customers would be paid by intensive or price-based payments if they are inclined to reduce electricity usage at the peak time of the system (high wholesale price) or when changing the system reliability. There are mainly three methods to change electricity usage and customers could have the opportunity to alter the timing, level of demand, and total electricity consumption.

2.1.2. Why Demand Response is Important?

Demand response offers a variety of financial and operational benefits for electricity customers, load-serving entities (whether integrated utilities or competitive retail providers), and grid operators. Electric power systems have three important characteristics. First, because electricity cannot be stored and the supply and demand for electricity must be maintained in balance in real-time. Second, grid conditions can change significantly from day to day, hour to hour, and even within minutes. Demand levels also can change quite rapidly and unexpectedly resulting in mismatches in supply and demand and threatening the integrity of the grid over very large areas within seconds. Third, the electric system is highly capital-intensive, and generation and transmission system investments have long lead times and multi-decade economic lifetimes [2].

These features of electric power systems require that power grids be planned and managed for years in advance to ensure that the system can operate reliably in real-time, despite the many uncertainties surrounding future demands, fuel sources, asset availability, and grid conditions. Working in a competitive bulk power market, load-serving entities (integrated utilities or retail electric providers) buy or build from 60 to 95% of their electricity in advance, with the expectation that they will be able to generate enough electricity in real-time to meet changing system demands.

These challenges and uncertainties are what make demand response valuable. It offers flexibility at a relatively low cost. Grid operators or utilities and other entities can use demand response to curtail, or shift loads instead of, traditionally, building more generation. And although it takes time to establish and adopt customers for a demand response program, well-structured pricing and incentive-based demand response can produce significant savings in close to real-time, often at lower costs than supply-side resources.

2.1.3. Customer Response

There are three general actions by which a customer response can be achieved. Each of these actions involves cost and measures taken by the customer. First, customers can reduce their electricity usage during critical peak periods when prices are high without changing their consumption patterns during other periods. This option involves a temporary loss of comfort. This response is achieved, for instance, when the thermostat settings of heaters or air conditioners are temporarily changed. Secondly, customers may respond to high electricity prices by shifting some of their peak demand operations to off-peak periods, for example, they shift some household activities (e.g., dishwashers, pool pumps) to off-peak periods. The residential customer in this case will bear no loss and will incur no cost. However, this will not be the case if an industrial customer decides to reschedule some activities and the costs of rescheduling are incurred to make up for the services lost. The third type of customer response is by using onsite generation or customer-owned distributed generation. Customers who generate their own power may experience zero or very little change in their electricity usage pattern; however, from the utility perspective, electricity usage patterns will change significantly, and demand will appear to be smaller.

2.2. *Types of Demand Response Programs*

Demand response can be classified according to how load changes are brought about. There are two main types to this as follows.

2.2.1. Price-based Demand Response Programs

This refers to changes in usage by customers in response to changes in the prices they pay and includes real-time pricing, critical peak pricing, and time-of-use rates [2]. If the price differences between hours or periods are significant, customers can respond to the price structure with substantial changes in energy use, reducing their electricity bills if they adjust the timing of their electricity usage to take advantage of lower-priced periods and/or avoid consuming when prices are higher. Customers' load usage modifications are entirely voluntary.

2.2.2. Incentive-based Demand Response Programs

These are established by utilities, load-serving entities, or a regional grid operator. These programs give customers load reduction incentives that are separate from, or additional to, their retail electricity rate, which may be fixed (based on average costs) or time-varying. The load reductions are needed and requested either when the grid operator thinks reliability conditions are compromised or when generation costs are too high. Most demand response programs specify a method for establishing customers' baseline energy consumption level, so observers can measure and verify the magnitude of their load response. Some demand response programs penalize customers that enrol but fail to respond or fulfil their contractual commitments when events are declared.

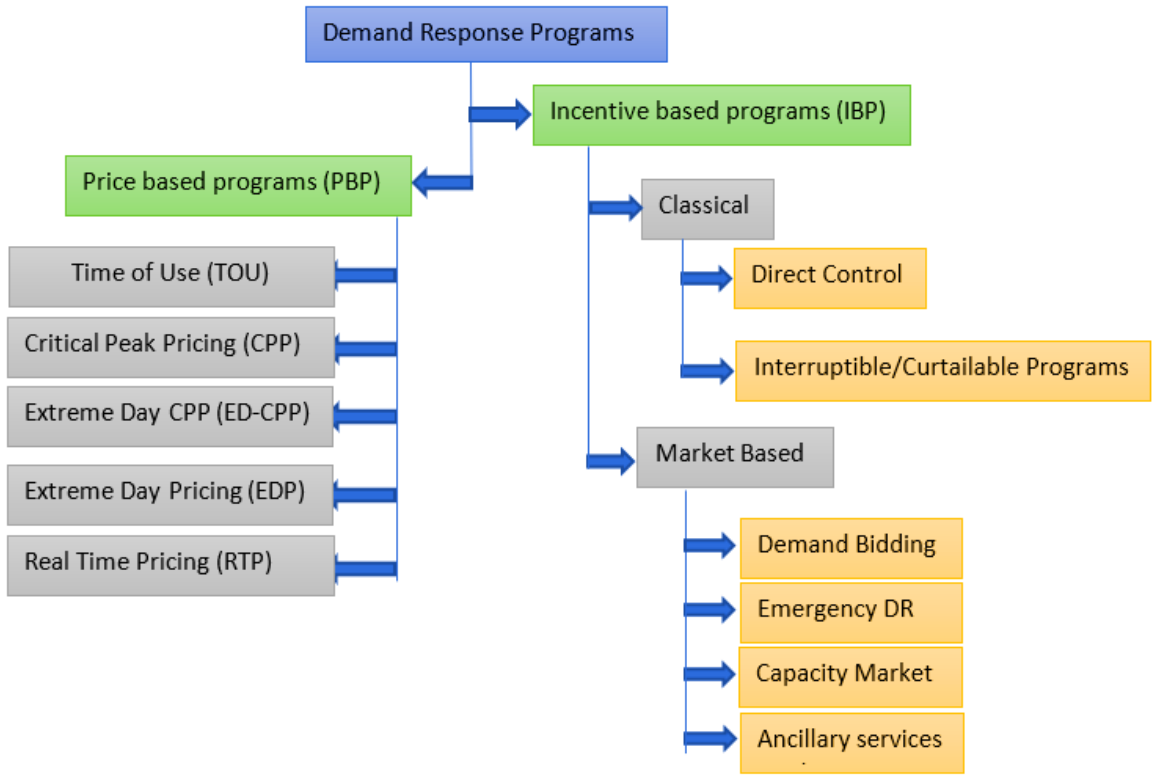


Figure 1. Existing Demand Response Programs

Different DR programs are shown in Fig. 1. These programs can be classified into two main categories: Incentive-Based Programs (IBP) and Price-Based Programs (PBP) [3]. IBP is further divided into classical programs and market-based programs.

Classical IBP includes Direct Load Control programs and Interruptible or Curtailable Load programs. In classical IBP, participating customers receive participation payments, usually as a bill credit or discount rate, for their participation in the programs. In market-based programs, participants are rewarded with money for their performance, depending on the amount of load reduction during critical conditions. In Direct Load Control programs, utilities have the ability to remotely shutdown participants' equipment on short notice. Typical remotely controlled equipment includes air conditioners and water heaters. This kind of program is of interest mainly to residential customers and small commercial customers. As with Direct Load Control programs, customers participating in Interruptible/Curtailable Programs receive upfront incentive payments or rate discounts. Participants are asked to reduce their load to predefined values. Participants who do not respond can face penalties, depending on the program terms and conditions.

Market-based IBP includes Emergency DR Programs, Demand Bidding, Capacity Market, and the Ancillary services market [3]. Demand Bidding (also called Buyback) programs are programs in which consumers bid on specific load reductions in the electricity wholesale market. A bid is accepted if it is less than the costs. When a bid is accepted, the customer must curtail his load by the amount specified in the bid or face penalties. On the other hand, in Emergency DR Programs, participating customers are paid incentives for measured load reductions during emergency conditions. Furthermore, Capacity Market Programs are offered to customers who can commit to providing pre-specified load reductions when system contingencies arise. Participants usually receive a day-ahead notice of events and are penalized if they do not respond to calls for load reduction.

PBP programs are based on dynamic pricing rates in which electricity tariffs are not flat; the rates fluctuate following the real-time cost of electricity. The ultimate objective of these programs is to flatten the demand curve by offering a high prices during peak periods and lower prices during off-peak periods. These rates include the Time of Use (TOU) rate, Critical Peak Pricing (CPP), Extreme Day Pricing (EDP), Extreme Day CPP (ED-CPP), and Real-Time Pricing (RTP) [2],[3]. The basic type of PBP is the TOU rates, which are the rates of electricity price per unit consumption that differ in different blocks of time. The rate during peak periods is higher than the rate during off-peak periods. The simplest TOU rate has two-timed blocks, the peak and the off-peak. The rate design attempts to reflect the average cost of electricity during different periods.

CPP rates include a pre-specified higher electricity usage price superimposed on TOU rates or normal flat rates. CPP prices are used during contingencies or high wholesale electricity prices for a limited number of days or hours per year. On the other hand, EDP is similar to CPP in having a higher electricity price and differs from CPP in the fact that the price is in effect for the whole 24 h of the extreme day, which is unknown until a day ahead. Furthermore, in ED-CPP rates, CPP rates for peak and off-peak periods are called during extreme days. However, a flat rate is used for the other days.

RTP are programs in which customers are charged hourly fluctuating prices reflecting the real cost of electricity in the wholesale market. RTP customers are informed about the prices on a day-ahead or hour-ahead basis [3]. Many economists are convinced that RTP programs are the most direct and efficient DR programs.

2.3. *Summary of Demand Response Options*

Table 1. Summary of Demand Response Options

Price-based programs	Incentive-based programs
	Classical
Time-of-use (TOU): A rate with different unit prices for usage during different blocks of time, usually defined as a 24-hour day. TOU rates reflect the average cost of generating and delivering power during those time periods.	**Direct load control:** a program by which the program operator remotely shuts down or cycles a customer's electrical equipment (e.g., air conditioner, water heater) on short notice. Direct load control programs are primarily offered to residential or small commercial customers.
Critical Peak Pricing (CPP): CPP rates are a hybrid of the TOU and RTP design. The basic rate structure is TOU. However, provision is made for replacing the normal peak price with a much higher CPP event price under specified trigger conditions (e.g., when system reliability is compromised, or supply prices are very high).	**Interruptible/curtailable (I/C) service:** curtailment options integrated into retail tariffs that provide a rate discount or bill credit for agreeing to reduce load during system contingencies. Penalties may be assessed for failure to curtail. Interruptible programs have traditionally been offered only to the largest industrial (or commercial) customers.
Real-time pricing (RTP): A rate in which the price for electricity typically fluctuates hourly reflecting changes in the wholesale price of electricity. Customers are typically notified of RTP prices on a day-ahead or hour-ahead basis.	Market -based
	Demand Bidding/Buyback Programs: customers offer bids to curtail based on wholesale electricity market prices or an equivalent. Mainly offered to large customers (e.g., one megawatt [MW] and over).
	Emergency Demand Response Programs: programs that provide incentive payments to customers for load reductions during periods when reserve shortfalls arise.
	Capacity Market Programs: customers offer load curtailments as system capacity to replace conventional generation or delivery

	resources. Customers typically receive day-of notice of events. Incentives usually consist of up-front reservation payments and face penalties for failure to curtail when called upon to do so.
	Ancillary Services Market Programs: customer's bid load curtailments in ISO/RTO markets as operating reserves. If their bids are accepted, they are paid the market price for committing to be on standby. If their load curtailments are needed, they are called by the ISO/RTO and may be paid the spot market energy price.

2.4. Study on Potential Benefits Expected from DR Programs for Participants and Owners

Demand response produces benefits primarily as resource savings that improve the efficiency of electricity provision. It is instructive to trace the flow of these benefits through the market to ascertain who gains and by how much. Accordingly, the benefits of demand response can be classified in terms of whether they accrue directly to participants or to some or all groups of electricity consumers.

Participant bill savings: electricity bill savings and incentive payments earned by customers that adjust the load in response to current supply costs or other incentives.

Bill savings for other customers: lower prices that result from demand response translate into reduced supply costs to retailers and eventually make their way to almost all retail customers as bill savings.

Reliability benefits: reductions in the likelihood and consequences of forced outages that impose financial costs and inconvenience on customers. Demand response also provides other benefits that are not easily quantifiable or traceable but can have a significant impact on electricity market operation.

Market performance: demand response acts as a deterrent to the exercise of market power by generators.

Improved choice: customers have more options for managing their electricity costs.

System security: system operators are provided with more flexible resources to meet contingencies.

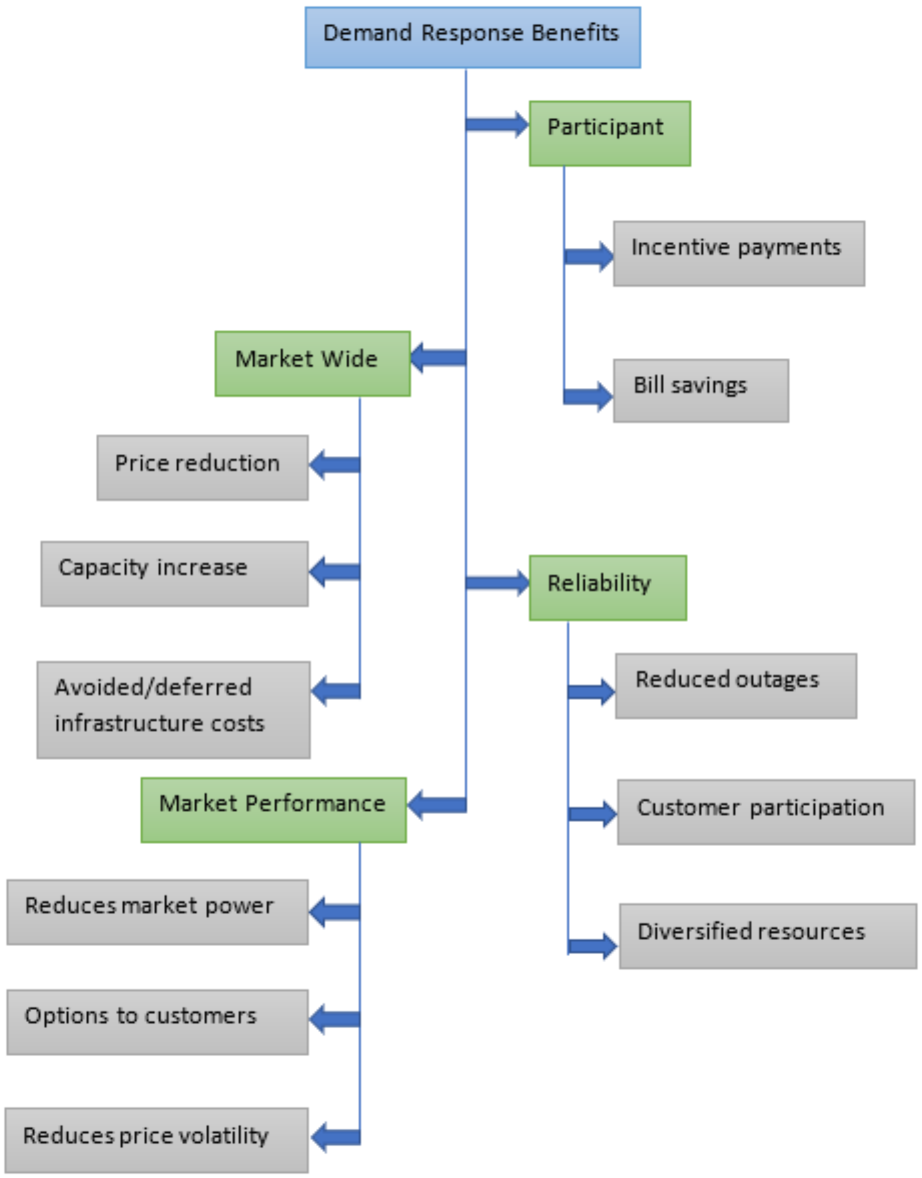


Figure 2. Benefits Associated with DR Programs

Fig. 2 summarizes the benefits associated with DR; they fall under four main categories: participant, market-wide, reliability, and market performance benefits. Customers participating in DR programs can expect savings in electricity bills if they reduce their electricity usage during peak periods. In fact, some participants may experience savings even if they do not change their consumption pattern if their normal consumption during high price peak periods is lower than their class average. Some customers might be able to increase their total energy consumption without having to pay more money by operating more off-peak equipment. Moreover, participants in classical IBP are entitled to receive incentive payments for their participation, while market-based IBP customers will receive payments according to their performance [4].

The benefits of DR programs are not only for program participants; some are market-wide. An overall electricity price reduction is expected eventually because of more efficient utilization of the available infrastructure, as in, for example, the reduction of demand from expensive electricity generating units. Moreover, DR programs can increase short-term capacity using market-based programs, which in turn, results in avoided or deferred capacity costs. The cascaded impact of DR programs includes avoided or deferred need for distribution and transmission infrastructure enforcements and upgrades. All of the avoided or deferred costs will be reflected in the price of electricity for all electricity consumers (DR program participants and nonparticipants).

Reliability benefits can be considered as one of the market-wide benefits because they affect all market participants. Because of their importance, we have considered reliability benefits as one category by themselves. By having a well-designed DR program, participants have the opportunity to help in reducing the risk of outages. Simultaneously and as a consequence, participants are reducing their own risk of being exposed to forced outages and electricity interruption. On the other hand, the operator will have more options and resources to maintain system reliability, thus reducing forced outages and their consequences.

The last category of DR program benefits is improving electricity market performance. DR program participants have more choices in the market even when retail competition is not available. Consumers can manage their consumption since they have the opportunity to affect the market, especially with market-based programs and dynamic pricing programs. This was the prime driver for many utilities to offer DR programs, especially for large consumers.

2.5. Summary of Demand Response Benefits

Table 2. Summary of Demand Response Benefits

Participant financial benefits are the bill savings and incentive payments earned by customers that adjust their electricity demand in response to time-varying electricity rates or incentive-based programs.	**Market-wide financial benefits** are the lower wholesale market prices that result because demand response averts the need to use the most costly-to-run power plants during periods of otherwise high demand, driving production costs and prices down for all wholesale electricity purchasers.
DR Benefits	
Reliability benefits are the operational security and adequacy savings that result because demand response lowers the likelihood and consequences of forced outages that impose financial costs and inconvenience on customers.	**Market performance benefits** refer to demand response's value in mitigating suppliers' ability to exercise market power by raising power prices significantly above production costs.

2.6. Demand Response Costs for Participants and Utilities

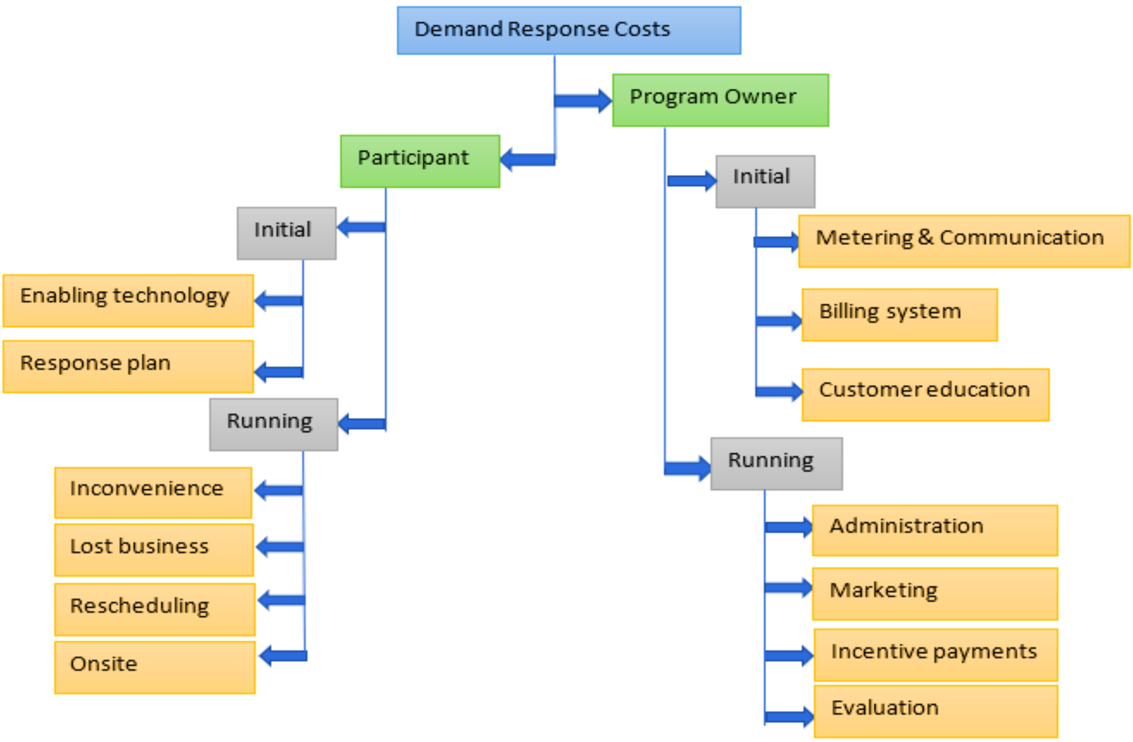


Figure 3. Costs Associated with DR Programs

Any DR program involves different kinds of costs. Fig. 3 shows a classification of DR program costs, where both DR program owners and participants incur initial and running costs. The program participant might need to install some enabling technologies to participate in a DR program: smart thermostats, peak load controls, energy management systems, and onsite generation units [5]. A response plan or strategy needs to be established so that it can be implemented in case of an event. These initial costs are usually paid by the participant; however, technical assistance should be provided by the program.

Participants running costs are those associated with events. Depending on the response plan, these costs may vary. A reduction of comfort may result if a customer decides to reset the thermostat, which results in customer inconvenience that is difficult to quantify. Other event-relevant costs are easier to quantify, for instance, lost business or rescheduling of industrial processes or activities. If a participating customer decides to use a backup onsite generation unit, fuel and maintenance costs need to be considered. The program owner must take care of initial and running system-wide costs. Most DR programs involve metering and communication costs as initial costs. Utilities need to install advanced metering systems to measure, store and, transmit energy usage at required intervals, e.g., hourly readings for real-time pricings. Running costs of DR programs include administration and management costs of the program. Moreover, incentive payments are considered a part of the running costs of IBP. Upgrading the billing system is necessary before most DR programs are deployed, especially PBP for enabling the system to deal with the time-varying cost of electricity.

2.7. *Researching on DR Measurements (Evaluation Indices)*

Evaluation and comparison of the existing DR programs have become a challenging task due to the different DR mechanisms in place such as price-based DR and incentive-based DR. It is of utmost importance to get an idea of the economic performance and the effectiveness of these DR mechanisms to decide how successful a particular DR program is.

Some considerations when analyzing the DR methods can be identified as follows [6].

- Effectiveness of the communication technologies between stakeholders
- The efficiency of financial incentives for different stakeholders
- The efficiency of flattening the peak load
- Efficiency towards sustainability of the DR program
- The efficiency of media in influencing the customer
- Security and privacy in the information and communication systems involved
- Economical, financially feasible, and sustainable designs

There are different performance metrics namely Key Performance Indicators (KPIs) that can be used to evaluate DR programs based on peak reduction, demand variation and reshaping, and economic benefits.

2.7.1. KPIs for Peak Reduction Quantification

The reduction in peak demand can be measured using the following indices.

- $Change\ in\ total\ electricity\ consumption\ per\ day = \frac{Original\ consumption - New\ consumption}{Original\ consumption}$

Original consumption refers to the consumption before starting the DR program and new consumption refers to the consumption after DR inception.

- $Change\ in\ total\ electricity\ consumption\ during\ the\ peak\ hours$
$$= \frac{Original\ peak\ consumption - New\ peak\ consumption}{Original\ peak\ consumption}$$
- $Change\ in\ total\ electricity\ consumption\ during\ the\ off-peak\ hours$
$$= \frac{Original\ off{-}peak\ \ consumption - New\ off{-}peak\ \ consumption}{Original\ off{-}peak\ consumption}$$

2.7.2. KPIs for Demand Variation Analysis and Demand Reshaping

- Uncertainty of demand shed

This is a time series that records the customer demand variation which is the difference between the actual demand and the baseline or the predicted demand during DR events. It can be measured using the flowing methods.

a. Variance – Higher the variance, the higher the uncertainty
b. Entropy – This is an estimate of the uncertainty in the demand reduction. Higher the entropy, the higher the uncertainty.
c. Risk – This indicates the uncertainty or the risk associated with the demand reductions of customers. The lower the probability, the higher the risk.

- Delay responsiveness of demand shed

This is a time series that records the time required by a customer to shed his demand during the past DR events. Customers can be classified into different categories based on this indicator and hence can be used for demand response programs during critical times.

2.7.3. Economic KPIs

DR economics is directly related to the user demand variation, user comfort, and benefits received by the customers [6]. Therefore, the following indicators can be used to quantify the economic-related DR effect.

- Price elasticity
  a. Self-elasticity

     This indicator measures the reduction in demand during a certain time interval as a result of the prices involved during that time. Higher elasticity values depict increased price response by the customers.
  b. Cross-elasticity

     This indicator measures the effect of the price of a certain time interval on electricity consumption during another interval. The effect of reduced electricity usage on other products and services is considered here. When a person buys less electricity, he/she has more money to spend on other products and services.

c. Elasticity of substitution

This indicator measures the rate at which the customers substitute off-peak consumption for peak consumption as a result of the change to the ratio of peak to off-peak prices. This is important in TOU and CPP pricing programs.

- Rate of participation

  Factors affecting the rate of participation include,

  a. incentives offered
  b. program requirement and conditions (duration and frequency of curtailment)
  c. risk assessment
  d. effectiveness of the DR programs

- Discomfort caused for customers

  KPIs for measuring the DR economics can be identified as follows.

a. Demand price elasticity (Self elasticity)

$$Demand\ price\ elasticity\ = \frac{Change\ in\ energy\ demand}{Change\ in\ price}$$

This measures the sensitivity of customer demand to price changes.

b. Customer responsiveness

This measures how many customers have responded to a particular DR program following the DR signals sent and can be expressed as a percentage.

c. Absolute or relative load impact

This indicates the intensity of the customer response and is measured as the number of kW of load curtailed or as a percentage of the customer's total load which is being curtailed.

d. Absolute discomfort impact

This indicates how the comfort levels of the customers have changed. For example, the customers may temporarily switch off the air conditioning or heating.

e. Discomfort level against total energy reduction constraint

This measures the level of discomfort caused as a result of the predetermined percentage reduction of total consumption by the customer.

f. Total energy reduction against discomfort level constraint

Here, the maximum reduction of energy consumption can be achieved without exceeding a specific discomfort.

2.8. Environmental Benefits of DR Programs

A proper Demand Response (DR) program will benefit the power system not only in the economic aspect but also in the environmental aspect as well. In addition to increasing the reliability of regional electric grids, the implementation of a DR program will provide numerous environmental benefits by decreasing the electricity demand during peak hours. These benefits include energy conservation, reduction of the need for conventional power plants, and facile integration of renewable energy into the electricity grid with better management and stability [7]. In the following sections, the environmental benefits of the DR programs will be discussed.

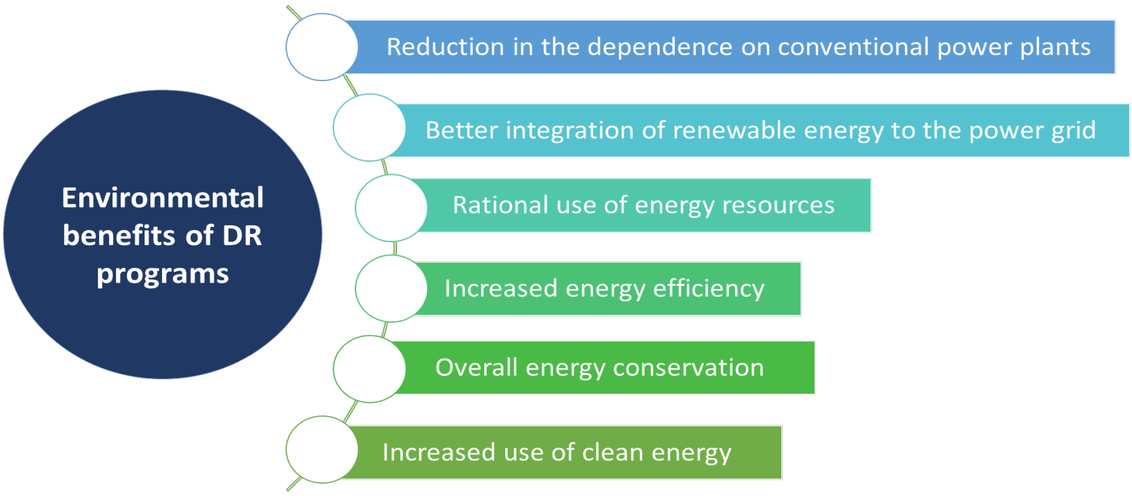


Figure 4. Environmental Benefits of the DR Programs

<u>Decrease in the dependence on conventional power plants</u>

Most of the power plants that run during peak hours are conventional. These power plants including diesel generators, combined cycles, and other on-site generations with microturbines and some biofuel plants that are used to cater to the increased demand during peak hours emit harmful gases during the generation. These gases include air pollutants like Nitrogen Oxides (NO_x), Sulphur Dioxides (SO_2), Carbon Monoxide (CO), Particulate Matter (PM), and other air toxicants [7]. These pollutants will cause multiple impacts on public health and environmental pollution by increasing ground ozone levels, acid rain, and climate change and will ultimately result in damage to the ecosystem.

These peak-period conventional energy generation can be reduced if a proper DR program was to be implemented thus reducing the cumulative environmental pollution. If the consumer demand during peak periods can be shifted to off-peak periods, the required amount of fossil fuel-based generation will be reduced.

Increased energy efficiency

By employing a proper demand response program, the overall power system efficiency will be increased since it shifts individual electricity consumption from peak hours to off-peak hours when the demand has settled. Furthermore, along with shifting the demand, DR programs decrease the total energy consumption due to the appropriate coordination of conventional and non-conventional resources.

Better integration of renewable energy into the power grid

Renewable energy sources, such as solar and wind are variable, hence the energy generation from them will vary depending on the weather conditions and time of the day. However, large power plants are unable to adjust their output quickly responding to these fluctuations from renewable generation. In contrast, demand response resources can respond to these sudden variations, hence, more renewables can be integrated into the existing power grid.

When the share of renewable energy increases, it benefits the environment by lowering greenhouse gas emissions and lowering the carbon footprint, but it requires more flexibility in the system to manage the sudden fluctuations in supply [7]. Hence, the system operators are bound to limit the supply from renewable energy generations as far as the system is not flexible for these variations. Employing a demand response program to match with renewable energy generation can mitigate this problem of limitations and ensure the renewable energy resources meet their full potential. For example, some peak energy usage can be shifted to night when the demand is settled, and also the wind energy production is generally high. Furthermore, from the daily load curve, it is seen that there is a sudden rise in the demand when people get home from work, coinciding with the reduction of solar energy generation due to the setting sun. Hence, this drop in solar power combined with high demand should be supplied by other resources. So, a demand response program will benefit the system operators to respond quickly to these changes.

DR offers a lot of environmental benefits such as a reduction in the dependence on conventional power plants, increased energy efficiency, and better integration of renewable energy to the power grid. Apart from that, it will benefit the power grid from the rational use of energy resources, increased use of clean energy, and overall energy conservation [8]. The more the country's power needs are met by increased energy efficiency and clean renewable energy technologies, the greater the benefits to the public and power sector. Hence, employing a proper DR program is important to maintain an efficient, reliable, and environmentally friendly power system.

2.9. Analysis of the Worldwide DR Programs

Demand Response Programs currently in use in electricity markets can either be active, in which case they are fully integrated into market-based programs and participate in the market-clearing price, or reactive, in which case they are unable to participate in the market-clearing price but provide the same common services as fully integrated demand response programs. Fully integrated market-based demand response can now play a significant role in the electrical market [8],[9], for example:

Energy Resource: Dispatch is the real-time adjustment of resource output in response to demand conditions. For economic reasons, demand response that participates in an electricity energy market can be dispatched.

Capacity Resource: This service entailed a payment structure aimed to entice market participants to commit a certain amount of company capacity to produce electricity or reduce demand during peak periods. In capacity markets, demand response can play a significant role in ensuring resource adequacy. Demand response program providers should be able to reduce load within 30 minutes to two hours on little notice.

Ancillary Services Resource: This service assists the system in maintaining needed characteristics such as voltage or frequency ratio, as well as the ability to restore demand and supply balance following large unanticipated changes. Demand response, which can reduce loads with little warning (less than 30 minutes), can be an important ancillary service in ancillary markets. The following are some examples of ancillary services

Frequency regulation (primary reserve): This service is an automatic generation control offered by reserves that may respond to any changes in system frequency promptly.

Spinning reserve: This service is on-demand and underutilized reserve capacity that is synced to the grid and can be activated at any time by the operator's discretion.

Supplementary reserves (Replacement service): This service is similar to spinning reserve, but it will take longer to respond (usually 30 to 60 minutes).

Non-spinning reserve: This is an off-line generation capacity that can be synced to the grid by system operation decision.

Regulating reserve: This service comprises a centralized, automated control system with authorities to alter the sources and demand in order to maintain the system's reliability. This service typically starts after 30 seconds with full availability.

Responsive reserve: This is a reserved supply generation service that will be used when abnormal conditions occur.

It has been seen that most countries have a strong inclination towards conducting DR programs in order to reduce their peak demand considerably.

DR in USA	In USA, spinning reserve, supplemental reserve and regulation response services are used with day ahead option or real time option.
DR in UK	The demand response program in the UK market is based on real-time and day-ahead options. This program is authorized to participate in forward capacity auctions (FCA) and is aimed to lower demand side load within 30 minutes to two hours after a request from the UK independent system operator, which are known as "reliability events." It is permissible to respond to demand. To collect and record their consumption, participants in this program should install special smart metering devices.
DR in China	China has been particularly effective in reducing the amount of power outages and improving the system load factor by implementing demand response programs, which are divided into three categories: time of use pricing, interruptible load pricing, and storage device development.
DR in New Zealand	Incentive-based demand response solutions, such as dispatchable demand and interruptible load, are commonly utilized in New Zealand. Home energy management systems (HEMS) have recently been developed, and they are capable of monitoring, controlling, and evaluating demand energy use with the smart meters and controllers.
DR in Japan	To encourage customers, the government has begun to employ digital smart metering and wants to increase efficiency in household energy management by implementing smart meters, HEMS, and using dynamic pricing programs such as real-time pricing and critical peak pricing.

It is also essential to understand the features of the DR programs and the following table represents the features of various DR programs such as the event notification time window, event duration, trigger criteria, etc [9].

Table 3. Comparison of Features of DR Programs

Feature	DR program types					
	Ancillary Service	Capacity Market (DLC, I&C)	Economic DR (Demand bidding/buyback)	ToU pricing	Real-Time Pricing	Critical Time pricing
Event notification window	Variable 10 to 30 minutes based on spinning or non-spinning reserve service	Day-ahead for direct load control Intra-day for Interruptible DR	Day-ahead	Notified through tariff structure embedded in meter	Day head forecasted market prices are notified	Day head
Event Duration	Variable	Depending on the cycling settings of the equipment	Typically, 2 hours	Varies with the time of day and different seasons of the year	Price signal varies as per the forecasted market price	Depending on the trigger criteria
Choice of participation	Mandatory if entered into a contract	Mandatory for DLC& Voluntary for I&C	Voluntary	Mandatory	Voluntary	Voluntary
Trigger Criteria	System emergencies, frequency regulation violation	Price spikes Peak load time	Forecasted demand less than the available generation capacity	Applicable throughout the year	Applicable throughout the year	High temperature and high forecasted spot market power prices
Target Load category	Customers with dispatchable loads that can be fully controlled remotely.	Small residential customers for DLC Agriculture & pumping for I&C	Small, medium, and large commercial facilities whose maximum demand usually crosses a particular threshold value (say 200 kW).	Large commercial and industrial customers. Also available for small customers	Large commercial and industrial customers. Also available for small customers.	Customers whose maximum demand usually crosses a particular threshold value (say 200 kW).

Incentive	Energy and capacity payment	Monthly bill credits, and rebates.	Energy and capacity payments at the forecasted Market price with adjustments	The cheaper rate during off-peak and more expensive during peak time	Customers are able to defer their usage to take the advantage of low market prices	Discount on all parts and on-peak usage on all other days of the year/ season.
Penalties	Compliance violation	Varies from no penalty to application of excess energy charge during the event	No penalties	High usage price during peak load periods.	High usage price during periods of the high market price.	High usage prices during CPP events
Pre-requisites	Depends on the types of Ancillary Services. Under frequency relay for responsive reserves. Real-time telemetry	Load control switches and smart metering infrastructure	Internet access and AMI are capable of recording usage in a 15-minute interval.	The meter that registers cumulative usage during different time blocks	The meter that registers cumulative usage during different time blocks	The meter that registers cumulative usage during different time blocks
International Case Studies	Load Acting as a resource, Texas	Economic Load Response program – PJM	Demand Bidding Program - California	ToU rate, Texas	Commercial/Industrial Schedule RTP-2 (California)	CPP, Texas

According to the analysis, common drawbacks and challenges of the demand response programs are listed below [8],[9].

- Demand response programs require two-way communication, which will necessitate certain modifications to the current electric grid. The initial cost of the utility will be increased by control, monitoring, and communication systems.
- The participation of customers is the most important aspect of demand response. Customers may be hesitant to participate because they believe these programs will solely benefit service providers financially. They also don't want to waste time for monitoring and controlling the load.
- The market structure of DR programs is less appropriate than the currently utilized electricity market structure and the ability to respond in real-time conditions will be restricted if it is not planned well.
- To participate in DR programs, smart meters and smart thermostats must be installed on the premises of residential consumers. Customers are hesitant to hand over their personal information and control to utilities.
- Because of the high success and income associated with commercial and industrial customers, DR programs have a greater emphasis on them than on residential customers.
- Customers have no control over the monetary funds of DR programs. Contracting and incentive policies for DR programs may change from year to year, or they may be eliminated entirely. Customers see DR as not being a "sure bet" because of these minor uncertainties.

CHAPTER 3

3. Challenges when Implementing DR Programs in Sri Lanka

3.1. Technological Challenges

Demand Response is an emerging competitive resource that can be used to maintain the balance between demand and supply for grid operations through the active participation of the consumers. DR programs have the potential to help the electricity providers save money through reductions in peak demand and the ability to defer the construction of new power plants and power delivery systems especially those reserved for use during peak times.

However, the implementation of demand response programs involves numerous challenges in different aspects. Technological challenges play a prominent role as DR programs incorporate many advanced technologies with the ability to dynamically optimize grid operations and resources while dealing with the issues in conventional power grid networks. The technological challenges for implementing demand response programs in the existing utilities can be identified as follows.

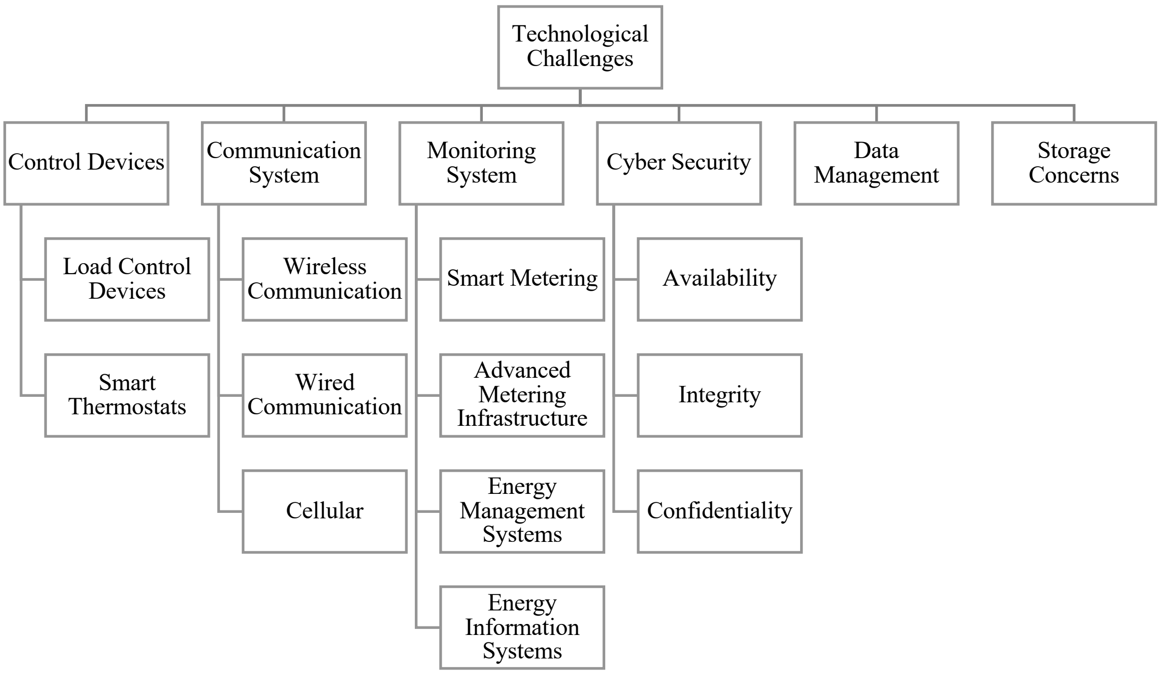


Figure 5. The Technological Challenges for Implementing Demand Response Programs

Grid infrastructure in Sri Lanka is still evolving, and it is insufficient to accommodate the future electricity requirement with distributed and clean energy generation which gives rise to challenges in design, operation, and maintenance.

Integration of multiple digital and non-digital technologies and systems such as new and advanced grid components, smart devices and smart metering, integrated communication technologies, programs for decision support and human interfaces, and advanced control systems are the most significant technological challenges to be dealt with when implementing efficient DR programs in the existing utility [10].

3.1.1. Control Devices

Load control devices, smart thermostats, and other sensors and sensor networks come under control devices. When implementing DR programs, many control devices should be placed at different locations in the existing power system network for remote monitoring of the functionality and health of grid devices, temperature, and detecting outages [10]. The installed sensors can perceive peak load problems and utilize automatic switching to divert or reduce power in strategic places, removing the chance of overload and the resulting power failure. Further, faster and more accurate responses such as remote monitoring, time-of-use pricing, and automated demand response can be handled.

3.1.2. Communication Systems

Communication technologies play a major role in the implementation of Demand Response (DR) programs. This helps to establish secure and fast communication links for two-way interactions like exchanging information and signals between the hardware and software components at the different stakeholders involved such as utility, load aggregators, and customers [5]. Load aggregators act as intermediate personnel who try to reduce the risk of penalty by load aggregation among different customers such that the expected reduction in loads can be met as a whole.

Network configurations used for setting up communication between different entities at stakeholder premises for carrying out DR programs can be identified as follows.

Table 4. Network Configurations for the Communication

Stakeholder category	Network configuration used	Coverage range	Data range
Utility	WAN (Wide Area Network)	10 – 100 km	10 Mbps – 1 Gbps
Load aggregator	NAN (Neighbourhood Area Network)/ MAN (Metropolitan Area Network)	100 m - 10 km	100 kbps – 10 Mbps
Customer	Wi-Fi/ZigBee based Wireless HAN (Home Area Network OR PLC-based Wired HAN	1 – 100 m	1 – 100 kbps

Communication architecture for residential DR

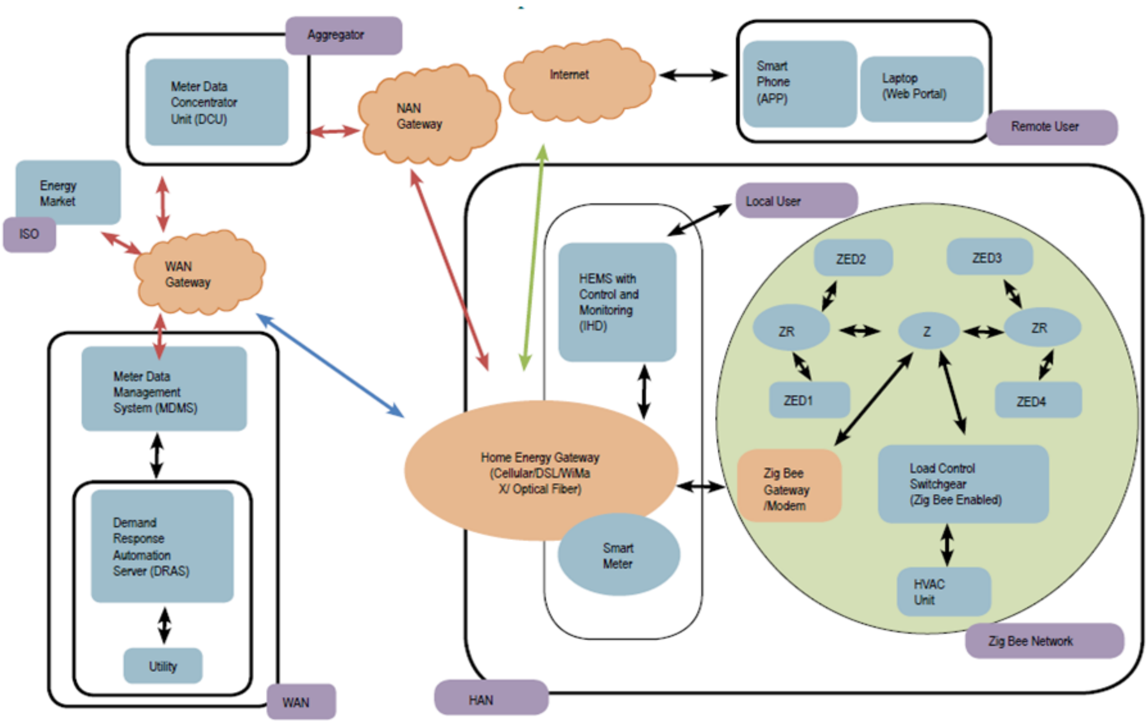


Figure 6. Communication Architecture for Residential DR

A Personal Area Network (PAN) is configured by ZigBee devices such as ZigBee coordinator, router, and end devices using PAN IDs.

Here, ZEDs are the end devices of the network which are often electric appliances used in DR programs and ZRs are the router devices which are mainly battery-powered devices used to extend the range and increase the device capacity [5]. This ensures the connection of all shiftable loads such as air conditioning units, heaters, washing machines, dryers, and electric vehicle chargers to the line-powered ZigBee Coordinator (ZC). The ZigBee coordinator connects these electrical appliances to the home energy gateway through a ZigBee modem. This is also a part of the smart meters. Smart meters are energy meters that allow two-way communication between the utility and the customer by the two radios installed. One radio uses the licensed 902-928 MHz band for communicating with the utility and the other radio uses 2.4 GHz for communicating with the appliances connected to the Home Area Network (HAN).

The HAN consists of the ZigBee network, smart meters, and the Home Energy Management System (HEMS). HEMS is embedded in the smart meter through the home energy gateway and connects the appliances with a centralized control system. It is operated through In-Home Displays (IHDs) installed inside the customer premises. It collects real-time energy consumption data from the smart meter to control the activation/deactivation of home appliances [5]. Meter data of many Home Area Network (HAN) in the close-by areas are collected through the Data Concentrator Unit (DCU). This forms a Neighbourhood Area Network (NAN). The HANs are connected using a DSL, PLC, or cellular connection. The data collected through the DCUs are then sent to the utility through the Wide Area Network (WAN). The utility end consists of Meter Data Management System (MDMS) and Demand Response Automation Server (DRAS) for monitoring and controlling the DR programs.

Different network requirements for carrying out DR programs

Table 5. Different Network Requirements for DR programs

Network attributes	Demand response
Latency	500ms to several minutes
Bandwidth	14 to 100 Kbps per node
Minimum reliability	99 %
Security	High
Power backup	Not required

Table 6. Comparison of Available Communication Technologies for DR

Communication mode		Wireless				Wir			Cellular			
Technology		ZigBee	WiFi	WiMax	RF	PLC	Ethernet (DSL)	Optical fibre	GSM	GPRS	3G	4G (LTE)
Range		Up to 50 m	Indoor-100 m Outdoor–250 m	10-50 km	10-15 km	Up to 15 km	1 – 10 km	Depends on signal BW	1–10 km	1-10 km	50-70 km	10-12 km
Data Transfer	Latency	10-150 ms	425 ms	~ 60 ms	~ 50 ms	10–15 ms	2-5 ms	~1 ms	> 50 ms	> 50 ms	~50 ms	~5 ms
	Data rate	20-250 kbps	11-105 Mbps	75 Mbps	100-250 kbps	4-128 kbps, 2-3 Mbps	> 100 Mbps	Up to 100 Gpbs	56-114 kbps, 14.4 kbps	160 kbps	384 kbps – 28 Mbps	500-1000 Mbps
	Frequency and Bandwidth	915/868/2400 MHz (BW 22 MHz)	2.4 – 5.8 GHz (BW 20-40 MHz)	2.5,3.5, 5.8 GHz (BW 20-25 MHz)	~900 MHz, 2.4 GHz	1.7-80 MHz (0.6-1.2 kHz)	> 1 MHz	Cat 6a: 600 MHz over 100m Multimode: 1000 MHz over 100 m	800-1900 MHz	800-1900 MHz	1.92-1.98 GHz, 2.11-2.17 GHz	700-800 MHz
	Quality	Noise interruption	Better than Zigbee	Better than Zigbee	Interference with other RF signals	Noisy because of power line interference	Frequent out of service as hard wired	Highest among wired media	Better than RF and Wi-Fi	Better than GSM	Better than GPRS	Highest quality among wireless and cellular media

Cost	Implementation cost					Only module cost	Depends on distance	Very high	GSM module cost is higher than Wi-Fi	GPRS module cost	High module cost	High
	O&M cost	Low	Medium for HAN	Low	Low	High because of hardwiring	High	High	Costly spectrum fee	Costly spectrum fee	Costly spectrum fee	Costly spectrum fee
Power consumption		0.036 W	0.21 W	< 24W	Negligible	-	-	-	~0.08 W	~0.08 W	-	-
Existing support structure		No	Mature and proven technology	Mature technology	RF communication channel needs to be upgraded	The existing grid can be used with lower investment costs	The existing telephone network can be used	Used for high speed, essential and secure communication as this is costly	Widely spread across the country	Can use existing public network and infrastructure	Very mature but phased over to future standards like LTE	Currently in use
Security		128-bit symmetric encryption (Security is still at the research level since this is a relatively new technology)	WPA2 protocol	64/128 bit WEP, WAP/ WAP2	IEEE WPA2/ 802.11i security methods	IPv6 internet security protocol for PLC	IPv6 and IPv4 internet security protocol	Optical encryption	64 bit-A5/1 stream cipher algorithm	64 bit-A5/1 encryption	Better than 2G and has end to end security	Availability of potential threats as open architecture is used
Application		LAN, NAN	LAN, NAN	NAN, WAN	LAN, NAN	LAN, NAN	LAN, NAN	WAN	NAN, WAN	NAN, WAN	NAN, WAN	NAN, WAN

Advantages and disadvantages of different communication technologies

Table 7. Comparison of Merits and Demerits of Different Communication Technologies

Communication technology	Advantages	Disadvantages
ZigBee	• Cost-effective for short-range communication • Low power consuming • Long battery life	• Prone to noise interruption • As the number of load controllers increases, the quality of the signal deteriorates. Hence, for a large network such as building EMS or industry EMS, Wi-Fi or PLC is suitable
RF	• Countrywide existing network of RF • Low cost • Penetration into remote areas • A dedicated band for DR and smart gird communication will mitigate issues on noise and low data transmission capacity in an RF network	• Less security in RF network • Vulnerable to third party interference • Data manipulation • User privacy threat • Not a reliable option for DR
Existing power lines as PLC communication	• Saves the installation cost of the network • Facilitates access to remote locations where other modes of communications have poor accessibility • Suitable for integration of rural loads into DR spectrum	• Noisy because of power line interference

Ethernet-based communication	• Uses existing telephone network	• Poor penetration in a rural region • Suitable only for urban areas
Fibre optic-based communication	• Suitable for long-distance communication • Offers highly secure • Fast communication	• High cost associated with the installation of optical fiber network
Cellular technologies	• Countrywide penetration of cellular (GPRS) services • Reliable long-distance communication • Cheap access from the customer point of view • Multiple objectives of technology	• Lower security as the system uses a public network that is subjected to third party intrusion, data manipulation, and threat to user privacy

3.1.3. Monitoring Systems

Monitoring systems are crucial to monitor the essential components for rapid diagnostics and formulation of precise solutions for any event.

3.1.4. Advanced Metering Infrastructure (AMI)

AMI helps in implementing time-based rate programs that can be offered to consumers through demand response. Smart customer systems such as in-home displays or home-area networks can make it easier for customers to change their behaviour and reduce peak consumption based on the information available.

3.1.5. Smart Metering

Smart meters are installed at customer premises to read the consumption patterns of the customers both locally and remotely and thus provide the real-time determination and information storage of customer energy consumption. Further, they can be used to detect power fluctuations and power outages, to apply limits on energy consumption remotely by the customers, and to switch off the meters.

The use of smart meters is of immense importance for the utility to get a better picture of the customer energy consumption at different points in time and develop new pricing mechanisms for DR programs accordingly. The price signals can be transmitted to home controllers or customer devices which consequently enable evaluation of the information received. This results in customers becoming more interactive with the utility which adds increased visibility into their energy consumption habits.

Implementation of DR programs requires the replacement of existing energy meters at customer premises with smart energy meters which involves a higher initial cost for the utility. But despite the high-cost component, this can be considered a crucial step in putting the DR programs into action.

3.1.6. End-user Interfaces and Decision Support Systems

The end-user interfaces and decision support systems are required to handle the integration and management of generated data at customer premises and to present these data to the grid operators and managers in a user-friendly manner to support their decisions in implementing precise DR programs.

3.1.7. Energy Management Systems

Energy management is the process of monitoring, controlling, and conserving energy in a particular environment such as home, organizations, etc. Energy management practices benefit both the utility and the customers. However, motivating and attracting customers to control energy consumption patterns is a challenging task. It can be achieved by the following practices [10].

- Embedding renewable energy sources at the consumption end of the utility end
- Intelligent controlling of appliances using smart metering and PLC

  This provides easy to access real-time energy consumption information to coordinate the operation of the appliances
- Pursuing energy-efficient retrofits

An energy management system consists of three main elements namely sensors, controllers, and controlled devices. Sensors measure parameters like temperature, pressure, and light levels which are used to initiate responses by the system. Controllers compare a signal received from a sensor with the desired set point and then send out a signal to a controlled device for action. The controlled devices are the equipment that receives the signals from the controllers, such as a fan, pump, air conditioner, or refrigerator.

3.1.8. Energy Information Systems

Energy information systems are web-based software, data acquisition hardware, and communication systems used to store, analyze, and display energy data. These enable energy and cost savings by providing visibility into energy performance and identifying opportunities for improving energy efficiency.

Developing advanced metering infrastructure, replacing old energy meters with smart energy meters, designing end-user interfaces, decision support systems, installing energy management systems, and energy information systems at customer premises are the system upgrades that need to be performed for the implementation of DR programs. The high initial cost and uncertainty in customer acceptance of these systems are the main challenging factors here.

3.1.9. Cyber Security

The DR programs operate through a multilayer structure which requires specific security concerns for each layer. Numerous vulnerabilities could happen in the system when connecting the grid to the cyber network. Development of advanced technologies for spotting and eliminating such issues before any security breach is important in tackling sophisticated cyber threats.

Availability, integrity, and confidentiality are the main three objectives of cyber security that should be addressed effectively to avoid potential threats to the utility and the customers involved in DR programs. A single loophole in these could turn into a disaster for all the participants involved. Availability refers to reliable and timely access to the database and other information while integrity refers to protection from improper format/modification/destruction of information. And confidentiality refers to the security of information from unauthorized access.

Cyber security initiatives involve a common approach for critical infrastructure sectors, such as in the case of energy, by developing guidelines on how utility, operators, and regulators should implement preventative measures aimed at mitigating maliciously driven cyberattacks. The sheer volume of interconnected and highly distributed machine-to-machine communication makes it vulnerable to attacks by malicious actors leading to system outages or destruction. Hence, continuous standards development related to cybersecurity such as device authentication is of utmost importance in securing the system. Cyber security can be strengthened by implementing standard-based public key infrastructure [11]. This enables users of an unsecured public network such as the internet to securely and privately exchange data through the use of encryptions obtained and shared through a trusted authority. This can be considered a secure, scalable, flexible, and cost-effective method to securely authenticate the many digital identities involved in the wholesale electricity market. Therefore, smart grid equipment and software manufacturers, as well as operators, need to step up efforts to upgrade technology, especially in replacing weak passwords with stronger authentication measures and also develop a cybersecurity framework that would consist of adopting industry best practices wherever possible. In the case of demand response, this risk is potentially catastrophic and thus needs to be mitigated to a greater extent.

3.1.10. Data Management

A large number of sensors, controllers, and meters need to be integrated into the existing electricity network to implement DR programs. The data collected from these devices as well as other sources which are listed below need to be accurately analyzed to ensure smooth system operations. Further, they can be used for demand, generation, price forecasting, and identifying system malfunctions before occurrence.

Table 8. Data for the Smooth System Operations in DR Programs

Data Collected	**Description**
Energy Schedules	Energy Schedule Database submitted to the System Control Center and System Modeling
Weather Forecast Data	Information on weather forecasts
Customer Participation Schedule	Tables of customers agreeing to participate in the load control program classified by geographic location (by substation providing control)
Load Schedule	Schedule for Customer Load equipment: turning on and off, cycling, and/or level of load
Customer Load Forecasts	Forecasts of individual customer load that can be controlled
Aggregated Customer Loads	Forecasts of aggregated customer load that can be controlled – broken down by geographical location and substation
Loads Forecast	Load forecasts, based on different inputs and possible operating scenarios
Real-time Monitoring and Control Data	Status, settings, curtailable load requirements, automated on/off commands, automated settings, responses back from substation control units, and load control transponders
Real-time Power Systems Operations Data	Loads, generation, A/S, etc.

Generation, Transmission, and Distribution System Data	Data including scheduled outages, operating constraints, and real-time information

The data collected from these devices is really big in volume. For example, readings are collected from smart meters several times an hour, instead of once a month. Therefore, this increases the volume and the accuracy of the data set. The high volume of data is not only difficult to collect but also difficult to handle, store and retrieve.

Thus, database management is a critical challenge and should be carefully addressed to enhance the speed of data collection and analysis to take immediate actions in DR programs. Further, the development of standards and protocols for big data handling, analysis, and security concerns is another key consideration to be addressed under challenges involved in data management.

3.1.11. Storage Concerns

Intermittency and variability of renewable resources make it necessary to install storage devices to meet the varying demand with an uninterrupted grid supply.

Battery storage is the most common storage technology, but it is not economical and commercially viable to use on a large scale in Sri Lanka as an invetment. High initial cost, short life span, low energy density, and shortage of raw material are the few concerns making batteries difficult to use in the existing grid and an investment. But utility can invest on deployment of Battery Energy Storage Systems depending on the requirements of the network. Pumped storage power plants can be considered a better storage option for Sri Lanka based on the studies conducted by CEB. They can be used to meet the peak electricity demand as well as to integrate more distributed energy resources into the system effectively. The issue with pumped storage techniques is that they require large areas as reservoirs which are only available in the hill country.

3.2. Socio-economic Challenges

Utilities try to change the demand profile of end-users through positive incentive schemes allowing consumers to schedule their consumption at a time that will reduce the energy bill. This in turn helps the utility to move the portion of electricity demand away from peak periods to off-peak periods. Accordingly, direct reduction of energy consumption from peak hours and shifting it to a different time is possible if structured consumer awareness programs and appropriate tariff schemes are introduced. In some countries, consumers are charged negative incentives for the continuous operation of inefficient heavy loads and to encourage them to upgrade their equipment. In this chapter socio-economic challenges which lead to the implementation of DR programs in Sri Lanka are discussed under the following subtopics.

- High capital investment
- Stakeholders' engagement
- System operation aspects
- Lack of awareness
- Privacy and security
- New tariffs

3.2.1. High Capital Investment

The high initial capital investment needed for the demand response technologies is a challenge due to the poor financial health of the country and the utility. In general, technology investments (i.e., for control devices, monitoring devices, storage devices, communications systems, data management systems, cyber security networks, energy management and control systems, and peak load management and control devices) occupy a significant portion of the total capital investment [12].

Capacity and growth, sustainment, and business operation and support are primary investment categories identified by the industry. Capacity limitations and future demand growth relevant to geographic areas are addressed under capacity and growth investments. Continuous performance of the system and issues of aged assets are considered under the sustainment investment. Corporate operations comprising information technology, fleet investments, and corporate facilities are addressed under the business operations and support investments [10].

In addition to infrastructure development, investments are needed for awareness programs to encourage organizations and individuals on the advantages and disadvantages of demand response programs. Loan programs are needed to fund the consumers' initial investments and various types of incentives are required to actively engage them in the programs.

3.2.2. Stakeholder's Engagement

High capital investment, new technology, less transparency, and uncertainty might give a negative perception to stakeholders, despite the clear benefits offered which are well mentioned in the literature. Therefore, utilities should provide the benefits to the customer after implementing the DR programs in order to make the confidence among them.

3.2.3. System Operation Aspects

Operational strategies of the system, billing, and tariff structures are a few aspects that can directly influence the demand response programs. Instead of a unified approach, a flexible approach must be introduced from place to place considering the perception of operators, the mindset of participants, the state of supporting elements and policies, etc.

3.2.4. Lack of Awareness

Lack of awareness can create obstacles in implementing sophisticated programs in society. Educating consumers on the economy, efficiency, and environmental benefits of demand response technologies through awareness programs is essential in inducing faith for acceptance. A high level of awareness among regulators and policymakers on present and future technology is also important.

Having a sound knowledge of consumer awareness does not certainly guarantee market success. Most of the time people are driven by the habits and behavior of other people and they always try to be within a comfort zone with their family, neighbors, and friends without taking a risk.

3.2.5. Privacy and Security

Cyber security and privacy of consumers' data are important concerns in handling an enormous amount of information. Attacking the software algorithms or gaining access to the exchanged data such as a load of users and price signals by attackers may occur because of less security or inadequate policies of the country. With that, the attackers can easily change the price signals and the load scheduling in demand-side management. Injecting misinformation to the service providers through smart meters could lead to take wrong decisions on system capacity and electricity load. In addition to that, the ability of smart meters to record the detailed energy consumption of the user helps the attacker to figure out the living pattern, behavior, activities, and habits of him/her. Therefore, to install any of this kind of technology, consumers' faith must be ensured and maintained first through tough regulations and advanced security methods.

3.2.6. New Tariffs

Reduction of the peak load and the cost of power generation and increasing the social welfare of the people are the most popular objectives of demand-side management programs. However, the users' continuous contribution depends on the fairness of the system despite the financial benefits it offered. In other words, the system is considered fair if it charges less from the people who contribute more. But those criteria for fairness are difficult to select and implement without a proper study.

Electricity consumers have different opinions on pricing for consumption. For example, it is believed that a tariff system that reflects the value of consumers' flexibility is more important to encourage them to be more flexible. But from the operators' perspective, new tariff schemes based on time of use, real-time use, critical pricing, etc. have more significant effects on the efficiency of the program than the traditional billing methods.

In addition to that, consumers who are satisfied with the existing tariff rates do not like to accept new tariff schemes willingly. They may be interested in having low tariffs at off-peak loads, but those who are liberal in their usage would not like to pay high rates at peak hours.
Many industrial and commercial customers who consume more electricity can easily respond to demand response programs. Due to the lack of skilled personnel and less awareness of the benefits of energy efficiency, most of those customers still have not carried out any energy audits to gather reliable information on their current operational status. Therefore, the proportion of load that can be controlled with their support is yet to be decided. Furthermore, reduction of demand from them and providing incentives do not seem viable for the utility in long term.

3.3. *Miscellaneous Challenges*

Energy efficiency, demand response, and demand-side management programs are novel concepts to Sri Lankans. Therefore, marketing these new models helps utility and customers to corporate in novel ways to reorganize supply and demand more flexibly. This section is mainly focused on miscellaneous challenges (i.e., regulation and policies, workforce, and coordination between parties) in implementing demand-side management in Sri Lanka.

Regulations and policies are essential to actively engage all parties in demand response programs. Sharing the risk and maximization of the contribution of all sectors can be achieved by introducing new scientific frameworks. For that. identification of the limitation of the existing frameworks with the knowledge of skilled individuals is important. Policymakers and regulators should pay attention to providing incentives to promote demand response programs defining standards, road maps, time frames, targets, awareness initiatives, etc [12].

Demand response programs are crucial in achieving the stability of the electric grid and energy efficiency targets. The conduct of appropriate training sessions to address the skill gaps of the present workforce eliminates the scarcity of the expert working force in the country.

Coordination and understanding between different parties are essential in developing a successful demand response program. Proper coordination between government, utility, and the end-user is important in obtaining optimum results in these programs. For that, each of these parties must play an identified significant role. Government bodies formulate regulations and policies and provide funds for the programs. The utility can successfully implement the customized programs in coordination with the end energy consumer. Finally, they should work in cooperation to overcome new challenges and issues that have to face in the future.

CHAPTER 4

4. Opportunities of Existing Utility to Implement DR Programs

4.1. Performing a Study on the Current Renewable Penetration Level in Sri Lanka

4.1.1. Introduction

Nowadays fossil fuel-based electricity generation caters to a significant percentage of total growing demand. Recently people have become more concerned about the reduction of fossil fuel-based electricity generation as it contributes to environmental pollution following the emission of greenhouse gases, global warming, etc. which results in life-threatening conditions. In addition to that several international agreements on environmental protection were introduced by allowing countries to come up with environment protection protocols relevant to their contexts. For example, the Paris agreement on climate change emphasizes the need for decarburization to protect the planet from the impacts of global warming by keeping the global average temperature rise below 2℃ by end of the century [5]. Therefore, the penetration of renewable energy sources such as solar, wind, etc. to the utility grid has been identified as a timely solution to cater to the growing demand for electricity rather than limiting it to large-scale, centralized, fossil fuel-based power plants.

4.1.2. Harnessing Renewable Energy Resources in the Sri Lankan Context

The current context of renewable energy resources in Sri Lanka

Sri Lanka, as a tropical country, is blessed with rich renewable energy resources, which have fuelled the country's economic progress for decades. In the 1990s, renewable energy sources met the majority of the country's electricity demands, with substantial hydropower resources playing a key role. As a result, the country has been able to preserve its sustainability efforts in recent years, with low carbon emissions per capita in energy generation. The emergence of various renewable energy sectors, as well as thermal-based resources, was driven by increased economic growth and energy demand. Though large hydro resources accounted for a big portion of renewable energy in the past, variable renewable resources such as wind and solar are expected to become more important in the future. Sri Lanka has steadily increased its ambitious aims and development initiatives on renewable energy production, in accordance with global efforts to minimize the effects of climate change. As a result, as the country moves forward on a low-carbon path to fulfil its future electricity needs, a significant increase in indigenous wind and solar resource development is expected.

Wind and solar photovoltaic sources are highly intermittent and seasonal, whereas hydro power and biomass power generation are not. These intrinsic physical properties of resources create grid integration issues, and different power systems have variable grid integration capabilities based on system and resource characteristics.

Statistical Analysis

In 2018, other renewable energy (wind, solar, biomass, and small hydro) contributed to 3.7 percent of the total energy supply [15]. In the country, there is a lot of room for wind and solar power development. Steps have been taken to fully utilize Sri Lanka's economically viable wind and solar potential. The first commercial wind power plants were built in 2010, and by the end of 2020, wind power plants would have a total capacity of 179 MW. In 2020, Mannar Island will host the country's first large-scale wind farm. The first commercial solar power plants were installed in 2016, and by the end of 2020, commercial solar power plants had a total capacity of 67 MW, with almost 347 MW of solar rooftops connected [15]. Scattered small-scale solar power plant development has already begun, as have feasibility studies to create solar power plants in a park idea. Through dendro, agricultural waste, and municipal waste sources, a small percentage of the biomass supply is utilized for electricity generation.
Biomass (4629 ktoe), petroleum (5144 ktoe), coal (1313 ktoe), hydro (1239 ktoe), and other renewable sources made up the principal energy supply in 2018. (475ktoe). Figure 7 depicts the contribution of these to the gross primary energy supply from 2009 to 2018.

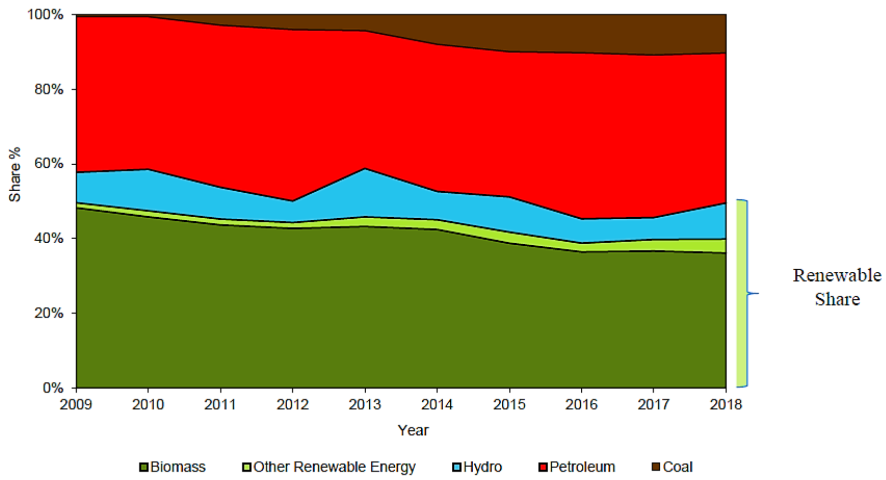


Figure 7. Share of Gross Primary Energy Supply by Source

The main renewable source of generation in Sri Lanka's electricity grid is hydropower, which is primarily held by CEB. Other renewable energy sources, including small hydro, wind, solar, dendro, and biomass, are also connected to the system, with the majority of them held by private companies.

The CEB has developed the majority of Sri Lanka's comparatively large-scale hydro resources. Hydro projects with a capacity of less than 10 MW (known as small hydro) can currently be constructed by the private sector as run-of-the-river plants, whereas larger hydro plants must be created by the CEB. Because these run-of-the-river small hydro plants are non-dispatchable, they are represented differently in the generation expansion planning simulations than CEB-owned hydro plants. The annual operating and maintenance cost of these CEB hydropower plants was calculated to be $12.80 US$/kW [15].

Initially, the Sri Lankan government decided to establish hydropower projects with capacities of less than 10 MW with private sector participation. Since 1996, the system has been connected to a number of small hydro plants and other renewable energy plants. Apart from micro hydro power plants, the system has seen a significant surge in Wind and Solar additions in recent years.

Other Renewable Power Plants Owned by IPPs

As of December 31, 2020, the total capacity of IPPs-owned power plants is roughly 683 MW. The majority of these units are connected to 33 kV distribution lines. Table 9 shows the capacity contributions from other renewable source

Table 9. Capacity Contributions from Other Renewable Sources

Project Type	Number of projects	Capacity (MW)
Mini Hydro	210	409.5
Wind Power	17	148.45
Biomass	14	50.09
Solar	32	75.36

Source: CEB long term generation expansion plan (2022-2041)

In addition, total Rooftop Solar capacity of approximately 350 MW (both CEB and LECO) has been integrated to the system by 31st December 2020.

Existing Agreements to Encourage Small Power Producers (SPP)

The grid-connected small renewable energy resource development was first initiated in 1997 through the regularization of small renewable energy power producers by the Ceylon Electricity Board with the publication of a Standardized Power Purchase Agreement (SPPA). The growth of other renewable energy sources in Sri Lanka on a commercial scale commenced with the development of mini-hydro resources in 1997 and its continued growth under a feed-in tariff system.
The first version of the agreement, introduced in 1997, was continued until 2007. In 2007 a revised agreement was introduced.

In the Sri Lankan context, investor-friendly and transparent agreements are available to encourage renewable generation. As an example, since 2007 technology-specific, cost-reflective tariffs are provided to the small power producers under renewable power purchase agreements. The introduction of the cost-reflective, technology-specific feed-in tariff in 2007 paved the way for the development of wind resources and considerable growth was achieved in local wind resource development.

Considering the salient features of both agreements.
SPPA (1996 to 2007) [6]

- The main intention was to develop renewable power generation in Sri Lanka.
- Projects under 10 MW were entitled
- The agreement was valid for 15 years.
- Technology neutral – avoided cost-based tariff
- No penalties for the developer for not providing power to CEB and also no penalty on CEB for not purchasing energy.
- It was a valid bankable document.

However, this tariff was sufficient only for the construction and commercial operation of small hydropower plants only. This did not encourage other renewable sources as intended.
SPPA (2007 to present)

- Projects under 10 MW were entitled
- The agreement was valid for 20 years.
- Technology specific –cost-based tariff

- Different tariffs for different renewable technologies

Three-tier tariffs, including maintenance and fixed charges. To encourage local producers, higher tariffs are allocated for them.

- No penalties for the developer for not providing power to CEB and also no penalty on CEB for not purchasing energy.
- It is a valid bankable document.

With the introduction of the solar net metering facility in the country in 2009 followed by the rapid technology cost decline and rapid growth in the global solar PV industry after 2010, solar resource development gained steep growth over the past years. The introduction of Net metering, Net accounting and Net plus schemes stimulated the growth of rooftop solar applications and grid-scale solar PV developments are also growing at different scales.

4.1.3. Recent Renewable Energy Projects in Sri Lanka

Thambapawani Wind Farm (Mannar Wind Power Park 100MW)

Mannar Wind Farm, on the southern coast of Mannar Island, is Sri Lanka's first large-scale wind farm. 100MW of wind power has been created as a first phase. The wind farm has a total installed capacity of 103.5 MW and is made up of 30 state-of-the-art wind turbines, each rated at 3.45 MW. This project was created to take use of Sri Lanka's primary monsoonal wind systems. The plant is planned to produce 400 GWh of power per year. The project's entire anticipated cost is $200 million, which was funded by an Asian Development Bank loan (ADB). The project began in March 2019 [15].

The first phase, known as "Thambapawani," was commissioned on December 8, 2020, and 30 MW was connected to the National Grid. After the completion of the Nadukuda Grid substation in June 2021, the remaining capacity was planned to be connected. The savings from this project's ADB financing will be used to build another 20 MW of wind power on the same site. The Sri Lanka Sustainable Energy Authority (SLSEA) has begun surveying specified lands in Mannar Island in order to develop an additional 200 MW of capacity in the second phase.

Figure 8. Thambapawani Wind Farm

Floating Solar Plant – Kilinochchi

The Norwegian ambassador to Sri Lanka, Trine Jranli Eskedal, launched Sri Lanka's first floating solar power plant with a capacity of over 46 kWp at the university's Kilinochchi campus, with the help of Current Solar AS, a Norwegian developer of floating photovoltaic solar systems, as part of a collaboration between the Western Norway University of Applied Sciences and the University of Jaffna, and with the support of the Royal Norwegian Embassy in Colombo.

The system was designed by the Current Solar AS, using data from the Singapore test site. The composite material was used to construct the solar modular base unit. High-density polyethylene is used to make floating pipes. The beams are made of glass fibre, which is stable and well suited for use in water. Depending on the kind and size of the module, the solar base unit is employed. There are also four modules: two Twin Peak modules and two N-peak modules. On the floating system, one TP and one N-peak module were installed, and one of each was installed on the land-based reference system. The floating design was installed without any equipment or amenities in the east and west directions. The data recorder and sensors have been placed in order to capture data for further study. Three solar insulation and temperature recorders, one water temperature logger, and one humidity and air temperature logger are included.

The floating PV plant will be utilized for research and information sharing, with the electricity generated being used on the Kilinochchi campus of the University of Jaffna (UoJ). When comparing floating solar to rooftop solar, it appears that the temperature difference has the greatest impact.

Figure 9. Floating Solar Plant – Kilinochchi

The monthly performance of the floating solar string inverter for July 2020 is as in the graph given in Figure 10.

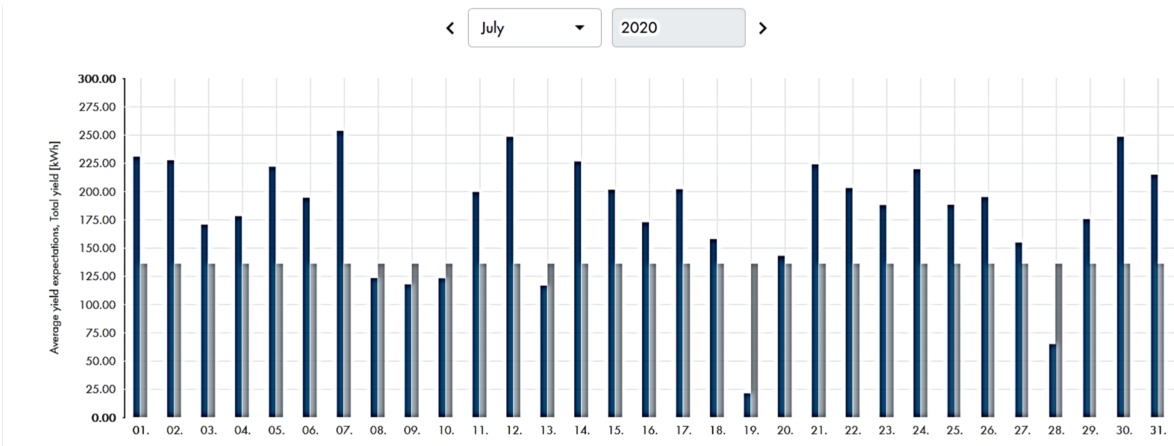
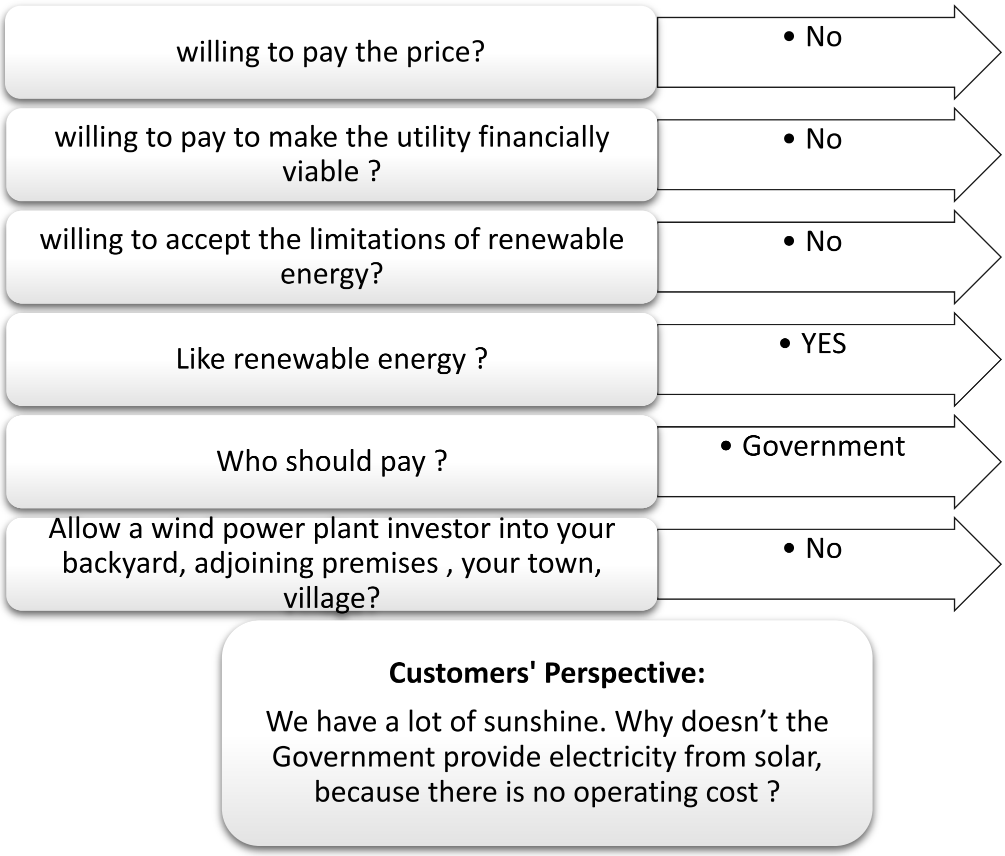


Figure 10. Monthly Performance of Floating Solar String Inverter for July 2020

4.1.4. Challenges in Increasing Renewable Penetration Level in Sri Lanka

There are certain challenges and barriers as discussed in this section, that should be overcome in increasing renewable penetration level.

- The electricity customer is the most important but forgotten stakeholder in all energy discussions. The impression about the electricity customers is that they want an all-renewable generating system. But in reality, is the customer



  Likewise, the opinions of electricity customers and their less awareness and contribution are challenges in promoting renewable generation.

- The eminent engineers differ in their opinions on having 100% of renewable generation in Sri Lanka. Then the electrical engineers have to clearly understand and articulate the issues, without biasing to certain facts.
- There are other barriers to renewable generation such as lack of system inertia and spinning reserves, and storage requirements.
- A power system needs to meet the demand in real-time, matching demand and supply. Presently this requirement is met with inertia (rotational kinetic energy), spinning

reserve, and storage (as water and fuel). Since renewables do not have the above three attributes, they have to be artificially created. For example,

    - Artificial inertia: battery storage can act fast and provide/absorb the power, to help stabilize after a disturbance
    - Battery storage: to stabilize fluctuations of renewable energy
    - Distributed generation: to balance the fluctuations of the resource

- Renewable-based generation, except for larger hydropower, in general, is still financially more expensive than conventional sources.
- Distributed generation requires the grid.
    - Customers are not willing to pay for the grid.
    - Reverse power flow causes voltage rise (during the day for rooftop solar PV).
    - Higher harmonics may cause problems.
- Managing seasonality and intermittency of renewable energy resources such as Solar PV is intermittent; Wind is seasonal and intermittent; Hydro and biomass are seasonal.

4.1.5. Role of DR Programs in Increasing Renewable Penetration

Building energy loads are the main resource for electric demand-side management, via energy efficiency and peak load shifting by utilities. However, the degree to which these demand-side resources can enable the deployment of renewable energy generation on the supply side, to further reduce fossil fuel use and emissions from power generation is yet to be discussed.

The combined time variations of customer loads (mostly heating and cooling buildings) and large renewable power flows will require a substantial increase in the flexibility of the power grid to provide adequate balancing capability to maintain system reliability. Demand-side resources can contribute to reliable balancing, by decreasing or postponing power demand when needed. Some demand-side resources (heating or cooling via thermal storage) can also provide a flexible load to increase demand when needed to avoid curtailment of renewable sources. When more variable renewable energy is integrated into electricity systems, system operators are researching for tools and approaches to boost their system's flexibility. In terms of renewable integration, there are two primary situations.

To understand the potential contributions and limits of the demand-side resources, a range of renewable integration challenges is studied. First, the main renewable integration problems, are categorised based on the criteria developed above, in terms of the following categories [13]:

- Under-generation (too little wind and solar resource relative to load),
- Over-generation (too much wind or solar resource relative to load), and
- Ramping rates (too fast a change in load net of renewable production).

Under-generation

Under-generation occurs when *net load*, i.e., system load net of renewable production, is relatively high. When renewable production is low, the load on the generation fleet is similar to the load that was experienced before much renewable capacity was connected. The difference today is that there may be less non-renewable generation capacity available because renewable generation is considered to provide some capacity value that substitutes for conventional generation capacity.

Over-generation

Over-generation is a very low network load. This condition requires the coincidence of relatively strong renewable output when the system load is relatively low, as renewable generation is unlikely to overtake load during peak periods. For solar generation, over-generation is most likely during morning hours, when the solar resource is already strong but the load has not yet reached peak levels. To date, there has been little incidence of solar generation being curtailed due to over-generation, although there has been concern about problems with specific distribution circuits in locations where distributed solar penetration is high.

Ramping rates

Ramping events are related to under- and over-generation in that they are caused by the same types of imbalances between load and renewable generation. However, ramping depends on the relative rate of change in netload, rather than the absolute level of renewable production, system load, or netload.

Renewable Integration and Demand Response

For each of the above integration problems, we explore the dynamics of energy available from DR resources and assess their performance in balancing load and renewable variations. The most promising application of DR to renewable power integration is in the relatively slow, predictable delivery of load following and ramping.

Under-generation and Demand Response

The first scenario is one in which there is an insufficient generation or a large net load. In such scenarios, demand response programs reduce customer load by using a combination of manual, automatic, and pricing-based demand adjustments to meet the utility's needs.

Dispatchable DR programs involving demand response or thermal storage are capable of balancing under generation, which is driven by high coincident loads. Depending on whether the renewable generation portfolio is mostly wind or solar, the timing of DR or thermal storage deployment would vary.

The main limitation of DR programs in this application is that the frequency of under generation might exceed the limits of customer acceptance of the DR program, in which case only the most extreme under-generation events could be covered. Thermal storage is not subject to such customer-related constraints and could be applied to under-generation without a frequency limit.

Over-generation and Demand Response

Neither efficiency nor conventional DR is likely to help balance over-generation, which is driven by relatively low coincident loads and the need to increase the load by shifting it in time. An exception would be situations where a building's thermal mass could be used by the demand control technology, but this approach would require advanced building controls and integration with grid operations.

Thermal storage, on the other hand, is rather well suited to balancing over-generation, as the charging of the storage battery can increase the load with flexibility in terms of its timing. The main limitation of this application is that the HVAC end-use must at least be active during the day of the event, although the timing need not coincide with the over-generation event.

4.1.6. Energy Efficiency-based Demand Side Management for Long-Term Renewable Resources Planning

One of the most important demand-side resources is energy efficiency. Utilities across the country are conducting efficiency programs that represent a significant resource for meeting customer energy service demand, i.e., this resource replaces supply-side resources in the form of generation plants (and sometimes transmission lines) that do not need to be sited, built, operated and fuelled. On the other hand, efficiency is generally not regarded as a practical option for addressing time-dynamic problems such as balancing variable renewable generation. The reason is that efficiency is not dispatchable, i.e., it cannot be called on to increase its capacity at a given time. Therefore, when a wind forecast error arises in real-time, the presence of efficient lighting hardware in the utility's service territory will not help. Efficiency is not an active resource to balance renewables in real-time or within the short time horizon of grid operations, for example by providing this ramping capability.

Efficiency can contribute, however, to balancing renewables in the longer time frame of resource planning. This contribution can occur when specific loads can predictably add to the net load, which must be met by dispatchable supply resources, during periods when variable renewable production will be relatively low. Reducing such loads with efficient end-use technology helps balance the variation in renewable production during these times.

4.1.7. Sri Lanka's Achievements and Initiatives in Energy Efficiency

- Supply-side: T&D Losses below 9% of net generation (was 21% in the year 2000)
- Appliances: Popularization of energy-efficient lighting through easy-payment schemes implemented by electricity utilities. (1997-2002)
- Laboratory: A regional lighting centre and a laboratory have been established by Sri Lanka Sustainable Energy Authority/Ceylon Electricity Board
- Regulatory: implementation of appliance energy efficiency performance standards,
    - Initially for CFLs
    - Planned to be introduced shortly for ceiling fans, refrigerators, air conditioners, and televisions
- Tariffs:
    - Demand charge for large customers based on the measured monthly maximum demand
    - Introduction of time-of-use tariffs (for large electricity customers optional since 1986, mandatory since 2011, and for retail customers, planned to be optional from 2015).

4.2. Identifying the Contribution of Storage-Type Resources in Sri Lanka in Balancing Demand-Supply Variations in the Power Network.

4.2.1. Introduction

It is essential to analyze the storage type resources as they can be used to balance the supply-demand variations in the power system and for the demand response programs. For example, if customers are inclined to use TOU tariff rates, then they should reduce their electricity consumption at peak hours in order to reduce the cost, however, energy storage type resources such as batteries, capacitors, etc are imperative to store the energy for the use of peak hours. In this study, all the existing grid-scale energy storage systems and future developments in Sri Lanka are investigated by referring to the CEB long-term generation expansion plan (2022-2041) [15].

4.2.2. Energy Storage Technologies in Grid Scale

Few different energy storage systems are available in the market and each storage technology inherits its pros and cons depending on the way it is constructed, and the materials used. Hence selection of an energy storage system (ESS) for a particular application must be done carefully. Capacities, response time, charging-discharging times and efficiencies, lifetime, etc. of each technology must be taken into account to evaluate the performance of the storage systems for a particular application as a whole system [8]. Also, must consider the performance of each technology in economic terms as well.

Table 10. Comparison between Different Energy Storage Technologies

Energy Storage System	**Key factors**	**Response time**	**Efficiency**	**Discharge time**
Battery	• Long lifetime • Minimal environmental impact • Technical diversity	Seconds	60% - 80%	min – 1 hour
Hydrogen Energy	• Minimal environmental impact • Production cost is higher (usage of platinum as the catalyst)	Seconds	20% - 50%	Sec – 24 hours

Storage (Fuel cell)				
Super-capacitors	• High power density • High capital cost	Milliseconds	84% - 94%	Milliseconds
Capacitors	• Technology development ✓ high-capacity capacitors with different electrodes	Milliseconds		

In the utility grid, energy demand and supply should be balanced quickly to avoid power interruptions. Also, maintaining power quality by keeping the voltage and frequency within acceptable levels is of paramount importance. To properly manage both energy demands and power quality, the ESS that choose must be able to respond to fluctuations quickly and possess high capacities with high discharge time. On the other hand, even if there are a few among the options mentioned above which satisfy all requirements, in economic terms, not all can be viable. With all factors considered, battery banks had been identified as the most feasible energy storage system for the microgrid and have been around for quite some time now. Battery banks provide the following benefits over other technologies [8].

- Longer life cycle (depends on several factors including charge and discharge cycles, depth of discharge, and environmental factors such as temperature, humidity, etc.)
- Higher discharge time (time duration that the energy storage system can discharge at rated power, which depends on the available energy capacity, depth of discharge, and other operational conditions)
- Higher discharge rate.
- Higher recharge rate.
- Shorter response time.
- Cost-effective.
- Higher round-trip efficiency (>75%).
- Capacity additions to the battery storage system can be easily done.
- Commercial availability of different battery technologies.

Just over the last few years, batteries have shown their potential in driving the future energy market to a whole new level. So that they were and are still being developed rapidly. There are a lot of new technologies that have been invented and experimented on which promise much greater performance compared to older batteries produced back then. When battery storage is concerned, there are various technologies available on the market. A few battery technologies and their key features are shown in the following table.

Table 11. Comparison of Battery Technologies

	Specific Energy (Wh/kg)	Specific Power (W/kg)	Cell Voltage (V)	Cycles	Life (years)	Maximum Depth of Discharge	Self-Discharge Rate	Efficiency
Lead-Acid	35-50	150-400	2.1	250-1,000	5 years	20-80%	2-8%/month,some 20-30%/month	75-85%
Nickel-Iron	50-60	80-150	1.5	2,000	20 years	80%	20- 40%/month	-
Nickel-Cadmium	30-60	80-150	1.2	1,000 to 50,000	10-15 years	60-80%	5- 15%/month	60-70%
Nickel-Hydrogen	50	220	1.4	1500-6000	15 years	-	High except at Low temperatures	-
Nickel Metal Hydride	60-80	200-300	1.2	300-600	2-5 years	-	15-25%/month	-
Nickel-Zinc	70 -100	170-260	1.6	up to 500	-	100%	<20%/month	-
Lithium-Ion	80-180	200-1000	3.05 ; 4.2	3,000	5+ years	100%	2-10%/month	-
Sodium-Sulfur	150-240	230	2.71	2,500 to 40,000	-	100%	-	86-89%
ZEBRA	90-120	130-160	2.58	-	-	-	-	-
Zinc-Bromine Flow	65-85	90-110	1.8	2,000	-	100%	-	75-80%
Zinc-Air	200	100	1.6	300	-	-	-	50%

Out of all battery technologies, Lead-Acid has been a quite popular technology for some applications. But, nowadays, li-ion battery technology has to get popular and more reliable than lead-acid batteries [9]. Even if that is the case, both technologies are being further improved competitively since for some specific applications each one inherited certain performance features and economic benefits affected differently. Other reasons behind these two technologies are well demanded in the battery banks market, higher energy densities, simplicities in charging-discharging mechanism and circuitry whereas Nickel-based battery technologies require a more complicated charging mechanism and some battery types (such as Ni-MH) have overheating issues which could result in serious fire hazards due to overcharging, improved and efficient manufacturing processes due to demand leads to a reduction in costs, durability and flexible charging-discharging cycles unlike some batteries (Ni-Cd) which can only provide with the capacity that was used during the repeated previous charge/discharge cycles unless it is fully discharged before charging can be pointed out. As previously mentioned, each battery type has different behaviors which are depending on the discharge rate, depth of discharge (DOD), and cycle life. Table 12 indicates characteristic data regarding the performance and economic aspects of each battery type.

Table 12. Comparison of Li-ion and Lead-acid Battery Technologies

Characteristic data	Unit	Lithium-ion battery technology	Lead-acid battery technology
Energy Density	Wh/L	250-360	54-95
Specific energy	Wh/kg	110-175	30-40
DOD	%	80	50
Acceptable Temperature range for charging	°C	-20ºc – 55ºc	-40ºc – 27ºc
Efficiency	%	97	75
Replacement timeframe	Year	5-7	1.5-2

By comparing the above characteristics, it can be concluded that the Li-ion battery is the most efficient battery technology for the utility grid.

4.2.3. Development of Grid-Scale Energy Storages

Integrating renewable energy sources with the main utility grid while ensuring a reliable supply of electricity has affected significantly increase energy storage systems. Storage technologies are numerous, and their applications are growing at a rapid pace around the world. Their use in power systems is expanding, and applications include energy shifting, frequency management, and renewable energy fluctuation control. Depending on the type of application, the amount of energy necessary, the amount of power required, and the location of the application, the economic value of various technologies is different. High energy density storage systems are appropriate for energy shifting in system operation, whilst high power density storage technologies are suitable for providing quick power to control immediate and transient supply-demand imbalances. Battery energy storages and pumped hydro energy storages are two of the most common storage technologies used in power systems today, and the Ceylon Electricity Board has identified the need to develop pumped hydropower projects as a long-term solution to increase power system flexibility, as well as develop grid-scale battery energy storages to improve the quality of electricity supply.

4.2.4. Grid-Scale Battery Energy Storage Development

Battery energy storage applications in power systems are expanding globally and the technology costs are declining notably. Even though the scale of battery energy storages applications in power systems are small compared to pumped hydro storage, battery energy storages have a wide array of applications in all generation, transmission distribution, and consumer endpoints. Given the range of applications, battery energy storage is employed to enhance the quality and reliability of the supply of electricity. The battery storage systems provide services in different time frames ranging from fast frequency support to energy arbitrage with economic dispatch. Also, it provides various support services for renewable energy grid integration. Lithium-ion types of batteries in power system applications are growing at present than the other forms of chemical batteries such as Flow batteries, Lead-based batteries, and Sodium Sulphur batteries. Techno-economic assessment of the type of battery storage application and the type of battery technology is essential to identify effective storage solutions. Ceylon Electricity Board in its latest renewable energy grid integration study has assessed the requirement of grid side application of battery energy storage with the introduction of a large amount of intermittent and non-synchronous generation into the power system. Accordingly, it is planned to deploy a 20 MW of Battery Energy Storage capacity by 2025 as a gird level application primarily to provide frequency support services [15]. It is expected to increase that to 100 MW by 2030 depending on the system requirement and the progress of wind and solar PV integration.

4.2.5. Pumped Storage Hydro Power Development

Pumped hydro storage, as a mature technology, now accounts for over 97 percent of storage applications in power systems around the world. Pumped hydro storage's main purpose was to offer peaking capacity by releasing stored energy. However, technology has progressed to provide increased services that enable flexible grid management, particularly with the inclusion of renewable energy. In 2014, CEB performed research on peak power generation possibilities, including pumped storage hydropower plants. JICA provided technical help for the study titled "Development Planning on Optimal Power Generation for Peak Power Demand in Sri Lanka." All conceivable peaking choices were analyzed during the study, and the following options were found as viable options.

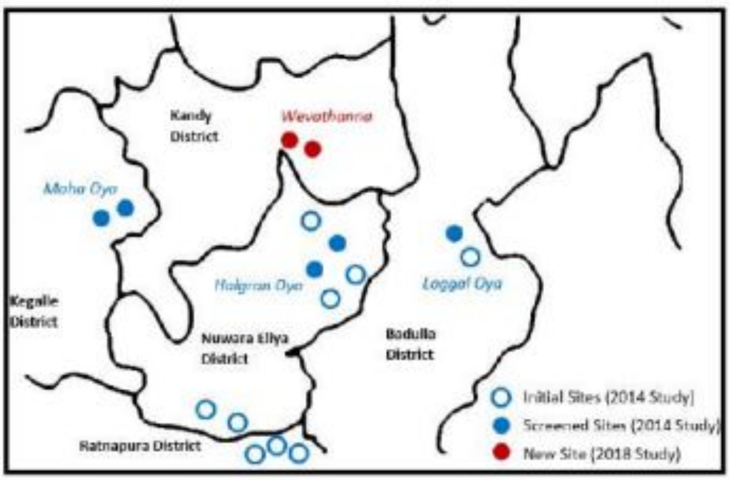
- Hydro Power Plant Capacity Extension
- Pumped Storage Power Plant
- LNG Combined Cycle Power Plant
- Gas Turbine Power Plant

The study indicated that Hydro Plant Capacity Extensions and Pumped Storage Hydro Power Plants are the most suitable solutions for future development, based on load-following capability and power plant features, environmental and social factors, and economic elements. The goal of the study "Development Planning on Optimal Power Generation for Peak Power Demand in Sri Lanka" is to find the most promising candidate site for future pumped storage power plant development.

Pumped storage hydropower plants serve as a large-scale storage medium that can be used for a variety of secondary applications in addition to delivering peaking electricity. Off-peak pumping allows for the storage of surplus renewable energy that would otherwise be limited owing to power system operational constraints. The new adjustable speed technology allows for more flexibility in pumping operations, as well as frequency regulation functions and improved stability due to quick responses to supply and demand fluctuations in the system. Furthermore, pumping during low-load periods allows base-load power plants in the system to operate at their most efficient loads. With predicted renewable energy capacity, the renewable energy grid integration research finds significant renewable energy curtailment requirements. Curtailments are mostly caused by the country's demand pattern, as well as the seasonality and fluctuation of renewable energy sources. Pumped hydro storage on a wide scale will allow for more efficient use of renewable energy supplies while also relieving system operational issues. As a result, to deliver the required flexibility for the Sri Lankan Island power system, this long-term generation expansion plan proposes the establishment of a pumped hydro storage project using variable-speed technology.

JICA and CEB conducted initial research in 2014 that identified 11 viable sites for the development of a 600 MW Pumped Storage Power Plant [15]. Each site was studied and ranked in terms of environmental, topographical, geological, and technical factors. Three promising sites for detailed site investigations were discovered during the preliminary screening procedure. According to the assessment, the most ideal areas for future development are Halgran Oya, Maha Oya, and Loggal Oya in the Nuwara Eliya, Kegalle, and Badulla districts [15]. The study found that the Maha Oya site location is the most promising site for the building of the future Pumped Storage Power Plant after conducting detailed site inspections for the above three sites. Based on peaking requirements beyond 2025, the analysis suggests that the proposed Pumped Storage power plant's optimum capacity should be 600 MW. The power plant's unit capacity was calculated using system limitations such as frequency variations and manufacturing constraints for high-head turbines. For the baseline situation, the study used a unit size of 200 MW, and the ultimate unit size will be determined after further evaluations.

The Electricity Sector Master Plan Study, which was completed with JICA's help in 2018, proposed a new site location for the PSPP plant. The proposed site is near the Victoria reservoir in the Kandy district. After the extension, the bottom pond will be the existing Victoria reservoir, and the higher pond will be an existing irrigation pond located at Wewathenna (on the eastern side of Victoria reservoir). The location has the potential to create a 1,400 MW pumped hydro storage power station, with a tiered development approach described in the study. The suggested location is depicted in Figure 11 below, and Table 13 displays the anticipated capital cost of development for the proposed site based on the two studies indicated above. It is planned to conduct detailed feasibility studies for the most promising site.



Source: CEB long term generation expansion plan (2022-2041)

Figure 11. Three Selected Sites for PSPP after Preliminary Screening

Table 13. Summary of the Studies

Proposed Project	Capacity (MW)	Capital Cost Pure ($/kW)	Capital Cost with IDC ($/kW)	Construction Period (Years)	Economic Plant Life (Years)
Proposed site (2014 study)	600	1055.8	1306.9	5.0	50
Proposed site (2018 study)	1400	649.0	803.33	5.0	50

4.3. Study on Spinning and Non-Spinning Reserves in Sri Lanka for DR Programs

The improvement of energy efficiency and conservation is recognized as one of the ten objectives declared by the National Energy Policy & Strategies (NEPS) of Sri Lanka, 2019. These exertions will lessen the overall energy cost to be borne by the consumer and also will save the valuable resources of the country while reducing the burden on the environment. Hence, by introducing demand-side management together with demand reduction techniques, the country will be able to successfully confront the upcoming energy crisis and save the environment in the foreseeable future.

According to statistics, Sri Lanka's electricity demand growth had an average rate of 5.7% during the last five years. In the meantime, the maximum peak demand was recorded to be 2,717 MW in 2020 [15]. However, the total net electricity generation in the country in 2020 was 15,714 GWh, with a total installed generating capacity, of approximately 4,615 MW including rooftop solar, as of the end of 2020. This breaks down to 2,168 MW of thermal generating capacity and 2,447 MW of renewable energy-based capacity [15].

Further, all thermal power plants and the major hydropower plants are operated as dispatchable plants with a total generation capacity of 3551 MW while other renewable energy plants are considered non-dispatchable with a balance of 1064 MW up to 2020. Thus, an adequate amount of dispatchable capacity should be supplied by the thermal and major hydro plants to cater to the growing demand. However, in recent years, some load shedding programs were carried out during the night peak when the highest electricity demand is recorded. With the high operating and starting costs of thermal power plants, it is challenging to introduce new spinning and non-spinning reserves to the power grid to be used in contingencies. Hence, by introducing Demand Response (DR) programs, this high electricity demand can be reduced during critical periods by reducing the overall energy cost. As an extension to this, it is crucial to identify the spinning and non-spinning reserves to be used in DR programs.

4.3.1. Introduction to Spinning and Non-Spinning Reserves

Power system operators should continuously maintain resources that can respond immediately in case of a generator or transmission line failure. The power system will rapidly collapse if there were no resources to reinstate the lost generation. Hence, spinning reserves provide the standby spinning generation and begin responding immediately with the reception of the dispatch signal from the grid. Moreover, spinning or rapid reserve can be defined as the unloaded generation which is rotating in synchronism with the utility grid. Hence, within minutes, the spinning reserve can be brought online to serve additional load demand or else to compensate for the unforeseen loss of an operating generator.

In contrast, non-spinning reserves do not respond immediately and are not synchronized with the grid but can be brought online after a short delay. To elaborate, the non-spinning reserve can be defined as the extra generating capacity, which is not connected to the power system, but can be brought online and run within a few minutes. However, both spinning and non-spinning reserves are expected to be responded to within a maximum time of 10 minutes and can be operated for a duration of 30 minutes as defined by the power system operators [11].

To ensure the reliability of the power system, demand response resources can be used to provide spinning and non-spinning reserves. This would enhance the entire contingency reserve available in the power system and would also reduce the cost incurred in the existing coal power generators used as spinning reserves. Here, though the intentional curtailment of consumer loads by power system operators in a DR program can bring certain discomfort to the consumers, it provides an adequate amount of available spinning reserves, which finally improves the reliability of the entire power grid that will benefit all the consumers. Furthermore, with reference to the non-spinning reserves, the participating loads in the DR program will provide the demand that can be restrained through a proper real-time dispatch process in the grid.

4.3.2. Literature Review on Spinning and Non-Spinning Reserves in DR Programs

Generally, the spinning reserve is provided by the surplus capacity of committed generating units. However, in recent years a huge focus is made on adopting demand response programs, with the aim of providing ancillary services to the power grid. Hence, in many countries, some research is done in order to find methods to propose DR programs in terms of spinning and non-spinning reserves.

The earliest research in the research of spinning and non-spinning reserves in DR programs was done by the Lawrence Berkeley National Laboratory, the USA in 2007 extending to 2009. Here, the project was a pioneering demonstration of the use of existing utility load-management assets to provide the most significant reliable resource in the power grid which is the spinning reserve. This provision of the spinning reserve from the aggregated demand-side resources has given the local grid operators in California, USA, a powerful new method to improve power system reliability while preventing rolling blackouts and reducing overall operating costs. They have mainly focussed on the use of air conditioning loads to provide the necessary spinning reserve [12]. Further, some independent system operators in the United States such as Pennsylvania-New Jersy-Maryland interconnections (PJM), New England (ISO-NE), New York ISO (NYISO), and Electric Reliability Council of Texas (ERCOT) have developed an opportunity for their demand response resources to participate in ancillary services markets; especially in spinning reserve market [12].

In another study [10], It is investigated that the potential of providing spinning and non-spinning reserves to the power grid using pump loads provided by the consumers in a DR program. The results of the study were encouraging since the economic benefit of the program was huge and the utilities were able to provide the necessary policy changes to contribute to spinning and non-spinning reserves using load response. Another study [10] compares the costs of using generation and DR for spinning reserve and concludes that the latter reduces the overall costs of generation so as the costs borne by each consumer in the DR program. Hence, from these, it can be concluded that the overall power system costs are decreased by a proper DR program and give insight into the kinds of spinning and non-spinning reserves to be used in implementing an appropriate DR program.

4.3.3. Sri Lanka's Context

As discussed before, it is difficult to cater to the maximum peak demand in the country alone by the existing generation. Therefore, appropriate DR resources should be identified in terms of spinning and non-spinning reserves. By analyzing DR programs and reserves employed by other countries, the following can be used as spinning reserves in Sri Lanka.

Air conditioning loads

In Sri Lanka, air conditioning is one of the curtailable loads that can respond to system issues much faster than generators. According to studies, air-conditioning demand can be reduced almost instantly within tens of seconds, in response to the system operator's orders. Further, owing to several reasons, a spinning reserve is an excellent match for air-conditioning load-response characteristics.

The employment of spinning reserve is generally brief; hence the entire air conditioning load can be curtailed for a short duration which the customers are implausible of the sudden curtailment. Apart from that, the employment of spinning reserves is relatively infrequent since the response is required only when a power system contingency occurs. Thus, the response can be supplied by the air conditioning loads rather occasionally without major discomforts to the customers.

Further, the response of air conditioning is reliable as the total requirement is supplied by a large number of small, independent units. Hence, the failure of the response of a single unit will not have a huge impact on the total load supplied compared with the failure of a large individual generator. Moreover, due to other factors such as the continuous availability of air conditioning loads and the natural capability to match the response speed, frequency, and duration which is required to back the spinning reserve, air conditioning loads are a very good match for spinning reserves.

Electric Vehicles

In recent years, the concept of Electric vehicles (EV) has got significant consideration as a sustainable, cost-effective, and environmentally friendly alternative for conventional internal combustion engine-driven vehicles. This also mitigates the dependence on fossil fuels and reduces harmful greenhouse gas emissions and collaborates with the concept of clean and green energy. However, there are many challenges in adopting EVs on a large scale which highly include the negative impact on the operation of the power grid owing to the contemporary and uncoordinated charging of many EVs. Hence, these challenges should be carefully addressed before adopting EVs in DR programs.

In the context of EVs as a spinning reserve in DR programs, EVs can behave in three ways, as a load to the grid, a supplier of electricity to the grid, or an energy storage device. With the use of smart grid enabling technologies, EV charging time and rates can be managed by utilities, meter data details on EVs can be gathered and, therefore, successful, and proper DR programs can be implemented.

By introducing EVs as a spinning reserve in DR, the utilities should integrate EV charge management in DR operation. Though not yet available in Sri Lanka, there are two types of globally presented interactions between EVs and power grids as Grid-to-Vehicle (G2V) and Vehicle-to-Grid (V2G) connections. In G2V, power flow is unidirectional, and the EV battery is charged from the power grid. On the contrary, in V2G, the power flow is bidirectional when charging the power flows from the grid to the EV, and from the EV to the grid when discharging [7]. Hence, EVs with V2G enabled facility can assist the demand and supply balance by charging during the off-peak hours and discharging during the peak hours. Therefore, the employment of EVs as a spinning reserve in DR programs helps utilities in providing a flexible and reliable electricity supply to the consumers while reducing the total energy costs.

Battery storage

At present, utilities are maintaining a spinning reserve in order to supply the demand in system contingencies, and due to this, the performance reliability of these is somewhat less. However, in a DR program, a Battery Energy Storage System (BESS) can be used to accomplish the same results. In this context, a BESS can transit from inactive to almost standby state within a few milliseconds to prevent a service interruption. Hence, a BESS can be identified as a rapid reserve rather than non-spinning since the response is very fast.

Further, batteries are identified as very suitable for power quality applications that are expected to have rapid responses within milliseconds, since they adapt to the load-levelling region that the power-quality applications require. Moreover, BESS is very well suited for renewable energy storage applications [8]. In Sri Lanka’s context, the use of BESSs in DR programs will be prominent. In peak hours, the consumers can be encouraged to use battery power either generated in rooftop solar plants or in dedicated batteries to reduce the demand on the system. With the reduced demand, power system operators can supply the other loads with high reliability and reduced interruptions. However, proper communication methods and access to the purchase of BESS should be made available to the public if this was to be implemented. More on BESS is discussed in another section of this report.

Small Diesel Generators

Further, small individual diesel generators can also be used as spinning reserves in DR programs. In Sri Lanka, there are a large number of mercantile customers that use diesel generators as backup power supplies when there is a power failure. In recent research, it is proven that the response reliability achieved by the aggregation of a large number of small loads is greater than that of a small number of very large generators. The researchers have used 6 large generators of high reliability and 1200 small diesel generators with lower reliability to compare the response reliability of the two. Figure 12 shows the comparison. The results show that the aggregation of small individual resources gives higher response reliability than the large generators. Hence, it can be concluded that the small diesel generators in a DR program are a good match for spinning reserves.

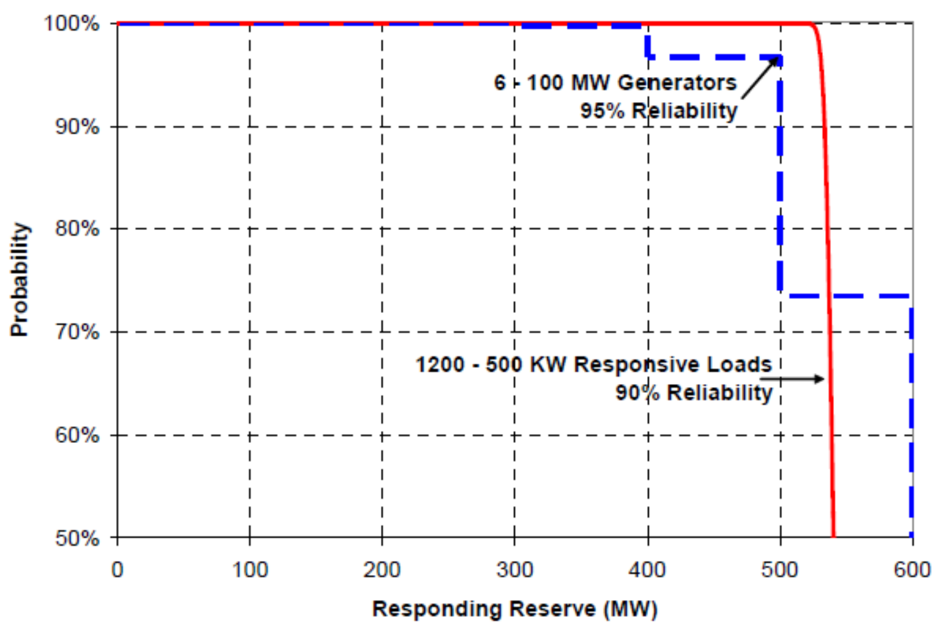


Figure 12. Response Reliability Comparison

Moreover, similar to the above analysis on the suitability of air conditioning load EVs, BESS, and small diesel generators as spinning reserves, the demand response resources will be further identified in the scope of this work.

4.3.4. Opportunities of Employing DR Resources as Spinning Reserves

In Sri Lanka, there are many opportunities to adopt a proper DR program and identify appropriate spinning and non-spinning reserves. They can be discussed as follows.

- The use of Air Conditioners (AC) for cooling has become prominent in the country. There is a huge amount of AC loads in commercial and industrial buildings and also in households in the urban parts of Sri Lanka. Since, these are distributed throughout, using them as spinning reserves will give a lot of benefits including, easy control, increased reliability, higher availability, and less consumer discomfort because of the typically brief employment periods. Hence, using ACs spinning reserve in DR programs is advantageous.
- With the objective of generating clean and green energy, Sri Lanka is looking at improving its share of renewable energy in the foreseeable future. Hence, the introduction of battery storage systems and smart grids comes hand-in-hand with the development of renewable power plants. Both these will be advantageous when adopting a DR program since it gives the benefits of high controllability, reliability, and spinning reserve provision. Apart from that, the following proposals are included in the Long Term Generation Expansion Plan 2022-2041 [15] which comes in handy for spinning and non-spinning reserve employment in DR programs.
    - Establishing monitoring and supervisory control facility for new renewable energy projects to provide visibility and controllability to the system control centre to manage both normal and contingency operating conditions.
    - Development of the planned pumped storage hydro plant as a long-term measure to enhance the flexibility and security of the system.
    - Implementing 100 MW battery energy storage systems starting from the pilot-scale to provide the fast frequency response requirement of the system.
    - Integration of solar PV with battery energy storage is encouraged to provide the capacity requirements and its potential to displace the peak capacity economically and really will be evaluated with the future progress and competitiveness with other alternatives [10].

Furthermore, from an economical point of view, when considering the DR participation in the spinning and non-spinning reserve market, the reserve capacity should be provided either by the demand or generation sides. If DR is implemented, the number of committed generation units will be decreased by further reducing the operation and maintenance costs.

From the technical point of view, the generator participation in providing reserve capacity will be less than DR participation as spinning reserves during the peak hours since more priority is given to DR resources to decrease the demand by regulating consumer loads rather than using costly committed generators during peak hours. This is because generators with low operating costs are working in full capacity and only the high-cost generators have the surplus reserve capacity. However, in off-peak hours, the demand can be supplied by generators with low operating costs since they have enough free capacity to deliver the necessary reserve capacity. Therefore, using DR resources in terms of spinning and non-spinning reserves provides great economic benefits.

4.3.5. Challenges

Since the employment of the DR program is a novel concept in Sri Lanka, many challenges are to be addressed by the utility and power system operators. Some of them are as follows.

- Proper infrastructure for communication and controlling techniques of consumer loads is not yet developed. Thus, if the DR program is to be developed, appropriate technical infrastructure should be improved.
- There are many challenges in the use of Electric Vehicles in DR programs as well. The use of EVs in Sri Lanka is comparatively low, due to the problems like high investment cost of EVs with higher driving range, high costs of electricity in Sri Lanka due to the different tariff schemes applied for EV users, capital investment requirement for EV charging infrastructure, and low second-hand market value of EVs. So, comparatively, there is a very small number of EVs in Sri Lanka to be employed in DR programs.
- Further, in Sri Lanka, the use of Battery Energy Storage Systems (BESS) is not very prominent. This is because, in rooftop solar power plants, the cost of batteries is a very high percentage of the total initial cost. So, people are reluctant to buy a BESS even if the upcoming cost saving is significant.

- In Sri Lanka, only Air Conditioners (AC) are used for cooling, so only this can be used as a curtailable load without much consumer discomfort. When using AC loads as a spinning reserve there are some challenges as well. They can be discussed as follows.
    - Generally, spinning reserves are given with a response duration of 30 minutes. Even if the spinning reserves are deployed for very short periods of time, the longer the AC loads are curtailed, the more will be the consumer discomfort. So, the individual loads should be controlled carefully.
    - To control individual small loads, proper communication, monitoring, and control system techniques should be employed. Further, some customers will not agree to curtail their AC loads at some times of the day. Hence, at first, consumer behavior should be analyzed in terms of their preferences and needs looking at the frequency of curtailment, response time, and time of the day.
    - Another concern in using responsive loads rather than generators as a spinning reserve is the impairment of power system stability. But a recent study [10] found that the provision of the spinning reserve by small loads increased the stability compared with generators as a spinning reserve since the response is much faster with consumer loads.

Cautiously addressing these challenges and providing necessary solutions for the problems discussed will allow the above-mentioned resources to be used as spinning and non-spinning reserves in DR programs.

CHAPTER 5

5. Detailed Summary; Opportunities and Challenges for DR

5.1. *Challenges Associated with DR Programs*

<table>
<tr><th colspan="2">Technological challenges</th><th></th><th>Recommendations</th></tr>
<tr><td>Control devices</td><td>Load control devices

Smart meters</td><td>Faster and more accurate responses such as remote monitoring, time-of-use pricing, and automated demand response cannot be implemented and handled properly without control devices.
There is a high initial cost associated with the instalment.</td><td>Control devices should be placed at different locations in the existing power system network for remote monitoring of the functionality and health of grid devices, temperature, and detecting outages.</td></tr>
<tr><td rowspan="7">Communication system</td><td>Technology</td><td>Associated challenges</td><td rowspan="7">A communication network is essential to establish secure and fast communication links for two-way interactions between the hardware and software components. Thus, a suitable communication technology should be selected by considering the challenges associated with them.</td></tr>
<tr><td>ZigBee</td><td>• Prone to noise interruption
• Limited by coverage range of 30–50 m only.
• As the number of load controllers increases, the quality of the signal deteriorates. Hence, for a large network such as building EMS or industry EMS, Wi-Fi or PLC is suitable</td></tr>
<tr><td>RF</td><td>• Less security in RF network
• Vulnerable to third party interference
• Data manipulation
• User privacy threat
• Not a reliable option for DR</td></tr>
<tr><td>Existing power lines as PLC communication</td><td>• Noisy because of power line interference</td></tr>
<tr><td>Ethernet-based communication</td><td>• Poor penetration in a rural region
• Suitable only for urban areas</td></tr>
<tr><td>Fibre optic-based communication</td><td>• High cost associated with the installation of an optical fibre network.</td></tr>
</table>

<table>
<tr><td></td><td>Cellular technologies</td><td>Lower security as the system uses a public network that is subjected to third party intrusion, data manipulation, and threat to user privacy.</td><td></td></tr>
<tr><td rowspan="5">Monitoring system</td><td>Smart metering</td><td rowspan="2">These monitoring systems are crucial to monitor the essential components for rapid diagnostics and formulation of precise solutions for any event. There is an associated high initial cost for the instalment.</td><td>Conventional home energy meters should be replaced by smart meters.
They should be installed at customer premises to read the consumption patterns of the customers both locally and remotely and thus provide the real-time determination and information storage of energy consumption of customers.</td></tr>
<tr><td>Advanced Metering Infrastructure (AMI)</td><td>Establishing AMI is essential for the implementation of time-based rate programs that can be offered to consumers through demand response.</td></tr>
<tr><td>Energy Management Systems</td><td>Motivating and attracting customers for controlled energy consumption patterns is a challenging task.</td><td>Customer acceptance can be achieved by the following practices.
Embedding renewable energy sources at the consumption end of the utility end.
Intelligent controlling of appliances using smart metering and PLC.
Pursuing energy-efficient retrofits</td></tr>
<tr><td>Energy Information Systems</td><td>There is an associated high initial cost for the instalment.</td><td>These systems should be implemented to enable energy and cost savings by providing visibility into energy performance and identifying opportunities for improving energy efficiency.</td></tr>
</table>

Cyber security	**Availability Integrity Confidentiality**	Numerous vulnerabilities could happen in the system when connecting the grid to the cyber network.	Implementation of standard-based public key infrastructure by enabling users of an unsecured public network (such as the internet) to securely and privately exchange data through the use of encryptions obtained and shared through a trusted authority. Technology upgrade by smart grid equipment and software manufacturers, and operators, to develop a cybersecurity framework.
Data management		The data collected from a large number of sensors, controllers, and meters that are integrated into the existing electricity network to implement DR programs need to be accurately analyzed. Databases should be carefully addressed to enhance the speed of data collection and analysis to take immediate actions in the DR program.	The development of standards and protocols for big data handling, analysis, and security concerns is essential for these critical data handling tasks.
Storage concerns		Intermittency and variability of renewable resources make it necessary to install storage devices to meet the varying demand with an uninterrupted grid supply.	A suitable storage technology should be selected considering its initial cost, life span, energy density, etc.

Socio-economic challenges		
High capital investment	The high initial capital investment needed for the demand response technologies is a challenge due to the poor financial health of the country and the utility.	Capacity and growth investment, Sustainment Investment, and Business Operation and Support Investment should be encouraged by appropriate loan programs to fund the consumers' initial investments and various types of incentives that are required to actively engage them in the programs.
Stakeholders' engagement	High capital investment, new technology, less transparency, and uncertainty might give a negative perception to stakeholders.	Advocators should induce faith in stakeholders after identifying the benefits of the demand response programs. Investments are needed for awareness programs to encourage organizations and individuals on the advantages and disadvantages of demand response programs.
System operation aspects		Instead of a unified approach, a flexible approach must be introduced from place to place considering the perception of operators, the mindset of participants, the state of supporting elements and policies, etc.
Lack of awareness		Educating consumers on the economy, efficiency, and environmental benefits of demand response technologies through awareness programs is essential.

			A high level of awareness among regulators and policymakers on present and future technology is also important.
New tariffs		Reduction of the peak load and the cost of power generation and increasing the social welfare of the people are the most popular objectives of demand-side management programs. Imposing fewer charges on the people who contribute to the DR programs is difficult to implement. Consumers who are satisfied with the existing tariff rates do not like to accept new tariff schemes.	A tariff scheme should be introduced to attract a large proportion of the customers and their contribution to demand response programs.
Miscellaneous challenges	Regulation and policies		Policymakers and regulators should pay attention to providing incentives to promote demand response programs defining standards, road maps, time frames, targets, awareness initiatives, etc.
	Workforce & Coordination between parties		Conduction of appropriate training sessions to address the skill gaps of the present workforce eliminates the scarcity of the expert working force.

5.2. Opportunities Associated with DR Programs

5.2.1. Role of DR Programs in Increasing Renewable Penetration Level in Sri Lanka

- Sri Lanka, as a tropical country, is blessed with rich renewable energy resources, which have fuelled the country's economic progress for decades.
- The main renewable source of generation in Sri Lanka's electricity grid is hydropower, which is primarily held by CEB. Other renewable energy sources, including small hydro, wind, solar, dendro, and biomass, are also connected to the system, with the majority of them held by private companies.
- Initially, the Sri Lankan government decided to establish hydropower projects with capacities of less than 10 MW with private sector participation.
- Since 2007 technology-specific, cost-reflective tariffs are provided to encourage the small power producers under renewable power purchase agreements.
- Renewable energy projects have been recently implemented in Sri Lanka.
  Example:
  - Thambapawani Wind Farm (Mannar Wind Power Park 100MW)
  - Floating Solar Plant – Kilinochchi

- Managing the seasonality and intermittency of renewable energy resources is essential. Therefore, demand-side resources can contribute to reliable balancing, by decreasing or postponing power demand when needed.
  - Example: Some demand-side resources can also provide a flexible load to increase demand when needed to avoid curtailment of renewable sources.
  - When more variable renewable energy is integrated into electricity systems, system operators need to identify tools and approaches to boost their system's flexibility.
- Under-generation and Demand Response
  - Under generation refers to an insufficient generation or a large net load.
  - Dispatchable DR programs involving demand response or thermal storage are capable of balancing under generation, which is driven by high coincident loads.
- Over-generation and Demand Response
  - For solar generation, over-generation is most likely during morning hours, when the solar resource is already strong but the load has not yet reached peak levels.

- In these situations, if available a building’s thermal mass could be used by the demand control technology to handle over-generation. But this approach would require advanced building controls and integration with grid operations.
- Thermal storage is rather well suited to balancing over-generation, as the charging of the storage battery can increase the load with flexibility in terms of its timing.

5.2.2. Identifying the Contribution of Storage-Type Resources in Sri Lanka in Balancing Demand-Supply Variations in the Power Network.

- Storage technologies are numerous, and their applications are growing at a rapid pace around the world. Their use in power systems is expanding, and applications include energy shifting, frequency management, and renewable energy fluctuation control.
- In this study, all the existing grid-scale energy storage systems and future developments in Sri Lanka are investigated by referring to the CEB long-term generation expansion plan (2022-2041).
- Globally, battery energy storage applications in power systems are growing, and technology costs are falling rapidly. Battery energy storages have a wide range of uses in all generating, transmission, distribution, and consumer endpoints.
- According to the CEB, it is planned to deploy a 20 MW of Battery Energy Storage capacity by 2025 as a gird level application primarily to provide frequency support services. It is expected to increase that to 100 MW by 2030 depending on the system requirement and the progress of wind and solar PV integration.
- In 2014, CEB performed research on peak power generation possibilities, including pumped storage hydropower plants. JICA provided technical help for the study titled "Development Planning on Optimal Power Generation for Peak Power Demand in Sri Lanka." All conceivable peaking choices were analyzed during the study, and the following options were found as viable options.
    - Hydro Power Plant Capacity Extension
    - Pumped Storage Power Plant
    - LNG Combined Cycle Power Plant
    - Gas Turbine Power Plant
- The study indicated that Hydro Plant Capacity Extensions and Pumped Storage Hydro Power Plants are the most suitable solutions for future development, based on load-

following capability and power plant features, environmental and social factors, and economic elements.

- JICA and CEB conducted initial research in 2014 that identified 11 viable sites for the development of a 600 MW Pumped Storage Power Plant. Each site was studied and ranked in terms of environmental, topographical, geological, and technical factors.
- The study found that the Maha Oya site location is the most promising site for the building of the future Pumped Storage Power Plant after conducting detailed site inspections. Based on peaking requirements beyond 2025, the analysis suggests that the proposed Pumped Storage power plant's optimum capacity should be 600 MW.
- The Electricity Sector Master Plan Study, which was completed with JICA's help in 2018, proposed a new site location for the PSPP plant. The proposed site is near the Victoria reservoir in the Kandy district. The location has the potential to create a 1,400 MW pumped hydro storage power station.

5.2.3. Spinning and Non-Spinning Reserves in Sri Lanka for DR Programs

- There is a huge amount of AC loads in commercial and industrial buildings and also in households in the urban parts of Sri Lanka. Since, these are distributed throughout, using them as spinning reserves will give a lot of benefits including,
    - Easy control
    - Increased reliability
    - Higher availability
    - Fewer consumer discomforts
- The introduction of battery storage systems and smart grids with the development of renewable power plants will be advantageous when adopting a DR program since it gives the benefits of high controllability, reliability, and spinning reserve provision.
- Several proposals are included in the Long-Term Generation Expansion Plan 2022-2041 for spinning and non-spinning reserve employment in DR programs.
    - Establishing monitoring and supervisory control facility for new renewable energy projects to provide visibility and controllability to the system control centre to manage both normal and contingency operating conditions.
    - Development of the planned pumped storage hydro plant as a long-term measure to enhance the flexibility and security of the system.

    - Implementing 100 MW battery energy storage systems starting from the pilot scale to provide the fast frequency response requirement of the system.
    - Integration of solar PV with battery energy storage is encouraged to provide the capacity requirements and its potential to displace the peak capacity economically and really will be evaluated with the future progress and competitiveness with other alternatives.
- If DR is implemented, the number of committed generation units will be decreased by further reducing the operation and maintenance costs.
- The generator participation in providing reserve capacity will be less than DR participation as spinning reserves during the peak hours since more priority is given to DR resources rather than using costly committed generators during peak hours.

CHAPTER 6

6. Detailed Summary; Outcomes and Recommendations

6.1. Objective 1

Use DR resources as equivalents to traditional generation resources to ensure sufficient capacity during peak-load hours

<table>
<tr><th>Expected Outcome/ Outcome</th><th>Recommendations</th></tr>
<tr><td>Identifying DR resources for implementing DR programs with the existing utility grid in Sri Lanka
<table>
<tr><th>Generation based</th><th>Load based</th></tr>
<tr><td>Renewable Generation Resources-Solar & Wind</td><td>Industrial-- Industrial motors and machinery</td></tr>
<tr><td>Storage Systems-Battery and Pumped storage</td><td>Commercial -AC, Heating and Ventilation, Lighting</td></tr>
<tr><td>Diesel generators</td><td rowspan="3">Residential- Thermal loads(AC & Heaters), EV, Dryers, Washing machines</td></tr>
<tr><td>Micro turbines</td></tr>
<tr><td>Combined Heat and Power (CHP) modules</td></tr>
</table>
</td><td rowspan="2">A study should be carried out to identify the available capacity of these DR resources in Sri Lanka.</td></tr>
<tr><td>Identifying the customer perception on Net Metering, EVs, Diesel Generators and Microgrids by means of surveys</td></tr>
</table>

According to the definition, DR resources are the resources which can be adapted with DR programs. Under this objective, all the DR resources which are available in Sri Lanka are identified and all resources are categorized into generation based and load-based resources. Renewable generation resources such as wind and solar generations, storage resources such as Battery Energy Storage Systems (BESS) and pumped storage hydro generations, diesel generators, micro turbines, Combined Heat and Power (CHP) modules can be considered as generation-based resources. In Sri Lanka, pumped storage power plants are still not implemented and there is no significant amount of battery storage systems, whereas they should be implemented in future as spinning reserves in order to make the balance between supply and demand in the emergency conditions. With the generation-based resources, customers can participate in DR programs by decreasing, postponing, and rescheduling their loads at the peak or emergency periods.

When it comes to the load-based resources, all the shiftable and controllable loads can be taken into this category. In the industrial aspect, motors and similar machinery can be considered as the existing controllable loads, and majority of industrial customers are not interested in completely shedding their loads and reducing the energy consumption at peak time, however will participate in the DR programs by shifting their loads. In addition to the industrial customers, all the air conditioning system, heaters, ventilation and lighting systems in commercial buildings can be used for DR programs. Same as the case of industrial customers, they are reluctant in completely shedding their loads, but they have an opportunity to reduce the energy consumption at peak or emergency periods. For example, they can increase the temperature setting of ACs in system emergencies in order to avoid the imbalance between the supply and demand. Moreover, residential customers are also important since some of the high end energy consumers who use ACs and heaters can participate in the DR programs and EV owners can charge their electric vehicles during off peak time in order to reduce the energy consumption during peak periods. In addition, there are a lot of research undergoing in order to adapt domestic dryers and washing machines into DR programs.

Under this objective, customer motivational factors are also identified by conducting surveys on net metring, EVs, Diesel Generators (DGs) and microgrids. All the results are discussed under the proposals which are explained ahead in the relevant chapters.

Recommendation

As the recommendations, a study should be carried out to identify the available capacity of above explained DR resources in Sri Lanka.

6.2. Objective 2

Formulate DR programs that act as spinning and non-spinning reserves to provide resources during system emergencies

Expected Outcome/ Outcome	**Recommendations**
Identifying and analysing the suitable demand response programs that demonstrate characteristics of spinning and non-spinning resources	• Study to be carried out to identify the available capacities of spinning and non-spinning reserves. • Necessary policy changes to be recognised to adopt spinning and non-spinning reserves to the existing utility grid in Sri Lanka
Researching on opportunities and challenges when implementing DR programs	

Under this objective, all the demand response programs are identified which demonstrate the characteristics of spinning and non-spinning reserves.

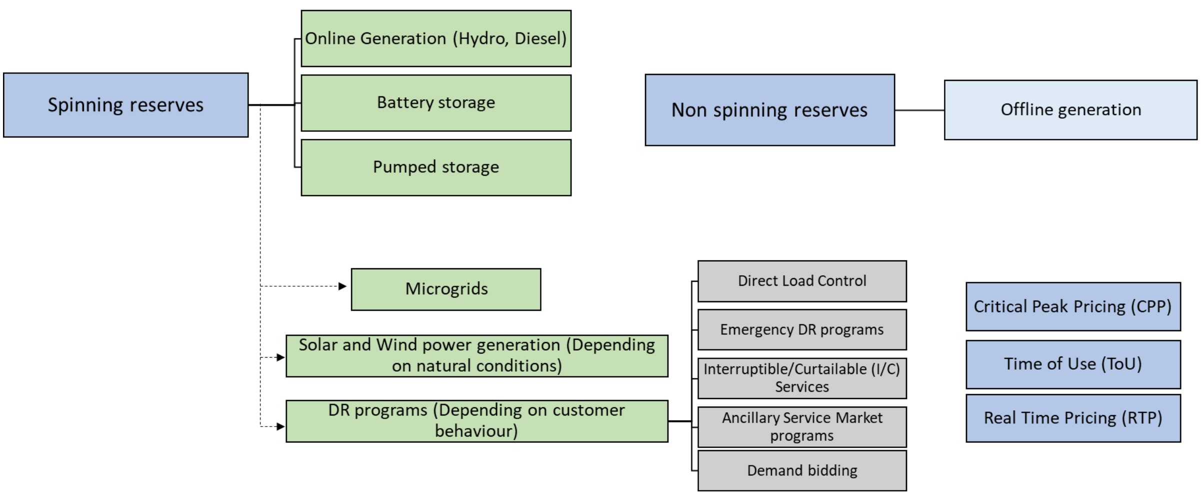


Figure 13. Spinning and Non-Spinning Reserves

Spinning Reserves

According to the definition, the spinning reserve is the provision of standby “spinning” generation ready to commence generation within a few minutes of receiving a dispatch signal from the grid. When the imbalance between power supply and load occurs, the utility grid should have to go for demand-side management programs. But if they have more spinning reserves, all the fluctuations and power quality issues can be solved very quickly. In Sri Lanka, online generations such as hydro and diesel generators which are already synchronized with the utility grid can be considered as spinning reserves. Further, BESS and pumped storage can be used as spinning reserves because of their fast response.

Microgrids can be considered as one of important spinning reserves available in the world because they consist of synchronized diesel generators as well as battery storages. In addition to that, solar and wind power generations can be categorized into spinning reserves even though they are dependent on the natural conditions. We can adapt those resources by implementing more battery storage or any other storage technology in order to increase the inertia level of the system. Moreover, some of the demand response programs, especially incentive based programs can be adapted as spinning reserves because significant number of loads can be reduced at the peak time or emergency time with the aid of those programs. All DR programs are discussed under chapter 2.

In addition to the DR programs, Air conditioning systems and Electric vehicles can be used as spinning reserves. Air conditioning is one of the curtailable loads that can respond to system issues much faster than generators. The utility can introduce smart thermostats, load control devices or smart sockets for the customer ACs with DR programs such as DLC, I/C services. In the context of EVs as a spinning reserve in DR programs, EVs can behave in three ways, as a load to the grid, a supplier of electricity to the grid, or an energy storage device. EV charging time and rates can be managed by utilities by integrating with DR programs.

Non spinning reserves

According to the definition, non-spinning reserve or supplementary reserve is the extra generating capacity that is not currently connected to the system but can be brought online after a short delay. When power imbalances occur, these resources can be connected to the utility grid within a very short time period and all the non-synchronized hydro and diesel generators can be used as non-spinning reserves.

Further, small individual diesel generators in residential areas and also large individual diesel generators (1MW or above) in commercial buildings and industries can be used as a non-spinning reserve, but the problem is they don't come with synchronizing mechanisms. Thus, it is necessary to update the existing generators and upcoming diesel generators with relevant synchronizing arrangements.

In addition to that, each challenge is identified when implementing the above explained DR programs. All possible challenges are categorized as technological, socio-economic and miscellaneous challenges. When it comes to technological challenges, first, it is essential to consider about control devices when implementing DR programs in the existing utility grid in Sri Lanka. Load control devices, smart sockets, smart fan controllers, smart thermostats are some of the control devices which can be used in order to control the critical loads of the residential areas such as ACs, heaters, dryers, water pumps and etc. In addition to that, a proper communication system and monitoring system should be developed. Smart meters should be introduced for the participants and advanced metering infrastructure should be developed with them.

Further, if the utility is implementing new DR program for domestic customers, consideration about Home Area Network (HAN), Neighbour Area Network (NAN) and Wide Area Network (WAN) is a must. In HAN, all the controllable and shiftable loads should be connected through a wired communication network for controlling purposes so that each consumption rate and load profiles of the appliances can be detected through smart meters. In NAN, all the smart meters should be connected through wireless communication system in order to maintain connectivity and proper coordination. Finally, each smart meter should be connected to the utility grid via wired or wireless communication platforms in WAN. If such kind of smart metering infrastructures were to be implemented, it is essential to consider about cyber security system in order to protect system from cyber-attacks and cyber bullying. Moreover, a proper data management system and a data storage system should be developed to secure the data and information.

In terms of socio-economic challenges, first the utility or service provider should consider about the initial investment for developing such kind of a smart system. For that, they should focus on getting low interest loan schemes, government funding or support from international banks. It is imperative to conduct a survey to be familiar with the stakeholders' engagement and their motivational factors. According to previously implemented DR programs worldwide, a huge focus was given into customer responses by the utilities to make the program successful. Moreover, apart from this, system operational aspects and awareness should be developed. For that, more workshops should be conducted with related organizations and service providers such as solar companies, smart meter manufacturers, DG solutions and EV manufacturers/users, smart device solutions etc. In addition to that, privacy of the customers should be protected, and a new tariff structure should be introduced for the participants. For Sri Lanka, it is recommended to introduce a new Time of Use (TOU) tariff for the customers as it will build up a motivation among them to adapt with the DR programs. With that, they have an opportunity to reduce their electricity bills if they decrease, postpone or reschedule their loads during the peak periods.

As a miscellaneous challenge, it is important to develop policies and regulations when introducing DR programs. For that, more workshops should be conducted in collaboration with CEB, LECO, SEA and PUCSL. Moreover, system infrastructure should be developed, and a proper coordination system should be maintained.

Recommendations

Under this objective, it is recommended that a study should be carried out to identify the available capacities of spinning and non-spinning reserves and required policies and regulations in order to adapt those reserves to the existing utility grid in Sri Lanka.

6.3. *Objective 3*

DR to provide energy services that primarily enhance efficient price formation, but also enhance reliable operation of the system

Expected Outcome/ Outcome	Recommendations
Introduction of new TOU tariff rates for domestic customers based on their consumption such that their electricity bill remains unchanged. or Introduction of an optional meter connection with existing TOU tariff rates for the domestic customers.	• Formulate policies to promote the use of smart appliances in domestic level in order to automate the load shifting process • A workshop to enhance the customer awareness on the possible benefits of new TOU tariff rates and meter connection.
A survey on TOU tariff targeting domestic customers in order to identify the customer behaviour and motivating factors	
Finding savings for the utility as well as the customers by implementing attractive TOU tariff rates.	

Under this objective, a new TOU tariff structure is introduced for the domestic customers in order to make the proposed DR programs successful. According to the previously conducted surveys, there is less motivation among domestic customers to participate with demand side management (DSM) programs because of the existing block tariff rates. Therefore, new TOU tariff rates are proposed based on the energy consumption of the domestic customers such that their electricity bill remains unchanged. For each and every consumption block of the residential tariff, new TOU tariff rates are introduced for the peak, off-peak and daytime. More details for this TOU tariff structure are discussed under Chapter 7.

Otherwise, an optional meter connection can be introduced for them with the exiting TOU tariff rates. There is no argument that the existing TOU tariff structure is not attractive as the price rates are high when compared to the block tariff rates. An optional meter connection with the existing TOU tariff, side by side with the block tariff meter connection is proposed as a solution. Then domestic consumers have an opportunity to use their higher energy-consuming loads such as electric vehicle charging, water pumping at the off-peak time with the TOU meter connection and they can use all other loads with the block tariff meter connection as usual.

In addition to that, a survey is conducted to identify the motivational factors of domestic customers regarding the proposed new TOU tariff structure. With the introduction of this tariff structure, both participants and utility will be benefited. The participants will have to pay the almost the same amount of electricity bill, but they have an opportunity to further reduce their electricity bill if they reduce their energy consumption at peak hours or shift the loads by means of an on-site generating unit such as hybrid solar or DGs. On the other hand, utility grid can reduce the cost of expensive generation at peak time because, a significant amount of peak load will be reduced with the introduction of the proposed TOU tariff rates.

Recommendations

It is recommended that, smart appliances should be promoted among the participants so that they can reduce the energy consumption at peak hours or in emergencies by reducing their energy consumption. For that, policies and regulations should be developed. With the use of smart devices, participants have an opportunity to automate their load shifting, reduce processes or they can remotely control loads. All the smart devices that are currently available in the market are discussed in Chapter 7. Moreover, workshops should be conducted to enhance customer awareness on the possible benefits of new TOU tariff rates and meter connections.

6.4. *Objective 4*

To attain environmental benefits, resulting from DR's ability to facilitate the integration of renewable resources, the flexibility of DR allows the power system to accommodate higher penetrations of variable resources such as wind and solar.

<table>
<tr><th>Expected Outcome/ Outcome</th><th>Recommendations</th></tr>
<tr><td>Identifying the challenges and opportunities in order to increase the solar and wind energy integration level.
<table>
<tr><th>Challenges</th><th>Opportunities</th></tr>
<tr><td>Under-generation</td><td>Hybrid solar PV system should be promoted</td></tr>
<tr><td>Over-generation</td><td>A proper financial incentive such as low interest loan schemes and
A cost-reflective Time of Supply (ToS) feed-in-tariff (Time of supply) should be introduced.</td></tr>
<tr><td>Lack of system inertia and spinning reserves, and storage</td><td>A mandatory insurance scheme and a quality measurement index should be proposed</td></tr>
<tr><td>Higher harmonics (Power converters)</td><td>Implement more individual microgrids for critical loads and microgrid clusters</td></tr>
<tr><td>Reverse power flow causes voltage rise (during the day for rooftop solar PV)</td><td>Implement a co-ordination system in order to gather the data of rooftop solar PV generation.</td></tr>
</table>
</td><td rowspan="2">A study to be carried out to see the possibilities of expediting the execution of storage type resources such as battery storage and pumped storage.</td></tr>
<tr><td>Identifying the challenges and limitations in introducing battery storages at domestic customer levels.</td></tr>
</table>

Under this objective, all challenges and opportunities are discussed when increasing the renewable integration level in Sri Lanka.

Challenges

It is often agreed that there are quite a few challenges in increasing the renewable generations in the existing utility grid due to the fluctuations in solar power and seasonal variations of wind power. As solutions, more spinning reserves such as BESS and pumped storage hydropower plants should be developed. In order to manage the under-generation and over-generation of rooftop solar PV generation, all non-essential controllable loads at the under-generation period should be shifted to the over-generation period by adapting to DR programs.

On the other hand, system inertia is one of the important parameters which should be focused on when increasing the renewable integration level. With the introduction of solar or wind power generations, utilities should consider the spinning reserve requirement otherwise system inertia will be dropped causing reliability issues. For that, hybrid solar systems can be proposed at the domestic level and BESSs should be developed for large-scale ground-mounted solar generations. On the contrary, it will create more harmonics in the system because of power converters. For that, high-quality power converters with high efficiencies and low harmonic generation should be promoted. Moreover, it will create high voltages in the daytime of the rooftop solar PV generations because of the reverse power flow. It will trip the inverter in the daytime and sometimes it will be harmful to distribution lines, transformers, and customer equipment.

Opportunities

The utility has an opportunity to promote hybrid solar PV systems among domestic customers. For that, a proper financial incentive such as low interest loan schemes and a cost-reflective Time of Supply (ToS) feed-in-tariff should be introduced. Then customers will be motivated to build hybrid solar systems in their premises. In addition to that, a mandatory insurance scheme and a quality measurement index should be introduced in order to build up confidence between the customer and service provider. Further, in certain applications, microgrids can be used to increase the reliability of the system. A microgrid is a decentralized group of electricity sources and loads that normally operate, connected to and synchronous with traditional wide area synchronous grid, but it is able to disconnect from the interconnected grid and to function autonomously in "island mode" as technical or economic conditions dictate. Thus, they can be promoted for apartments, educational institutions, hotels, commercial buildings etc. Moreover, individual microgrids can be implemented for critical loads and microgrid clusters in the distribution network. Another important point is that utility should consider about implementing a co-ordination system in order to gather the data of rooftop solar PV generation as such data are highly essential for future research.

In addition to above outcomes, all the challenges and limitations in introducing battery storages at domestic customer levels are focused under this objective. It is seen that most of the domestic customers are using grid-tie inverters for the roof top solar PV generations, but those customers should be motivated to replace their existing inverters with hybrid inverter and BESSs. Otherwise, all grid-tie inverters should be replaced with AC coupled inverters and BESSs.

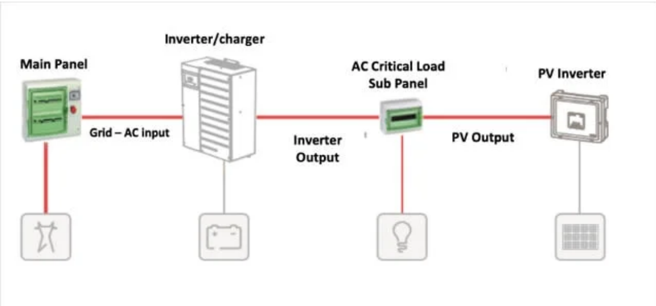


Figure 14. AC Coupled Inverter Solution with BESS

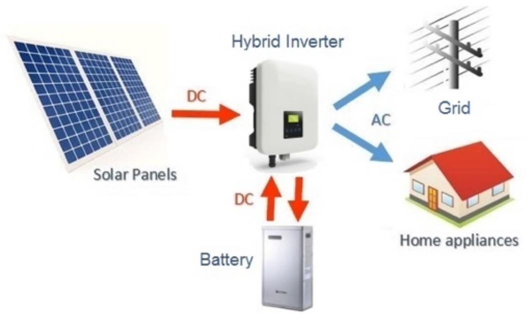


Figure 15. Hybrid Inverter Solution with BESSs

Recommendations

It is recommended that a study should be carried out to identify the possibilities of expediting the execution of storage type resources such as battery storage and pumped storage in Sri Lanka.

CHAPTER 7

7. Proposals for Implementing Demand Response Programs

7.1. Proposal 1

Introduction of a new TOU tariff for domestic customers based on their energy consumption to promote DR

In this task:

New TOU tariff rates and a smart meter connection are to be introduced to domestic customers such that their electricity bill remains almost unchanged.

Opportunities:

- Time Of Use (TOU) Tariff would be a win-win solution for both the participants and utilities.
- Use of proposed domestic TOU tariff rates for EV charging.
- Implementation of remotely and automatically switching off appliances at peak time by customers.

Motivational factors:

Establishing a way to provide financial incentives/assistance for the customers who are willing to implement hybrid solar systems or smart devices.

7.1.1. Introduction

In this proposal, a new TOU tariff rate and a smart meter connection are introduced for domestic customers such that their electricity bill remains almost unchanged. According to the previously conducted surveys, there is less motivation among domestic customers to participate in demand-side management (DSM) programs because of the existing block tariff rates. Therefore, new TOU tariff rates are proposed based on the energy consumption of the domestic customers by keeping their electricity bills unchanged. For each and every consumption block of the residential customers, new TOU tariff rates are proposed for the peak, off-peak, and daytime.

With the introduction of the proposed TOU tariff rates, both participants and utility will be benefited, that means this would be a win-win solution. The participants will have to pay almost the same amount of electricity bill, but they have an opportunity to further reduce their electricity bill if they reduce the energy consumption at peak times or shift their loads by means of on-site generating units such as hybrid solar or DGs. On the other hand, the utility grid can reduce the cost of expensive generation at peak time since a significant amount of peak load will be reduced with the proposed TOU tariff rates.

In addition to that, EV owners have an opportunity to charge their electric vehicles at the off-peak time and that will also reduce the peak demand. Moreover, this will lead to an increase in smart devices among domestic customers. With the introduction of smart devices, the customers have an opportunity to control their loads remotely or automatically at peak times. They can remotely control their highly energy-consuming loads by using an app or else they can schedule the time setting in order to switch on and off appliances during peak time. The following table shows some of the smart devices available in the market and their product details.

Table 14. Market Existing Smart Devices

Smart Devices	Product Details
Smart Wi-Fi Socket B25UK 	• HomeMate App Control • Timer Settings • Energy-saving reminders • Communication through Wi-Fi • Supplier : Shinrai Lanka (Pvt) Ltd. • Price : Rs.6300.00
Tuya Smart Power Socket 	• Dialog Smartlife App Control • Remotely switch on/off • Set on/off time schedules • Manual Switch control • Live status update • Communication through Wi-Fi • Supplier : Orange Electric & Dialog • Price : Rs.4990.00

<table>
<tr><td>Smart Power Strip
</td><td>Dialog Smartlife App Control
Remotely switch on/off
Set on/off time schedules
Manual Switch control
Live status update
Communication through Wi-Fi
Supplier : Orange Electric & Dialog
Price : Rs.7490.00</td></tr>
<tr><td>Smart Switches (for lighting)
Touch Classic 1/2/3 gang switches
</td><td>HomeMate App Control
Remotely switch on/off
Set on/off time schedules
Manual Switch control
Communication through ZigBee
Supplier : Shinrai Lanka (Pvt) Ltd
Price : Rs.11700.00</td></tr>
<tr><td>Smart Switches (for lighting)
In- wall switch (Single-Live)
</td><td>HomeMate App Control
Remotely switch on/off
Set on/off time schedules
Manual Switch control
Communication through ZigBee
Supplier : Shinrai Lanka (Pvt) Ltd
Price : Rs.8300.00</td></tr>
</table>

Smart Fan Controller (for Ceiling Fans) 	• Works with Amazon Alexa & Google Home • Remotely switch control • Set on/off time schedules • Controls fan speed. • Communication through Wi-Fi • Supplier : Dialog • Price : Rs.7390.00

The following methodologies demonstrated the calculation of new TOU tariff rates such that the electricity bill of the domestic customers remains almost unchanged.

Methodology to calculate the TOU rates for domestic purposes under the existing block and existing TOU tariff rates

A - Average energy consumption at peak time

B - Average energy consumption at off-peak time

C - Average energy consumption in daytime

D - Average energy consumption of the domestic customer

X - Price rate at peak time

Y - Price rate at off-peak time

Z - Price rate at daytime

FC_1, FC_2 - Fixed change rates

Example calculation: for the domestic customer category with (91-120) units

$$AX + BY + CZ + FC_1 = (D - 90) \times 27.75 + 30 \times 10 + 60 \times 7.85 + FC_2$$

Similarly, TOU tariff rates are calculated for each consumption block of domestic customers and compare with the exiting TOU and block tariff rates.

Table 15. Existing Block and TOU Tariff Rates

Customer Category	Consumption per month (kWh)	Unit Charge (Rs./kWh)	Fixed Charge (LKR/month)
D -1	0 - 30	2.5	30
	31 - 60	4.85	60
D - 2	0 - 60	7.85	N/A
	61 - 90	10	90
	91- 120	27.75	480
	121-180	32	480
	>180	45	540
Peak (18:30-22:30)		54	540
Day(05:30-18:30)		25	
Off-peak(22:30-05:30)		13	

In the following examples, new TOU tariff rates are calculated based on the newly proposed block tariff rates.

Methodology to calculate the TOU rates for the domestic purpose under the newly proposed block and TOU tariff rates.

A - Average energy consumption at peak time

B - Average energy consumption at off-peak time

C - Average energy consumption at daytime

X -Price rate at peak time

Y - Price rate at off-peak time

Z - Price rate at daytime

D - Average energy consumption of domestic customer

FC_3, FC_4 - Fixed change rates

Example calculation: for the domestic customer category with (91-120) units

$$AX + BY + CZ + FC_3 = (D - 90) \times 37 + 30 \times 18 + 60 \times 15.5 + FC_4$$

Table 16. Newly Proposed Block and TOU Tariff Rates

Customer Category	Consumption per month (kWh)	Unit Charge (Rs./kWh)	Fixed Charge (LKR/month)
D-1	0-30	8	430
	31-60	12.5	1100
D-2	0-60	15.5	N/A
	61-90	18	1350
	91-120	37	1650
	121-180	37	1650
	>180	50.5	1700
Peak (18:30-22:30)		54	1700
Day(05:30-18:30)		30.5	
Off-peak(22:30-05:30)		17	

The following tables demonstrate the proposed TOU tariff rates for domestic customers. The TOU tariff rates are calculated at peak, off-peak and daytime for each consumption block (0-30, 31-60, 61-90, 91-120, 121-180 and over 180 kWh) based on the exiting block and newly proposed block tariff rates. In this calculation, proposed TOU rates-01 means the proposed TOU tariff rates under the existing block tariff rates and proposed TOU rates-02 means the proposed TOU rates under the newly proposed block tariff rates.

Analysis of proposed TOU tariff: 0-30 kWh/month household customers

	Energy Units(kWh)	Existing TOU Rates (LKR/kWh)	Proposed TOU Rates-01(LKR/kWh)	Charge (LKR) (Existing TOU Rates)	Charge (LKR) (Proposed TOU Rates-01)	Charge (LKR) (Existing Block Rates)	Newly Proposed TOU Rates	Newly Proposed TOU Rates-02	Charge (LKR) (Newly Proposed TOU Rates)	Charge (LKR) (Newly Proposed TOU Rates-02)	Charge (LKR) (Newly Proposed Block Rates)
Peak (18:30-22:30)	13.01	54	3.5	702.54	45.535		54	12	702.54	156.12	
Day(05:30-18:30)	11.41	25	2	285.25	22.82		30.5	5	348.005	57.05	
Off-peak(22:30-05:30)	5.45	13	1	70.85	5.45		17	4.5	92.65	24.525	
Total Energy Charge				1058.64	73.805				1143.195	237.695	
Fixed Charge		540	30	540	30		1700	430	1700	430	
Total Bill				1598.64	103.805	104.675			2843.195	667.695	668.96

Analysis of proposed TOU tariff: 31-60 kWh/month household customers

	Energy Units(kWh)	Existing TOU Rates (LKR/kWh)	Proposed TOU Rates-01(LKR/kWh)	Charge (LKR) (Existing TOU Rates)	Charge (LKR) (Proposed TOU Rates-01)	Charge (LKR) (Existing Block Rates)	Newly Proposed TOU Rates	Newly Proposed TOU Rates-02	Charge (LKR) (Newly Proposed TOU Rates)	Charge (LKR) (Newly Proposed TOU Rates-02)	Charge (LKR) (Newly Proposed Block Rates)
Peak (18:30-22:30)	18.79	54	5.5	1014.66	103.345		54	14	1014.66	263.06	
Day(05:30-18:30)	21.56	25	2.5	539	53.9		30.5	8	657.58	172.48	
Off-peak(22:30-05:30)	11.09	13	2	144.17	22.18		17	6.5	188.53	72.085	
Total Energy Charge				1697.83	179.425				1860.77	507.625	
Fixed Charge		540	60	540	60		1700	1100	1700	1100	
Total Bill				2237.83	239.425	238.984			3560.77	1607.625	1608

Analysis of proposed TOU tariff: 61-90 kWh/month household customers

	Energy Units(kWh)	Existing TOU Rates (LKR/kWh)	Proposed TOU Rates-01(LKR/kWh)	Charge (LKR) (Existing TOU Rates)	Charge (LKR) (Proposed TOU Rates-01)	Charge (LKR) (Existing Block Rates)	Newly Proposed TOU Rates	Newly Proposed TOU Rates-02	Charge (LKR) (Newly Proposed TOU Rates)	Charge (LKR) (Newly Proposed TOU Rates-02)	Charge (LKR) (Newly Proposed Block Rates)
Peak (18:30-22:30)	24.59	54	13	1327.86	319.67		54	26	1327.86	639.34	
Day(05:30-18:30)	39.92	25	7.5	998	299.4		30.5	13	1217.56	518.96	
Off-peak(22:30-05:30)	18.6	13	4.5	241.8	83.7		17	10	316.2	186	
Total Energy Charge				2567.66	702.77				2861.62	1344.3	
Fixed Charge		540	90	540	90		1700	1350	1700	1350	
Total Bill				3107.66	792.77	792.1			4561.62	2694.3	2695.98

Analysis of proposed TOU tariff: 91-120 kWh/month household customers

	Energy Units(kWh)	Existing TOU Rates (LKR/kWh)	Proposed TOU Rates-01(LKR/kWh)	Charge (LKR) (Existing TOU Rates)	Charge (LKR) (Proposed TOU Rates-01)	Charge (LKR) (Existing Block Rates)	Newly Proposed TOU Rates	Newly Proposed TOU Rates-02	Charge (LKR) (Newly Proposed TOU Rates)	Charge (LKR) (Newly Proposed TOU Rates-02)	Charge (LKR) (Newly Proposed Block Rates)
Peak (18:30-22:30)	28.7	54	20	1549.8	574		54	34	1549.8	975.8	
Day(05:30-18:30)	53.7	25	10	1342.5	537		30.5	16	1637.85	859.2	
Off-peak(22:30-05:30)	26	13	6.5	338	169		17	12	442	312	
Total Energy Charge				3230.3	1280				3629.65	2147	
Fixed Charge		540	480	540	480		1700	1650	1700	1650	
Total Bill				3770.3	1760	1761.6			5329.65	3797	3800.8

Analysis of proposed TOU tariff: 121-180 kWh/month household customers

	Energy Units(kWh)	Existing TOU Rates (LKR/kWh)	Proposed TOU Rates-01(LKR/kWh)	Charge (LKR) (Existing TOU Rates)	Charge (LKR) (Proposed TOU Rates-01)	Charge (LKR) (Existing Block Rates)	Newly Proposed TOU Rates	Newly Proposed TOU Rates-02	Charge (LKR) (Newly Proposed TOU Rates)	Charge (LKR) (Newly Proposed TOU Rates-02)	Charge (LKR) (Newly Proposed Block Rates)
Peak (18:30-22:30)	37.19	54	28	2008.26	1041.32		54	40	2008.26	1487.6	
Day(05:30-18:30)	68.96	25	14	1724	965.44		30.5	20	2103.28	1379.2	
Off-peak(22:30-05:30)	36.86	13	9	479.18	331.74		17	15.5	626.62	571.33	
Total Energy Charge				4211.44	2338.5				4738.16	3438.13	
Fixed Charge		540	480	540	480		1700	1650	1700	1650	
Total Bill				4751.44	2818.5	2819.82		1650	6438.16	5088.13	5081.37

Analysis of proposed TOU tariff: over 180 kWh/month household customers

	Energy Units(kWh)	Existing TOU Rates (LKR/kWh)	Proposed TOU Rates-01(LKR/kWh)	Charge (LKR) (Existing TOU Rates)	Charge (LKR) (Proposed TOU Rates-01)	Charge (LKR) (Existing Block Rates)	Newly Proposed TOU Rates	Newly Proposed TOU Rates-02	Charge (LKR) (Newly Proposed TOU Rates)	Charge (LKR) (Newly Proposed TOU Rates-02)	Charge (LKR) (Newly Proposed Block Rates)
Peak (18:30-22:30)	70.05	54	50	3782.7	3502.5		54	56	3782.7	3922.8	
Day(05:30-18:30)	112.2	25	24	2805	2692.8		30.5	28	3422.1	3141.6	
Off-peak(22:30-05:30)	75.48	13	11	981.24	830.28		17	22	1283.16	1660.56	
Total Energy Charge				7568.94	7025.58				8487.96	8724.96	
Fixed Charge		540	540	540	540		1700	1700	1700	1700	
Total Bill				8108.94	7565.58	7561.35			10187.96	10424.96	10425.365

Table 17. Proposed TOU Tariff Rates Under Existing Block Tariff Rates

	0-30 kWh	31-60 kWh	61-90 kWh	91-120 kWh	121-180 kWh	over 180 kWh
Peak (18:30-22:30) (LKR)	3.5	5.5	13	20	28	50
Day (05:30-18:30) (LKR)	2	2.5	7.5	10	14	24
Off-peak (22:30-05:30) (LKR)	1	2	4.5	6.5	9	11
Fixed charge (LKR)	30	60	90	480	480	540

Then, the average electricity bill is calculated based on the average energy consumption at peak, off-peak and daytime by conducting a load survey. The calculated average electricity bill based on exiting TOU tariff, existing block tariff, and proposed TOU tariff rates are demonstrated in the following figures. According to the electric bill profiles, the calculated average electricity bill for existing block tariff rates is almost equivalent to the average electricity bill calculated from the proposed TOU tariff rates.

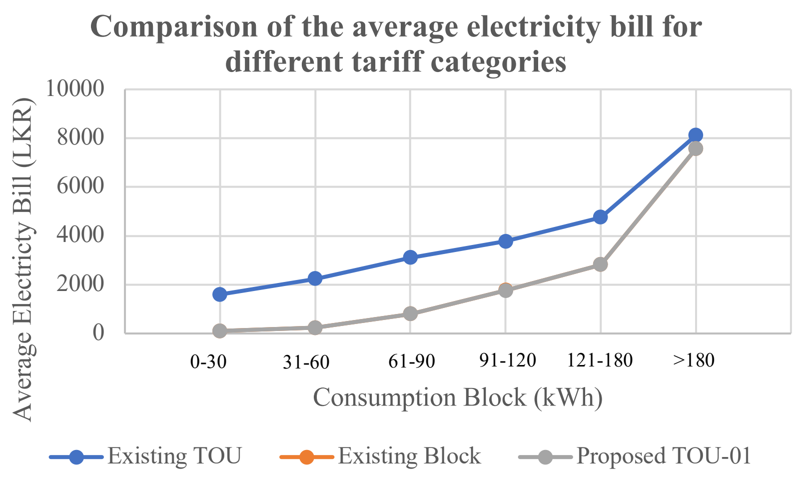


Figure 16. Average Electricity Bill Calculation under Existing Block and TOU Tariff Rates

In this method, the proposed TOU tariff rates are only introduced for high energy consumers. That means, the exiting block tariff rates can be used for 0-30, 31-60 and 61-90 kWh customers, and all other consumption block customers will have to use the proposed TOU tariff rates. That would be comparatively efficient because low energy consumers don't have a significant amount of controllable and shiftable loads and also their electricity bill is also very low because of the existing block tariff rates. Thus, there is less motivation among them to participate in DR programs. Therefore, there is no point in providing new smart meter connections and TOU tariff rates for low-energy consumers.

Table 18. Proposed TOU Tariff Rates Under Newly Proposed Block Tariff Rates

	0-30 kWh	31-60 kWh	61-90 kWh	91-120 kWh	121-180 kWh	over 180 kWh
Peak (18:30-22:30) (LKR)	12	14	26	34	40	56
Day (05:30-18:30) (LKR)	5	8	13	16	20	28
Off-peak (22:30-05:30) (LKR)	4.5	6.5	10	12	15.5	22
Fixed charge (LKR)	430	1100	1350	1650	1650	1700

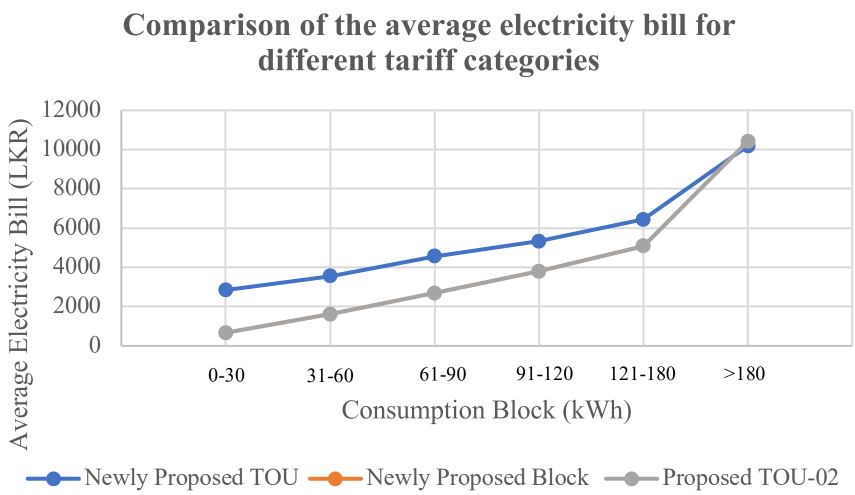


Figure 17. Average Electricity Bill Calculation under Newly Proposed Block and TOU Tariff Rates

According to the newly proposed block tariff rates, low energy consumers also will have to pay comparatively high electricity bill than pervious bills. If those tariff rates are approved, then the utilities have an opportunity to introduce the proposed TOU tariff rates for all the customers. It is a known fact that low energy consumers don't have significant amount of shiftable or controllable loads, and also, they are not in a position to implement hybrid solar systems, DGs, and smart devices on their premises to shift their higher energy consuming loads at peak time. But they will motivate to use some demand-side management programs. For example, the majority of customers who are using incandescent bulbs in their houses are low-energy consumers, thus, now they have an opportunity to replace their incandescent bulbs with CFL or LED bulbs. Likewise, they can participate in the DSM programs by using some energy-efficient methodologies.

7.1.2. Financial Impact on the Utilities Under the Proposed TOU Tariff Rates

Financial Impact on The Utilities- Under the Existing Block Tariff Rates

Time Of Use (TOU) Tariff would be a win-win solution for both the participants and utilities. In this cost analysis, savings per year for the participants as well as the utilities are calculated.

- **Sales revenue of the utilities under the existing Block Tariff**

For this calculation, average energy usage of different consumption blocks of domestic customers is selected as follows. Then based on the existing block tariff rates and the number of consumers, total sales revenue of the utilities is calculated.

Table 19. Sales Revenue of the Utilities Under the Existing Block Tariff

Block (kWh)	Average Energy Usage (kWh)	Number of consumers	Sales (GWh)	Energy Charge (MLKR)	Fixed Charge (MLKR)	Total Revenue (MLKR)
0-30	29.87	1,405,575	122.60	1,259.54	506.007	1,765.54
31-60	51.44	2,049,594	544.97	4,402.13	1,012.01	5,414.15
61-90	83.11	1,520,188	728.63	12,807.89	1,518.02	14,325.91
91-120	108.4	628,515	452.46	9,666.06	8,096.11	17,762.17
121-180	143.01	413,601	418.96	11,613.02	8,096.11	19,709.13
180<	257.73	162,834	529.35	13,719.77	9,108.13	22,827.90
Total		6,180,307	2,797.00	53,468.41	28,336.39	81,804.80

- **Average cost of supplying electricity to the customers.**

For this calculation, energy production cost per unit is used as shown in the following table.

Table 20. Energy Production Cost per Unit

Period	Average Energy production Cost (LKR/kWh)
Peak (18:30-22:30)	56
Day(05:30-18:30)	28
Off-peak(22:30-05:30)	22

Table 21. Average Cost of Supplying Electricity to the Customers

Block (kWh)	Average Energy Usage (kWh)	Number of consumers	Sales (GWh)	Energy Supply Cost (MLKR)
0-30	29.87	1,405,575	122.60	19699.5272
31-60	51.44	2,049,594	544.97	46728.2837
61-90	83.11	1,520,188	728.63	52975.5114
91-120	108.4	628,515	452.46	27776.3405
121-180	143.01	413,601	418.96	23944.7185
180<	257.73	162,834	529.35	17048.6416
Total		6,180,307	2,797.00	188,173.02

According to the calculation it can be observed that there is a loss of MLKR 106,368.22 from the sales of electricity to domestic customers. Normally the loss generated from the domestic customers is cross subsidized by the revenue from the other customer categories.

- **Sales revenue of the utilities if the proposed TOU Tariff rates-01 is made mandatory for all the domestic customers**

Introduction of a TOU tariff scheme will encourage the consumers to shift their loads from peak hours to off-peak or day hours. But a consumer whose consumption is low, will not be able to shift his/ her loads. But a high-end consumers will be able to shift his/her work such as ironing, water heating (hot water systems), pumping of water, charging, etc. to off -peak or day hours.

An analysis was done on the effects of load shifting, by considering the following assumptions.

Assumptions:

- The TOU tariff schemes are made mandatory.
- The customers who consume less than 90kWh, will not be able to shift their loads.
- The percentage shifts of load from peak to off-peak hours and peak to day hours are mentioned in the Table

Table 22. The Percentage Shifts of Load from Peak to Off-Peak Hours and Peak to Day Hours

Block	**Percentage shift of load from peak to off-peak hours**	**Percentage shift of load from peak to day hours**
0-30 kWh	0%	0%
31-60 kWh	0%	0%
61-90 kWh	0%	0%
91-120 kWh	5%	5%
121-180 kWh	10%	10%
>180 kWh	20%	20%

Table 23. The New Sales Revenue of the Utilities if the Proposed TOU Tariff Rates-01 is Made Mandatory

Block (kWh)	Average Energy Usage (kWh)	Number of consumers	Sales (GWh)	Energy Charge (MLKR)	Fixed Charge (MLKR)	Total Revenue (MLKR)
0-30	29.87	1,405,575	122.60	1,244.86	506.007	1,750.87
31-60	51.44	2,049,594	544.97	4,412.98	1,012.01	5,424.99
61-90	83.11	1,520,188	728.63	12,820.11	1,518.02	14,338.13
91-120	108.4	628,515	452.46	9,399.65	8,096.11	17,495.76
121-180	143.01	413,601	418.96	10,997.35	8,096.11	19,093.46
180<	257.73	162,834	529.35	11,948.62	9,108.13	21,056.75
Total		6,180,307	2,797.00	50,823.58	28,336.39	79,159.97

- **The new average cost of supplying electricity to the customers**

Table 24. The New Average Cost of Supplying Electricity to the Customers

Block	Average Energy Usage (kWh)	Number of consumers	Sales (GWh)	Energy Supply Cost (MLKR)
0-30	29.87	1,405,575	122.60	19699.5272
31-60	51.44	2,049,594	544.97	46728.2837
61-90	83.11	1,520,188	728.63	52975.5114
91-120	108.4	628,515	452.46	27105.3127
121-180	143.01	413,601	418.96	22800.311
180<	257.73	162,834	529.35	15351.3512
Total		6,180,307	2,797.00	184,660.30

According to the calculation it can be observed that here is a loss of MLKR 105,500.33 from the sales of electricity to domestic customers. It can be observed that if the proposed tariff is made mandatory, the utilities will be able to cover up the loss and participants will be also benefited. The loss of utilities will be reduced MLKR 867.89 per year and the MLKR 2,644.84 will be benefited for the customer side.

Financial Impact on The Utilities- Under the Newly Proposed Block Tariff Rates

For this calculation, average energy usage of different consumption blocks of domestic customers is selected as follows. Then based on the newly proposed block tariff rates and the number of consumers, total revenue is calculated.

- **Sales Revenue of the Utilities Under the Newly Proposed Block Tariff**

Table 25. Sales Revenue of the Utilities Under the Newly Proposed Block Tariff

Block (kWh)	Average Energy Usage (kWh)	Number of consumers	Sales (GWh)	Energy Charge (MLKR)	Fixed Charge (MLKR)	Total Revenue (MLKR)
0-30	29.87	1,405,575	122.60	4030.514424	7252.767	11,283.28
31-60	51.44	2,049,594	544.97	12494.32502	18,553.59	31,047.92
61-90	83.11	1,520,188	728.63	24553.71173	22,770.32	47,324.03
91-120	108.4	628,515	452.46	16221.72074	27,830.39	44,052.11
121-180	143.01	413,601	418.96	17030.61676	27,830.39	44,861.00
180<	257.73	162,834	529.35	17049.43301	28,673.73	45,723.16
Total		6,180,307	2,797.00	91,380.32	132,911.17	224,291.49

According to the pervious calculation of average cost of supplying electricity to the domestic customers, it can be observed that there now utility is benefited MLKR 36,118.47 from the sales of electricity to domestic customers.

- **Sales revenue of the Utilities if the proposed TOU Tariff rates-02 is made mandatory for all the domestic customers**

Table 26. Sales Revenue of the Utilities if the Proposed TOU Tariff Rates-02 is Made Mandatory

Block (kWh)	Average Energy Usage (kWh)	Number of consumers	Sales (GWh)	Energy Charge (MLKR)	Fixed Charge (MLKR)	Total Revenue (MLKR)
0-30	29.87	1,405,575	122.60	4009.1778	7252.767	11,261.94
31-60	51.44	2,049,594	544.97	12485.1019	18,553.59	31,038.69
61-90	83.11	1,520,188	728.63	24523.0647	22,770.32	47,293.38
91-120	108.4	628,515	452.46	15760.1393	27,830.39	43,590.52
121-180	143.01	413,601	418.96	16242.7788	27,830.39	44,073.16
180<	257.73	162,834	529.35	15351.3512	28,673.73	44,025.08
Total		6,180,307	2,797.00	88,371.61	132,911.17	221,282.79

After applying the TOU tariff rates, again the total revenue of the utility is calculated by assuming the same energy shifting and reducing process like previous calculation.

According to the cost analysis, now the total benefit of the utilities is MLKR 36,622.49. That means the benefit of utilities will be increased MLKR 504.02 per year and the MLKR 3,008.71 will be benefited for the customer side.

7.1.3. Financial Impact on Utilities by Replacing Incandescent Bulbs from CFL or LED Bulbs

The chart below illustrates the amount of brightness in lumens you can expect from different wattages of light bulbs. LED bulbs require much less wattage than CFL or Incandescent light bulbs, which is why LEDs are more energy-efficient and longer lasting than their competitors.

Table 27. Market Existing Different Types of Incandescent, CFL and LED Bulbs

Lumens (Brightness)	Incandescent Watts	CFL Watts	LED Watts	Average Energy Consumption Per Month (kWh)			Lifetime (hours)		
				Incandescent	CFL	LED	Incandescent	CFL	LED
400 – 500	40W	8 – 12	6 – 7	4.8	0.96-1.44	0.72-0.84	750	8000	25,000
650 – 850	60W	13 – 18	7 – 10	7.2	1.56-2.16	0.84-1.2			
1000 – 1400	75W	18 – 22	12 – 13	9.0	2.16-2.64	1.44-1.56			
1450-1700+	100W	23 – 30	14 – 20	12	2.76-3.6	1.68-2.4			
2700+	150W	30 – 55	25 – 28	18	3.6-6.6	3-3.36			

According to the above figures, it has been seen that, participants who can adapt with the DSM programs and proposed TOU tariff rates, have an opportunity to reduce their energy consumption in a greater extent by replacing their incandescent bulbs by CFL or LED bulbs. Further, lifetime of the bulbs also will increase. It will be highly benefited for low energy consumers as majority of the customers who are using incandescent bulbs are the low energy consumers (<90kWh consumers). Then they can use energy management methodologies like this in order to reduce their electricity bill further. In addition to that, it has more environmental benefits as will lead to reduce the heat generation from the bulbs. It has been seen that majority of the customers whose consumption is higher than 90kWh are already moved to CFL or LED bulbs. Therefore, energy savings are calculated by considering only low energy consumers whose consumption is lower than 90kWh.

In this calculation, assume as number of incandescent bulbs of 0-30kWh,31-60 kWh, and 61-90 kWh customers would be replaced by 1,2 and 3 respectively.

Table 28. Assumption: Number of Replaced Bulbs by Domestic Customers

Block	Number of replaced bulbs
0-30	1
31-60	2
61-90	3

- **Financial impact on the customers if customers replace their incandescent bulbs with CFL or LED bulbs.**

For this calculation, assume each and every customer usually switch on their bulbs for 4 hours from 18:30 to 22:30. It has been seen that they can save MLKR 4173.15866 per year by replacing their incandescent bulbs with CFL bulbs.

Table 29. Total Cost Savings by Replacing Incandescent Bulbs with CFL Bulbs

Block (kWh)	Average Energy Usage (kWh/month)	Number of consumers	Sales (GWh)	Energy Consumption Incandescent (kWh/month)	Energy Consumption CFL (kWh/month)	Unit Savings per month (kWh/month)	New Average Energy Usage (kWh/month)	Total Cost Savings (MLKR/year)
0-30	29.87	1,405,575	122.60	7.2	2.16	5.04	24.83	212.52
31-60	51.44	2,049,594	544.97	14.4	4.32	10.08	41.36	1,202.40
61-90	83.11	1,520,188	728.63	21.6	6.48	15.12	67.99	2,758.23
Total:								4,173.16

If the customers tend to replace their incandescent bulbs from LED bulbs, then they can save MLKR 4968.04603 per year.

Table 30. Total Cost Savings by Replacing Incandescent Bulbs with LED Bulbs

Block (kWh)	Average Energy Usage (kWh/month)	Number of consumers	Sales (GWh)	Energy Consumption Incandescent (kWh/month)	Energy Consumption LED (kWh/month)	Unit Savings per month (kWh/month)	New Average Energy Usage (kWh/month)	Total Cost Savings (MLKR/year)
0-30	29.87	1,405,575	122.60	7.2	1.2	6	23.87	253.00
31-60	51.44	2,049,594	544.97	14.4	2.4	12	39.44	1,431.44
61-90	83.11	1,520,188	728.63	21.6	3.6	18	65.11	3,283.60
Total:								4,968.05

- **Financial Impact on the Utilities**

For this calculation, Energy production cost per unit at the peak time, off peak time and daytime are assume as shown in Table 20.

According to the cost analysis of the utility side, they could save MLKR 34,090.0547 per year if customers replaced their incandescent bulbs from CFL bulbs and MLKR 40,583.3985 per year if they replaced incandescent bulbs from LED bulbs.

Table 31. Total Cost Savings for the Utilities by Replacing Incandescent Bulbs with CFL Bulbs

Block (kWh)	Average Energy Usage (kWh/month)	Number of consumers	Sales (GWh)	Energy Consumption Incandescent (kWh/month)	Energy Consumption CFL (kWh/month)	Unit Savings per month (kWh/month)	New Average Energy Usage (kWh/month)	Total Cost Savings (MLKR/year)
0-30	29.87	1,405,575	122.60	7.2	2.16	5.04	24.83	4,760.51386
31-60	51.44	2,049,594	544.97	14.4	4.32	10.08	41.36	13,883.4579
61-90	83.11	1,520,188	728.63	21.6	6.48	15.12	67.99	15,446.083
Total:								34,090.0547

Table 32. Total Cost Savings for the Utilities by Replacing Incandescent Bulbs with LED Bulbs

Block (kWh)	Average Energy Usage (kWh/month)	Number of consumers	Sales (GWh)	Energy Consumption Incandescent (kWh/month)	Energy Consumption LED (kWh/month)	Unit Savings per month (kWh/month)	New Average Energy Usage (kWh/month)	Total Cost Savings (MLKR/year)
0-30	29.87	1,405,575	122.60	7.2	1.2	6	23.87	5,667.2784
31-60	51.44	2,049,594	544.97	14.4	2.4	12	39.44	16,527.926
61-90	83.11	1,520,188	728.63	21.6	3.6	18	65.11	18,388.194
Total:								40,583.3985

7.1.4. Worldwide Experience of TOU Tariff Rates for Residential Customers

Green Energy UK's use of Time-Of-Use Tariff

Green Energy has introduced a new TOU tariff called "Tide" on 03/01/2017 and it is the second time-of-use tariff to be launched in the United Kingdom. In the first TOU tariff, called 'Free Time' tariff, electricity was provided without a charge to smart meter customers between 9 am and 5 pm on weekends.

Tide is an optional tariff. Green Energy UK has 20,000 customers and around 8,000 customers already have smart meters. If the customers who do not have smart meters, like to shift to a TOU tariff, Green Energy UK will install the meters for them.

Table 33. TOU Tariff Rates with Different Time Interval in Weekdays

Time Interval	Rate (Pence/kWh)
High Tide (4.00pm-7.00pm)	24.99
Low Tide (11.00pm- 6.00am)	4.99
Rest of the time	11.99

Table 34. TOU Tariff Rates with Different Time Interval in Weekends

Time Interval	Rate (Pence/kWh)
High Tide (6.00am-11.00pm)	11.99
Low Tide (11.00pm- 6.00am)	4.99

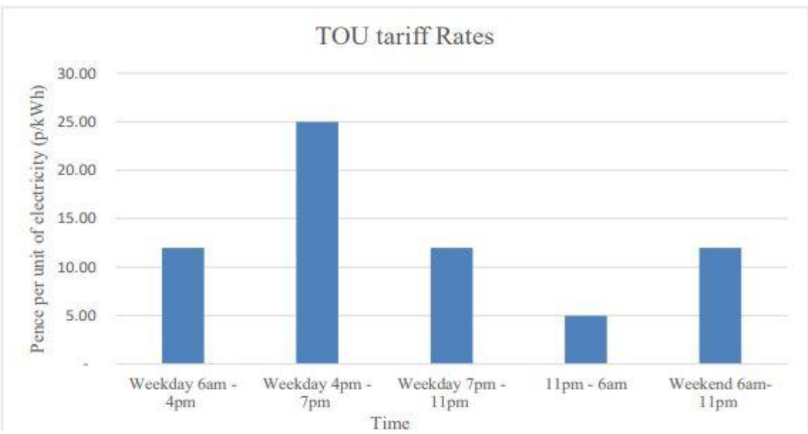


Figure 18. TOU Tariff Rates of UK

Australian Time of Use Pricing

In all regions of Australia, domestic customers have the capability of moving to optional time-of-use tariffs. On weekends and public holidays, there are no peak rates in most of the areas. In the Northern Territory, Time of Use rates is applied on a weekday and public holidays. In South Australia, the time-dependent rates are applied only in Summer (from 1st of November to the 31st of March).

Table 35. Time of Use Rates in Different States of Australia

Region		Off-Peak	Shoulder	Peak
New South Wales	*Time intervals*	*10pm-6:59am*	*7am-1:59pm,8pm-9:59pm*	*2pm-7:59pm*
	Rate	10 cents	18 cents	43 cents
Victoria	*Time intervals*	*10pm-6:59am*	*7am-2:59pm, 9pm-9:59pm*	*3pm-8:59pm*
	Rate	10 cents	17 cents	23.5 cents
Queensland	*Time intervals*	*10pm-6:59am*	*7am-3:59, 8:00pm-9:59pm*	*4pm-7:59pm*
	Rate	18 cents	23 cents	33 cents
Western Australia	*Time intervals*	*9pm-6:59am*	*7am-2:59pm,*	*3pm-8:59pm*
	Rate	13 cents	25 cents	48 cents
South Australia	*Time intervals*	*9pm-3:59pm*	*4pm-8:59pm winter only*	*4pm-8:59pm summer only*
	Rate	20 cents	24 cents	49 cents
Australian Capital Territory	*Time intervals*	*10pm-6:59am*	*9pm-4:59pm, 8pm-9:59pm*	*7am-8:59am, 5pm-7:59pm*
	Rate	10 cents	14 cents	21 cents
Northern Territory	*Time intervals*	*6pm-5:59am*		*6am-5:59pm*
	Rate	23 cents		30 cents

Time of Use Tariff to Residential Customers in Italy

Starting from 1st July 2010, Italian Authority for Electricity and Gas (AEEG) approved a mandatory TOU tariff scheme. There are only two parts in this time of use tariff.

- F1 time slot- Peak hours: 8.00 am to 7.00 pm
- F2 time slot - Off-peak hours: remaining hours

There was a transition period up to 31st December 2011 and in that period the variation between the peak and off-peak price was small. From 1st January 2012, the regular period started with a relatively large difference between the peak and off-peak price.

Table 36. The Difference in Energy Prices between Flat Tariff and Rates of TOU Tariff

Energy price difference	
Difference in Energy prices between flat tariff and Peak rate of ToU tariff	-0.0059 Euro/kWh
Difference in Energy prices difference between flat tariff and off-peak rate of TOU tariff	0.00295 Euro/kWh

With the introduction of mandatory TOU tariff, only a small shift of consumption from peak hours to off-peak hours was observed. But the usage of energy-efficient appliances has increased, a significant bulk of peak demand had been reduced. Because of the introduction of the mandatory TOU tariff, the overall saving during the period of July 2010-June 2012 was 6.75 million Euros.

Table 37. Energy Shifts from Peak to Off-Peak Hours

Winter 2012-2011		Spring 2012-2011		Summer 2012-2011	
Δ peak hours	Δ off-peak hours	Δ peak hours	Δ off-peak hours	Δ peak hours	Δ off-peak hours
0.39%	-0.39%	0.50%	-0.50%	-0.56%	0.56%

They have not experienced a big shift of consumption from peak to off-peak because of reasons like weak pricing signal and more than 50% of customers are benefiting from the TOU tariff even without shifting their loads. The TOU tariff can be made more effective by increasing the pricing signal, revising the allocation of the hours between peak and off-peak hours, and also introducing "Critical Peak Pricing".

Time of Use Tariff to Residential Customers in South Africa

In South Africa "City Power" has introduced a residential optional time-of-use tariff effective from 1st July 2015. Customers who want to shift to TOU tariff, have to install meters with the automatic meter reading capability. With the implementation of this program, City Power is able to remotely and automatically switch off geysers during peak periods. Customers who shift to the time-of-use tariff are free to choose the appliances which will be switched off during the peak period. • Peak periods are on weekdays from 7 am to 10 am and from 6 pm to 9 pm.

Table 38. TOU Tariff Rates for Single-Phase Customers

Supply	Service charge (Rand/ month)	Capacity charge (Rand/month)	Energy charge(cents/kWh)	
			Summer	Winter
Peak	60A:105.29 80A:105.29	60A:310.28 80A:341.06	123.29	294.04
Standard			97.53	117.41
Off-peak			76.73	82.23

Table 39. TOU Tariff Rates for Three-Phase Customers

Supply	Service charge (Rand/ month)	Capacity charge (Rand/month)	Energy charge(cents/kWh)	
			Summer	Winter
Peak	60A:105.29 80A:105.29	60A:386.38 80A:424.86	123.29	294.04
Standard			97.53	117.41
Off-peak			76.73	82.23

Customer's response to the Time of Use Pricing worldwide

- The TOU tariff can be made more effective by increasing the peak to off peak price rates, introducing based on the consumption patterns and seasonal variations.
- The utilities should bear the cost of installing the smart meters.
- With the implementation of this program, should be promoted remotely and automatically switching off appliances hybrid solar systems and diesel generators during peak periods.
- It is required to provide financial incentives/assistance such as low interest loan schemes for the customers who are willing to implement alternative energy resources and energy management methodologies.

7.1.5. Survey on TOU tariff rates

Time-of-Use (TOU) electricity pricing gives Sri Lankan customers a valuable opportunity to take control of their energy use and electricity bills. TOU is a voluntary program that enables people to choose when they power up appliances based on electricity prices and make decisions that can both save them money and reduce harmful pollution.

TOU tariff has been introduced in Sri Lanka in 2015 for the consumers who had 3 phase connections and consumptions of 30A or above. Those customers had the capability of shifting to the optional TOU tariff. In May 2017 the same tariff was extended to single-phase domestic consumers as an optional tariff. The total number of domestic consumers in Sri Lanka is more than 5.7 million. It is around 87% of the total consumers in the country. But the number of customers who have shifted to the existing TOU tariff is around 500. This indicates that the existing TOU tariff is not attractive among domestic consumers. As there is a low response from the consumers, the desired outcomes of introducing the TOU tariffs have not been realized.

The night-time peak demand drives the sector investments and hence has become a major target area for Demand Side Management programs aimed at energy conservation and efficiency improvement. Time Of Use (TOU) Tariffs are perceived as a major tool to curb the peak demand. If domestic customers are inclined to use optional TOU tariff instead of block tariff rates, they could have the opportunity to reduce their electricity bill further by shifting their demand from peak period to off-peak period.

With those intentions, an optional TOU Tariff should be introduced to domestic customers of Sri Lanka. This survey is conducted to develop a win-win solution for the TOU tariff by finding solutions for the following questions.

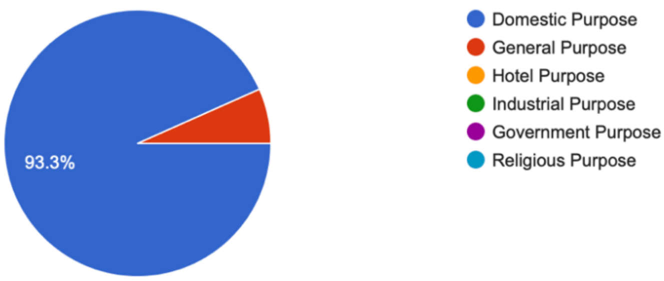
- Is it possible to change the TOU tariff rates based on the consumption of domestic customers?
- Is it possible to change the TOU tariff based on the season in the country (Industry/Domestic)?
- Is it possible to increase the peak to off-peak price rates (Industry/Domestic)?
- Is it possible to reduce the TOU tariff rates for domestic customers?

- Is it possible to reduce the duration of the peak period?
- Is it possible to promote integrated demand response programs for domestic customers (fulfill the requirement of energy for peak time with the help of solar panels?

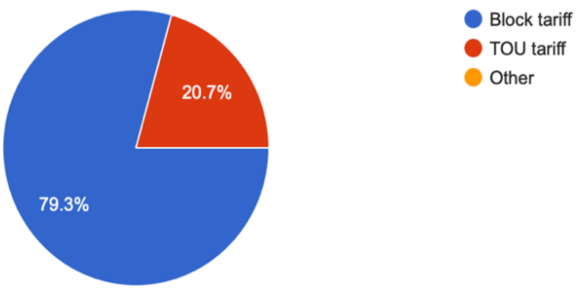
For this survey, a sample of 100 domestic customers were participated and their responses are demonstrated in following figures.

Section A – Common Questions and Answers

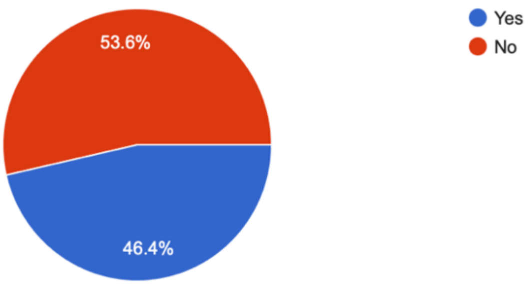
- Consumer Category



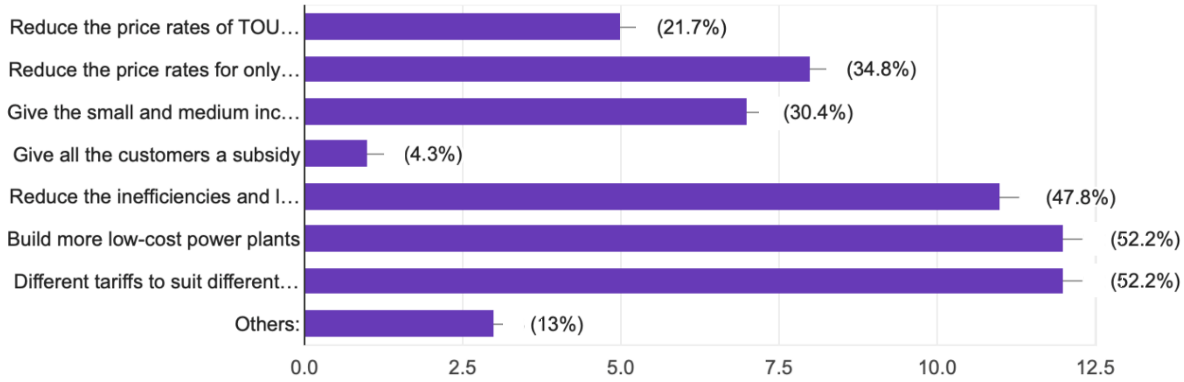
- What is your electricity tariff method?



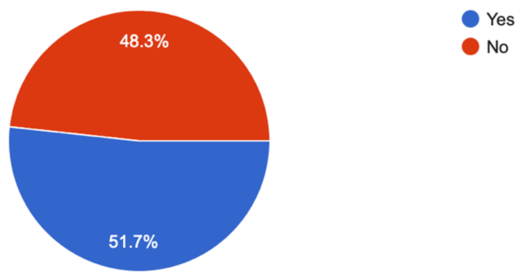
- Do you think that the current TOU tariff rates for electricity are fair and equitable?



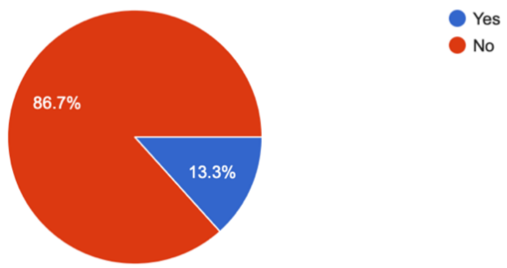
- If not, what suggestions you would give the CEB ?



- Did you feel any specific season when the electricity demand is higher?

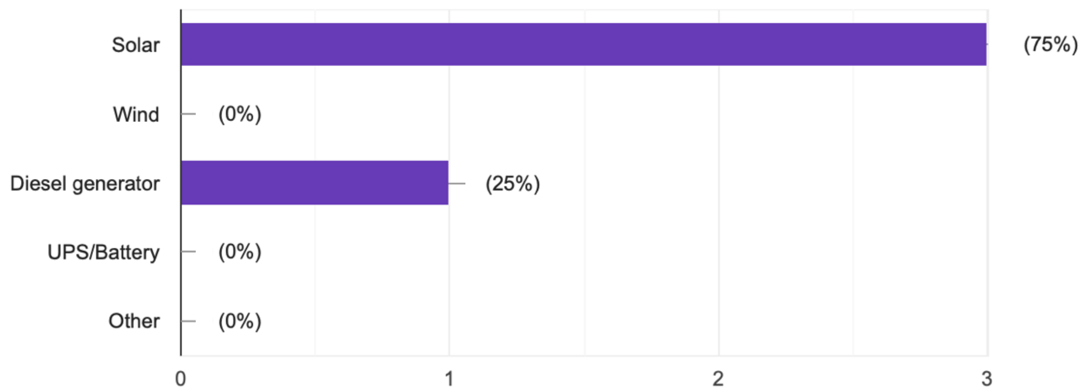


- Are you using any alternative energy source against electricity load shedding?

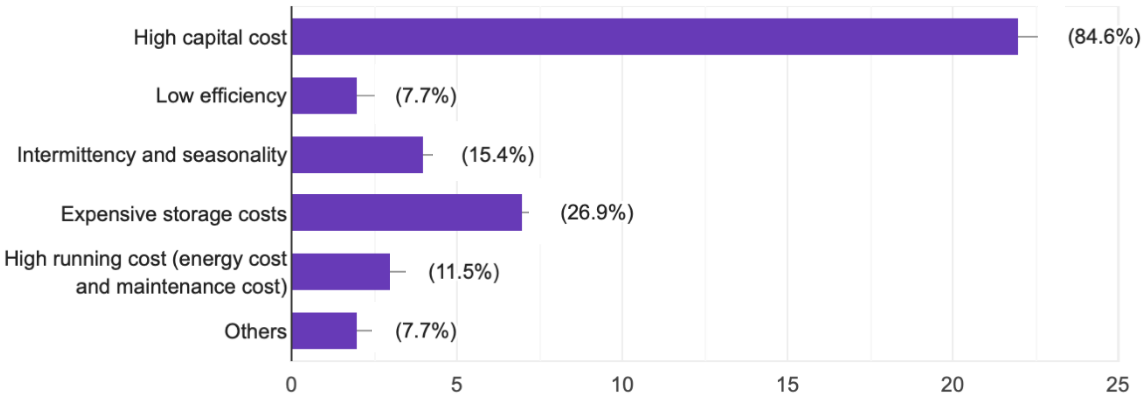


Section B- Survey on users of alternative energy resources

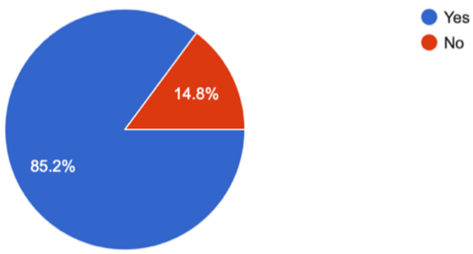
- If yes, what are those energy sources?



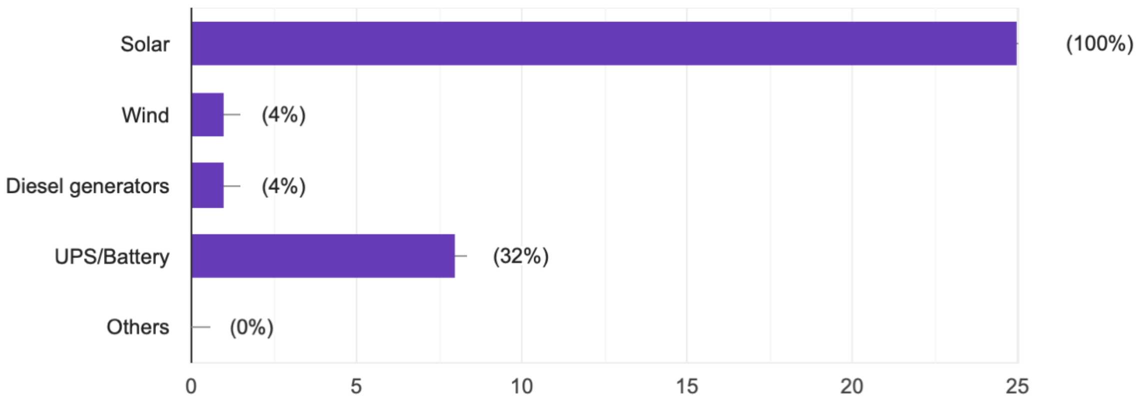
- If no, what is the main reason for that?



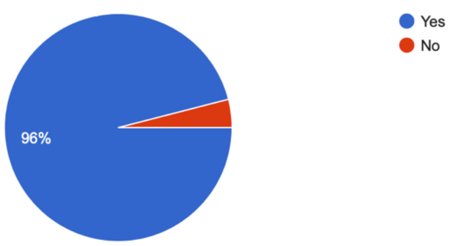
- Are you willing to use any alternative energy sources?



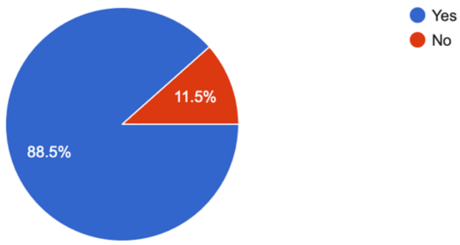
- if yes, what kind of energy source would you like to use?



- Would you like to get funds for implementing above mentioned energy sources in your home/area?



- Would you like to participate with a new TOU tariff after implementing alternative energy sources?



7.1.6. Workshop Comments

With the purpose of collecting feedback and gathering information on the policies required to implement the previously described proposals, A workshop and a discussion were conducted with the collaboration of PUCSL. The workshop was held in-person at the PUCSL premises on the 5th of April 2022 and the participants were representatives from the Ceylon Electricity Board (CEB), the Lanka Electricity Company (Pvt) Ltd (LECO) and the Diesel & Motor Engineering PLC (DIMO) apart from the members of the PUCSL and the research team of University of Moratuwa supervised by Prof. KTMU Hemapala and Prof. Anura Wijayapala. Another discussion was held virtually via an online platform between the Sustainable Energy Authority (SEA) and the UoM research team on the 18th of April 2022. The feedback and the comments given by the participants of corresponding authorities are summarised below.

Workshop 01 – Comments by CEB, LECO, PUCSL and DIMO

- The proposed TOU tariff is a combination of both Block Tariff and TOU tariff. According to one of the comments made during the workshop, it was stated that the billing process could be more complex and increased customer complaints will have to be dealt with as a result of the implementation of this proposed tariff.
- Also in this proposal, a load shifting method was suggested using smart appliances and devices in order to reduce the peak demand. But another comment was made stating that since most of the rural residences use only the basic loads such as lighting, this load shifting may not be practical when motivating them to participate in DR programs. It was further mentioned that this proposed method would not be practically viable, since the number of customers with consumption higher than 200 units is very low.
- The Demand Side Management consists of the concepts of energy efficiency, energy conservation and demand response. But in this project, demand response is our only

focus. It was suggested that it would be better if the other two concepts can also be incorporated into the proposals. For instance, energy efficiency is the best option for domestic customers and they can be encouraged to go for more energy-efficient options such as lighting.

- Moreover, in order to get adapted to the proposed TOU tariff, the need of replacing the existing meters was discussed during the workshop. The main point highlighted by the participants was that replacing meters for the customers above 60 units, for instance, will cost around Rs. 45 000 000.00. Therefore, a proper cost-benefit analysis needs to be done to ensure that this replacement is practically viable.
- Also, another suggestion was made to use the existing meters such as Type A and Type C to implement the proposed TOU tariff without going for a replacement.

Discussion – Comments by SEA

- Here the key feature to be marketed would be the opportunity provided for the customers to shift their loads from peak hours to off-peak hours to reduce the electricity bill.
- The aim of proposing the new TOU tariff scheme to accommodate DR programs was clarified as a method of persuading customers to shift their loads from peak to off-peak periods.
- In Germany, the maximum demand charge is applicable for the whole year and therefore, customers have been strictly adapted to the DR programs. For instance, they use hydrogen fuel cells to store energy using grid electricity during low-demand periods and use that stored energy during high-demand (peak) periods. Accordingly, it was suggested to make the maximum demand charge in Sri Lankan tariff scheme applicable for the whole year to motivate the customers to engage in DR programs.
- Also, the peak duration we are discussing now is almost outdated. For example, according to the publishers of energy balance in the country, the evening peak is now limited to 6.00 pm to 9.00 pm. Therefore, the need of updating them was emphasised.
- According to the suggestion made by the representative of SEA, parameters such as time bands, and KVA demand assessment methodologies need to be challenged when developing these tariffs.

7.1.7. Required Policies

- The policies and regulations need to be formulated to replace the existing block meter connections with smart meter connections and implement the proposed TOU tariff structure for domestic customers.
- A policy should be implemented to make the EV owners charge their EVs under the proposed tariff structure.
- The policies and regulations should be established to provide financial incentives/assistance for the customers who are willing to implement hybrid solar systems or smart devices on their premises.
- The necessary policy changes should be identified to implement smart devices for domestic customers to participate in DSM programs and load shifting processes to reduce the peak demand.
- The necessary policy changes need to be identified in order to make the maximum demand charge in Sri Lankan tariff applicable for the whole year to motivate the customers to engage in DR programs.

7.2. Proposal 2

Introduction of an optional meter connection with the existing TOU tariff rates

If the proposal-01 is not implemented, consider giving an optional meter connection with the existing TOU tariff, side by side with present block tariff meter.

- Same service wires are used and only the new metered connection is extended.
- The participants should bear the cost of installing the additional meter connection in their premises.
- Consumers shift their controllable loads, such as EV charging, water pumping to the new connection.

Opportunities:

- Consumers are benefited by cheap electricity during off-peak hours for some of their uses.
- Utility is benefited by reduced evening peak and expensive generation.

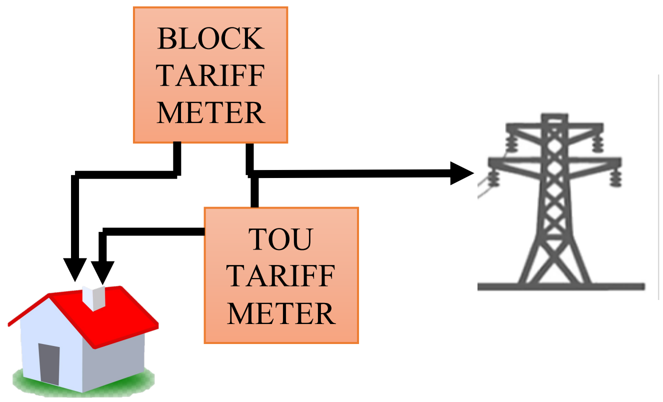


Figure 19. Proposed New TOU Meter Connection

7.2.1. Introduction

In this proposal, an optional meter connection is introduced for domestic customers with the exiting TOU tariff rates. The existing TOU tariff structure is not attractive as the price rates are high when compared to the block tariff rates, but if this tariff structure is provided with an optional meter connection side by side with the block tariff meter connection, then there is an opportunity for them to use their higher energy consuming loads such as electric vehicle charging, water pumping at the off-peak time with the TOU meter connection and to use all other loads with the block tariff meter connection. For that same service, both the participants and utility will be benefited, which means it would be a win-win solution for both parties because consumers are benefited from cheap electricity during off-peak hours for some of their uses and the utility is benefited from the reduced evening peak and expensive generation.

7.2.2. Survey on Electric Vehicles

An important contribution to DR programs can be provided by Electric Vehicles (EVs). EVs can behave as a load to the grid, a supplier of electricity to the grid, or as an energy storage device. With the technological advancements and the new concept of smart grids, EVs can be easily integrated with DR programs. For this, utilities have to manage EV charging time, and rates and gather EV detailed meter data to implement DR programs. Therefore, the survey is focused on the existing EV users to assess the availability and manageability of EVs in a DR program. The current population of EVs and the electricity consumption for each vehicle are assessed and views of EV users on their satisfaction and the choice of participation in a DR program are analyzed.

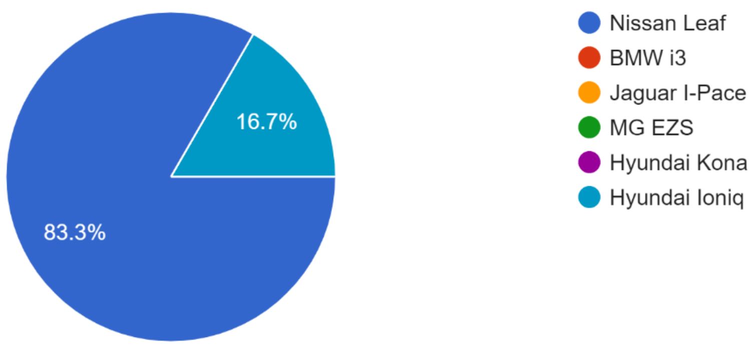
Demand response (DR) is the voluntary reduction or shift of electricity use by customers, which helps in keeping a power grid stable by balancing the electricity demand and supply. It further helps to make electricity systems flexible and reliable, and even increases the share of renewable energy.

In this regard, an important contribution to DR programs can be provided by the Electric Vehicles (EVs). Hence, through this survey, the availability and manageability of EVs in a DR program were assessed.

Here, a sample of 60 EV owners in different areas was analysed. Further, their electricity consumption patterns with regard to the EV and their view on the contribution of their vehicles in participating in a DR program were assessed.

Section A – Details of the Electric Vehicle

1. Details of the Electric Vehicle
    a. Model



b. Year of manufacture

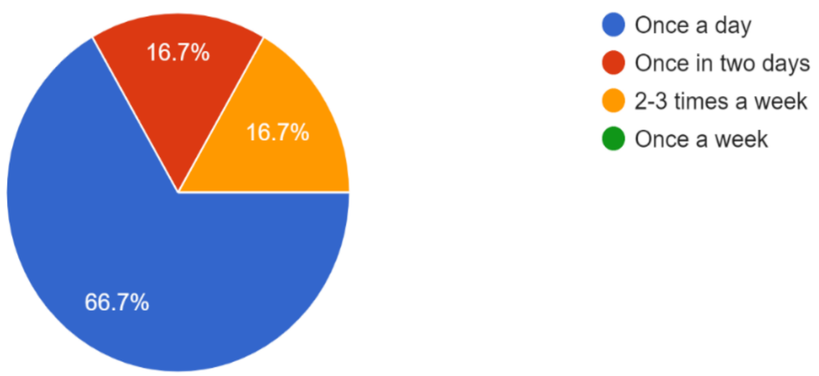
Most of the vehicles in the survey were manufactured during the period from 2012 to 2018.

c. Current Mileage

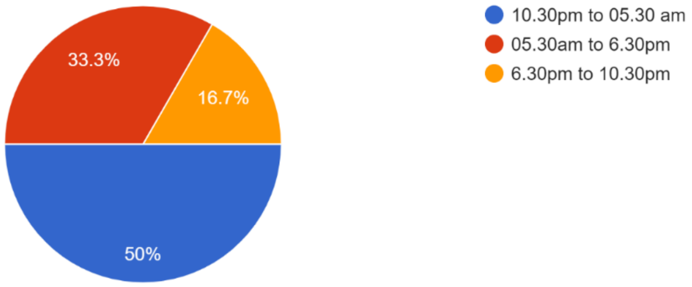
All the vehicles had a current mileage well above 45000 km which depicts the immense usage of the vehicles by owners.

Section B – Electricity consumption of the vehicle

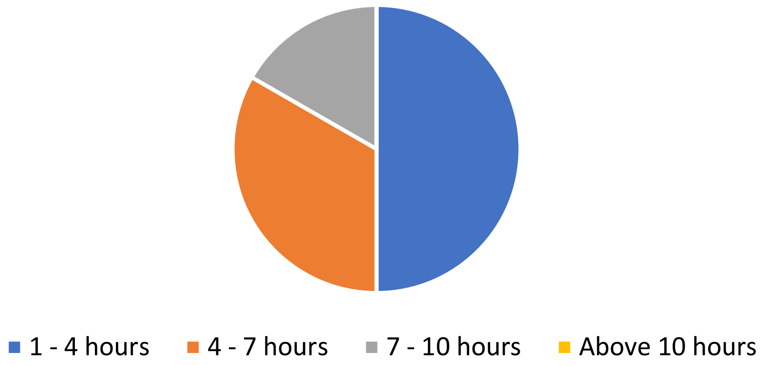
1. Approximate frequency of charging the vehicle



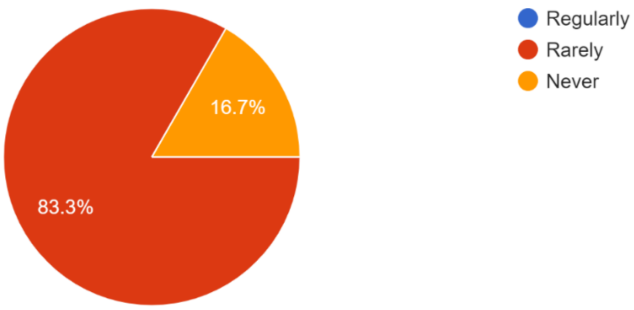
2. Current typical charging period of day



3. Average time taken to fully charge the battery in home-charger (in hours)

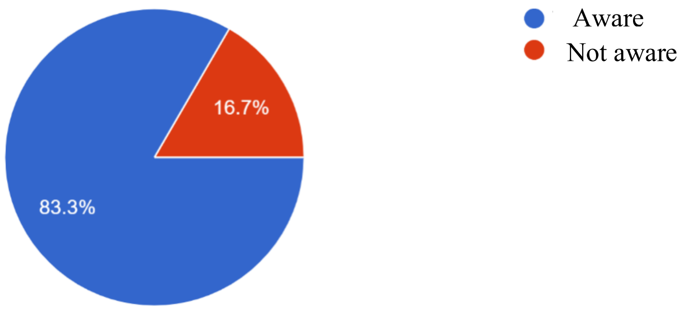


4. Frequency of using the "Fast-Charging" option by consumers?

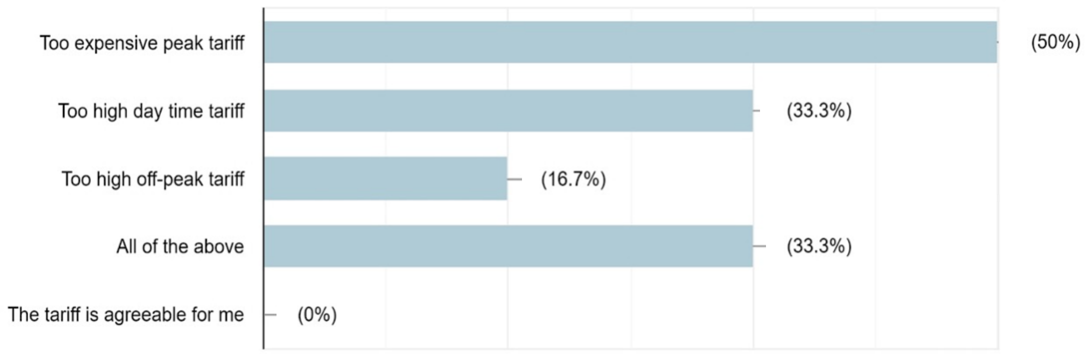


Section C – User satisfaction

1. Awareness of users of the Time of Use (TOU) tariff available to domestic consumers

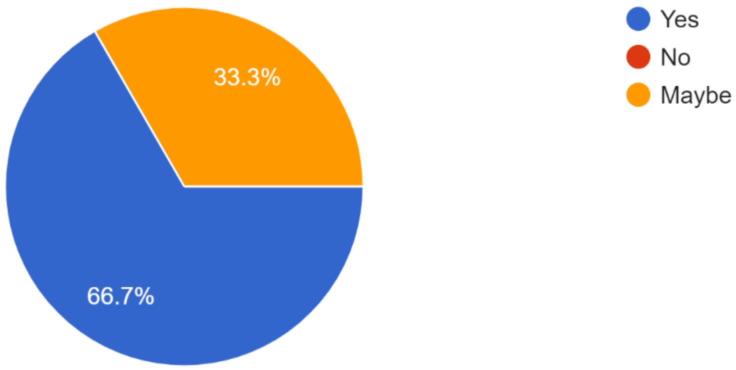


2. The opinion of consumers on the TOU tariff with respect to charging their EV



Section D – EVs and Demand Response programs

1. Willingness of EV owners to participate in a DR program



2. Owners' views as the best solutions to promote EV users to participate in DR programmes among the options below as a percentage of the total population.

Option	Percentage
a. Introducing an affordable tariff.	66.7%
b. Promoting "Smart charging", the intelligent charging of electric car batteries to charge EVs during periods when supply from renewable energies is at its highest, thereby reducing the demand for fossil fuel-powered plants.	83.3%
c. Introducing "Workplace charging", a possible solution to managing high volumes of intermittent renewable generation coming online during peak daytime hours, providing much-needed stability to the grid.	83.3%
d. Introducing more charging stations, so that the customers can charge their batteries frequently even during the day.	83.3%

3. EV owners' view of the following statements on utilities' role in using EV batteries in DR programmes as a percentage of the whole population

	Strongly agree	Agree	I don't know	Disagree	Strongly disagree
a. It's better if the utilities can bring about affordable electricity rates for charging the battery if used in a DR programme.	33.3%	66.7%	0	0	0
b. If utilities provide two tariff schemes for EV owners as Domestic Purpose and Time of Use tariff for EV charging with two different meters, users will be more interested in DR programs.	33.3%	16.7%	50%	0	0
c. More customer awareness of DR programmes and tariffs for EVs will attract new buyers and will encourage existing customers to participate in DR programmes.	0	83.3%	16.7%	0	0
d. EV usage in Sri Lanka can be increased by lowering capital investment in charging infrastructure and introducing more charging stations.	16.67%	50%	33.3%	0	0

7.2.3. Workshop Comments

Workshop 01 – Comments by CEB, LECO, PUCSL and DIMO

- The main concern of the participants regarding this proposal was the TOU tariff proposed for EV charging may not be viable due to the prevailing situation of the country and due to having less number of EVs in the country. But it should be noted that, in this proposal, not only the existing EVs but also the future EV market in the country is being targeted.
- Also, implementing hybrid solar systems was discussed during the workshop and it was identified as a better option to go for.

Discussion – Comments by SEA

- An already proposed method of an "on-board electric meter for all the EVs in the country and public charging network where the customer can connect their EVs and charge them, was discussed during the session. In this approach, the main difference is the charging point will not be billed and only the corresponding EV will be billed. Therefore, it was mentioned that it would be beneficial if this method can be implemented.
- It was suggested that the customer needs to pay for the proposed meter connection since it is an optional one so the utility will be benefited from that.
- Also, it was suggested that a TOU based prepaid option for the second meter should be available as an additional feature.

7.2.4. Cost-Benefit Analysis

Electric vehicles have become increasingly popular due to the high costs of the operation of gas / diesel powered vehicles and the potential to reduce CO_2 emission. Various previous research depicts that uncontrolled charging of electric vehicles can jeopardize the stability of the power system. In a worst-case scenario this can lead to an increase of peak demand, while by using appropriate scheduled charging the electric vehicles can have no contribution to the peak demand. Therefore, the aggregation of electric vehicle demand under an appropriate demand response control strategy has the potential to dramatically improve the stability of the power system with virtually no negative impacts.

It is clear that the population of EVs will be higher throughout the world as well as in Sri Lanka in near future. This large number of the EVs has the potential to significantly de-stabilize and reduce the efficiency of the current power system. However, this problem is eminently solvable by scheduling EV charging. There are several numbers of simplifying assumptions about most EVs that help in developing this scheduling solution. Furthermore, the aggregation of the scheduled charging can be integrated into the power system to provide frequency/voltage regulation, renewable power adoption and system optimization. To accomplish this, it requires the application of Demand Response (DR) and various enabling technologies. DR is designed to reduce peak demand and encourage electric consumption when renewable energy is available in response to market price and/or power availability over time. Hence, as the first step of this DR program in Sri Lanka, a new methodology is proposed to regulate EV charging by giving an optional meter connection to the EV owners with the existing TOU tariff, side by side with present block tariff meter. Here, the cost saving by an EV owner by using two separate meters is calculated.

Case 1 – With the existing tariff rates

Sri Lanka's state-owned electricity service providers are offered a domestic Time of Use (TOU) electricity tariff for cheaper charging of electric vehicles. The new tariff scheme is an alternative tariff system for domestic users who consume a three-phase, 30 A or above power supply which is shown in Table 40.

- **Existing TOU tariff rates**

Table 40. Existing TOU Tariff Rates for Domestic Customers

	Time	Charge (LKR per unit)	Fixed charge (LKR per month)
Off-peak	22:30 – 05:30	13.00	
Daytime	05:30 – 18:30	25.00	540.00
Peak	18:30 – 22:30	54.00	

For example, an EV owner in a domestic TOU tariff with the following specifications of his EV is considered.

1. The electric vehicle used for this analysis is a 2011 model of the Nissan Leaf - Generation 1, with a battery capacity of 24kWh.
2. The energy consumption is 0.177 kWh/km considering that the distance travelled per full charge of the vehicle is 135km assuming that the State of Health (SOH) of the battery is 100%.
3. Average battery charging rate is 4kW.
4. The average daily commute distance of the consumer is 50km.
5. The EV owner is assumed to be on a Time of Use(TOU) tariff and he typically charges the battery after returning from work every day.
6. The current average electricity consumption of a domestic consumer in each time interval excluding the electricity used for car battery charging is as follows. Three customer groups according to their consumption (i.e., 91-120 kWh, 121-180 kWh, above 180 kWh household consumers) are considered in the study as follows.

- **Average Energy consumption of three consumer categories**

Table 41. Average Energy Consumption of Three Consumer Categories

	Average consumption by each category (kWh/month)		
	(91 – 120) kWh	(121 – 180) kWh	Above 180 kWh
Off-peak (22:30-05:30)	26	36.86	75.05
Day (05:30-18:30)	53.7	68.96	112.2
Peak (18:30-22:30)	28.7	37.19	70.05
Total	**108.4**	**143.01**	**257.3**

<u>Scenario 1 – EV charging and other domestic usage measured by the same TOU meter</u>

Daily usage of EV battery = 24 kWh * 50 km / 135 km = 8.89 kWh
Number of hours to fully charge the battery per day = 8.89 kWh/4kW = 2.22 h
*If the time setting of the charger can be set to a predetermined time, it is seen that the battery can be charged fully charged during the off-peak period
Electricity charge for charging the EV battery = 8.89 kWh * LKR 13.00 /kWh = LKR 3466.67

The total electricity charge for the three consumer categories can be calculated as follows.

- **Electricity cost under TOU tariff**

Table 42. Electricity Cost under TOU Tariff for EV Owners

	Monthly electricity charge (LKR)		
	(91 – 120) kWh	(121 – 180) kWh	Above 180 kWh
Domestic charge	3770.3	4751.44	8103.35
Charge for EV	3466.67	3466.67	3466.67
Total	**7236.97**	**8218.11**	**11570.02**

Scenario 2 – TOU meter for EV charging and block tariff meter for domestic purpose

Table 43 shows the present block tariff rates for a domestic purpose consumer.

- **Existing block tariff rates**

Table 43. Existing Block Tariff Rates

Monthly Consumption (kWh)	Unit charge (Rs/kWh)	Fixed charge (Rs/month)
0-60	7.85	N/A
61-90	10.00	90.00
91-120	27.75	480.00
121-180	32.00	480.00
>180	45.00	540.00

Considering the same average usage patterns and the same EV specifications given above, the electricity bill calculation of a consumer using two separate meters; TOU meter for charging his electric vehicle and block tariff meter for other domestic consumption can be summarized as follows. Here, it should be noted that only one fixed charge is added up for one consumer though there are two separate meters.

- **Electricity costs under two meters**

Table 44. The New Electricity Cost Under Two Meters for EV Owners

	Monthly electricity charge (LKR)		
	(91 – 120) kWh	(121 – 180) kWh	Above 180 kWh
Number of units per month (kWh)	108.4	143.01	257.3
Domestic charge (with block tariff meter)	1761.6	2819.82	7542
Charge for EV (with TOU meter)	3466.67	3466.67	3466.67
Total	**5228.27**	**6286.49**	**11008.67**

Considering scenario 1 and 2, the saving for the consumer by using two separate meters under the three categories can be presented as follows.

- **Consumer bill saving**

Table 45. Consumer Bill Savings Under the New Meter Connection

	Consumer category		
	(91– 120) kWh	(121 – 180) kWh	Above 180 kWh
Saving (LKR/month)	2008.70	1931.62	561.35
Percentage saving (%)	27.76	23.50	4.85

Case 2 – With the newly proposed tariff rates

The new tariff rates proposed by the PUCSL are as follows.

- **Newly proposed block tariff rates**

Table 46. Newly Proposed Block Tariff Rates

Customer Category	Consumption per month (kWh)	Unit Charge (Rs./kWh)	Fixed Charge (LKR/month)
D-1	0-30	8	430
	31-60	12.5	1100
D-2	0-60	15.5	N/A
	61-90	18	1350
	91-120	37	1650
	121-180	37	1650
	>180	50.5	1700

- **Newly proposed TOU tariff rates**

Table 47. Newly Proposed TOU Tariff Rates

	Charge (LKR per unit)	Fixed charge
Off-peak (22:30-05:30)	17	1700
Day (05:30-18:30)	30.5	
Peak (18:30-22:30)	54	

Considering the same average electricity consumption by the three customer categories and the same EV specifications, the electricity charge, and the saving for a potential consumer can be summarized as follows.

- **Monthly electricity costs and bill saving**

Table 48. Monthly Electricity Costs and Bill Saving for EV Owners

		Monthly electricity charge (LKR)		
		(91 – 120) kWh	(121 – 180) kWh	Above 180 kWh
Number of units per month (kWh)		108.4	143.01	257.3
With TOU meter for both EV charging and domestic work		9862.98	10971.49	14713.98
With two separate meters	Domestic use (block tariff meter)	3800.8	5081.37	10403.65
	EV charge (TOU meter)	4533.33	4533.33	4533.33
	Total	8334.13	9614.70	14936.98
Saving (LKR/month)		**1528.85**	**1356.79**	**-223.00**
Percentage saving (%)		15.50	12.37	-1.52

Hence, it can be observed that in both the cases of existing tariff rates and newly proposed rates, customer will have a cost saving by using two separate meters under two tariffs.

7.2.5. Required Policies

- Since the additional TOU tariff with a new meter was proposed to address the need to separate EV charging and other bulk loads from common domestic loads, policies regarding the future population of EVs and EV charging infrastructural requirements should be looked at.
- Hence, the government can incentivize Electric Vehicle (EV) deployment through a variety of policies, only some of which involve direct financial assistance. Financial incentives such as tax credits, rebates, and reduced import tariffs help reduce the upfront cost of purchasing an EV. Other financial incentives, such as reduced vehicle registration fees and specialized tariff design, can also decrease the cost of owning, fueling, driving, and parking an EV. Further, a policy should be implemented for Electric Vehicle to Grid (V2G) with Time of Supply (TOS) tariff scheme. (V2G power export can be encouraged with a TOS tariff)
- Apart from these, a policy should be implemented on regulations with all the information on setting up a new meter, related tariffs, vehicle charging times, charging rates in public charging centers etc. which the current and prospective EV owners need to follow.
- For the proposed hybrid solar systems, necessary policies and regulations should be formulated including metering methodology and standards, forecasting and scheduling regulations, grant of connectivity and sharing of transmission lines, etc.

7.3. Proposal 3

Promoting DR programs by encouraging the installation of battery storage at the rooftop solar customer level and introducing an optional time-varying Feed-in Tariff (FIT)

Here, the following proposals were made.

- Upgrading the existing solar PV net plus systems with hybrid inverters to accommodate battery energy storage to participate in DR programs.
- Encouraging the net plus customers to participate in DR programs by introducing optional time-varying FIT and providing them with financial incentives such as low-interest loan schemes.

In this proposal, DR programs will be promoted by encouraging the installation of battery storage at the rooftop solar customer level and introducing an optional time-varying FIT for them.

7.3.1. Introduction

Rooftop solar schemes: Net Metering

When it comes to rooftop solar schemes; there are mainly three schemes Net Metering, Net Accounting and Net Plus. Net metering customers will have to pay only for the net electricity consumption. For an excess renewable generation, no fee will be paid but the excess energy balance can be brought forward to upcoming months and consumed. The following features can be summarized under the net metering concept.

- Generates electricity using renewable energy resources and utilizes it within the premises
- Only pays for the net amount of electricity consumed
- No fee will be paid for the excess electricity produced
- If the generation exceeds the consumption, the balance can be brought forward and consumed in the upcoming months

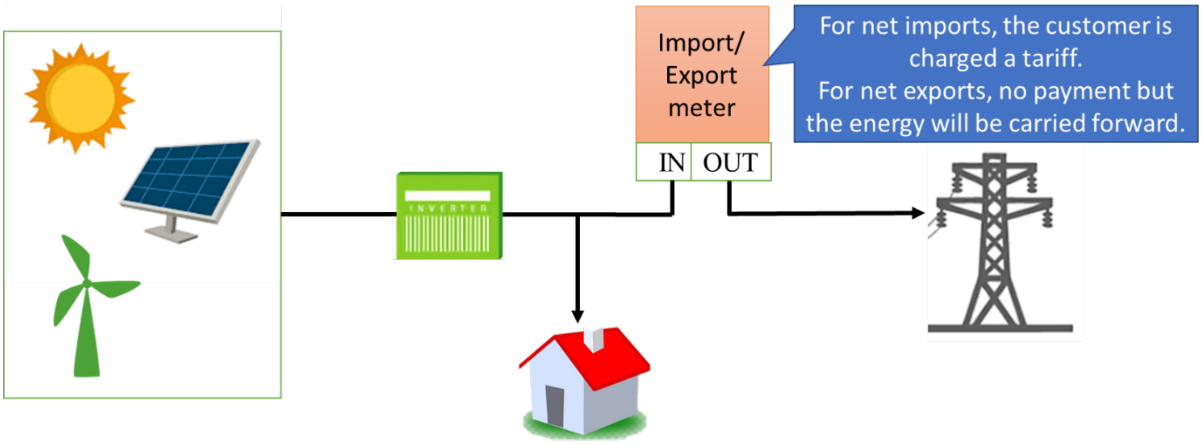


Figure 20. Net Metering Billing Scheme for the Rooftop Solar Systems

Rooftop solar schemes: Net Accounting

The second scheme is Net Accounting. This applies only to solar generation. If the renewable generation exceeds the consumption, the customer will be paid by a feed-in tariff. If the consumption exceeds the generation, the customer has to pay for excess energy consumed according to the existing tariff. All the features of the net accounting billing scheme are described in the following figure.

- Generates electricity using solar panels within the premises
- If the generation exceeds the consumption, the customer will be paid Rs.22.00/ kWh during the first 07 years and from the 8th year he will be paid Rs. 15.50/ kWh
- If the consumption exceeds the generation, the customer has to pay for the excess electricity consumed according to the existing electricity tariff

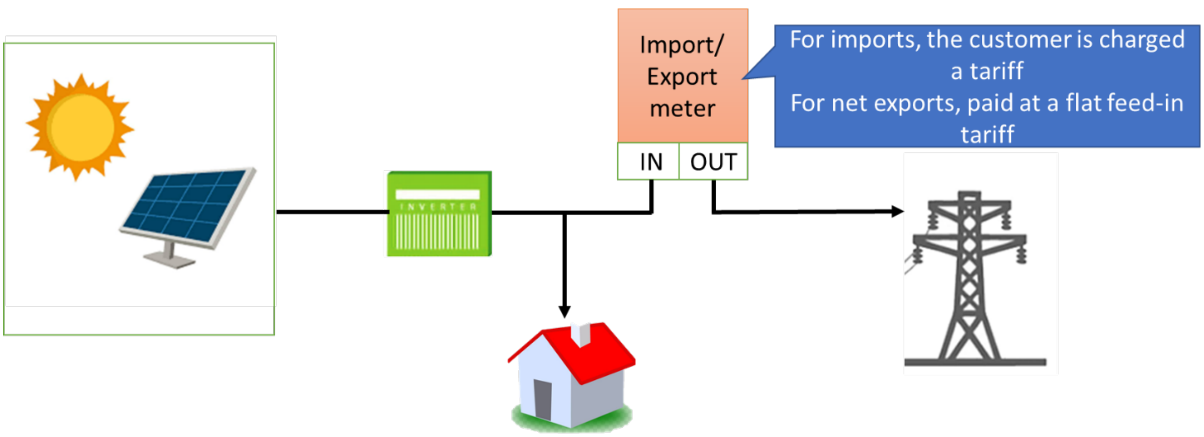


Figure 21. Net Accounting Billing Scheme for the Rooftop Solar Systems

Rooftop solar schemes: Net Plus

The final scheme is Net Plus. Unlike previously discussed schemes, two energy meters are available to measure imported and exported energy separately. There is no linkage in-between the electricity consumption of the customer and the electricity generation and the customer will be paid for the total renewable generation within the premises.

- Gets paid for the total electricity generated using the solar panels within the premises
- Pays for the electricity consumed according to the existing tariff
- Unlike the net metering method, there is no linkage in-between the electricity consumption of the customer and the electricity generation

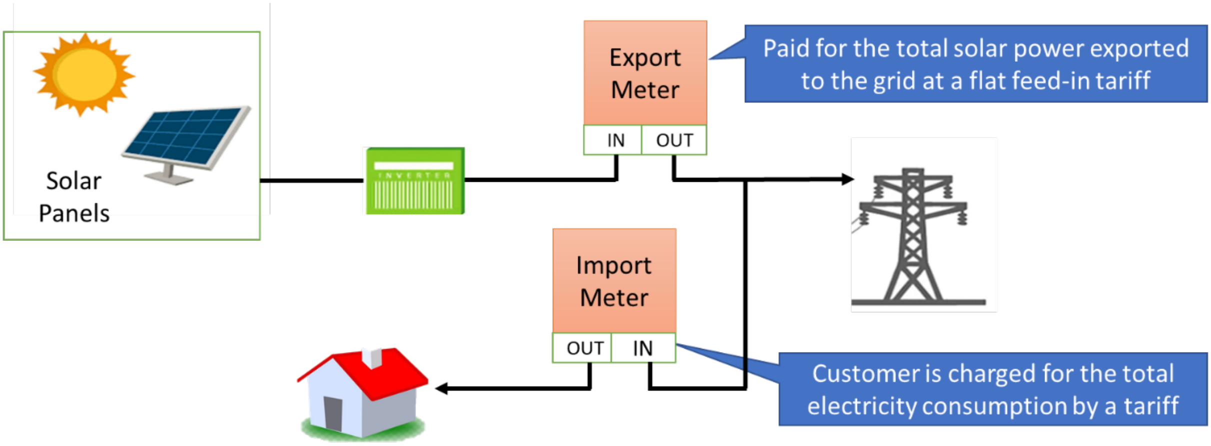


Figure 22. Net Plus Billing Scheme for the Rooftop Solar Systems

7.3.2. Solar PV Net Plus schemes for DR programs

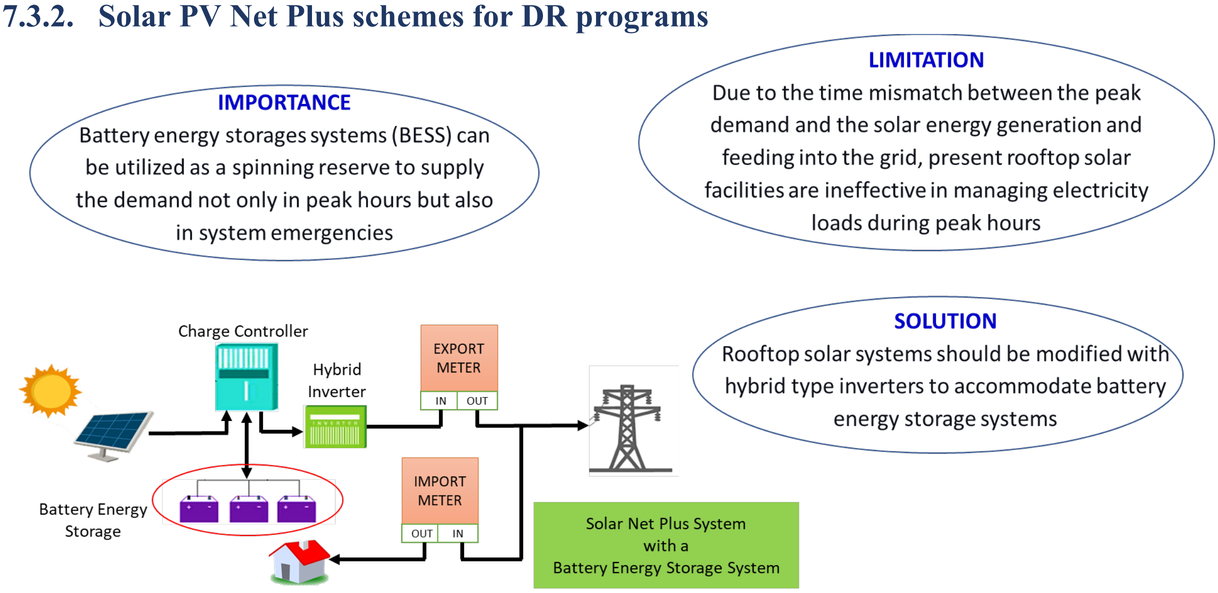
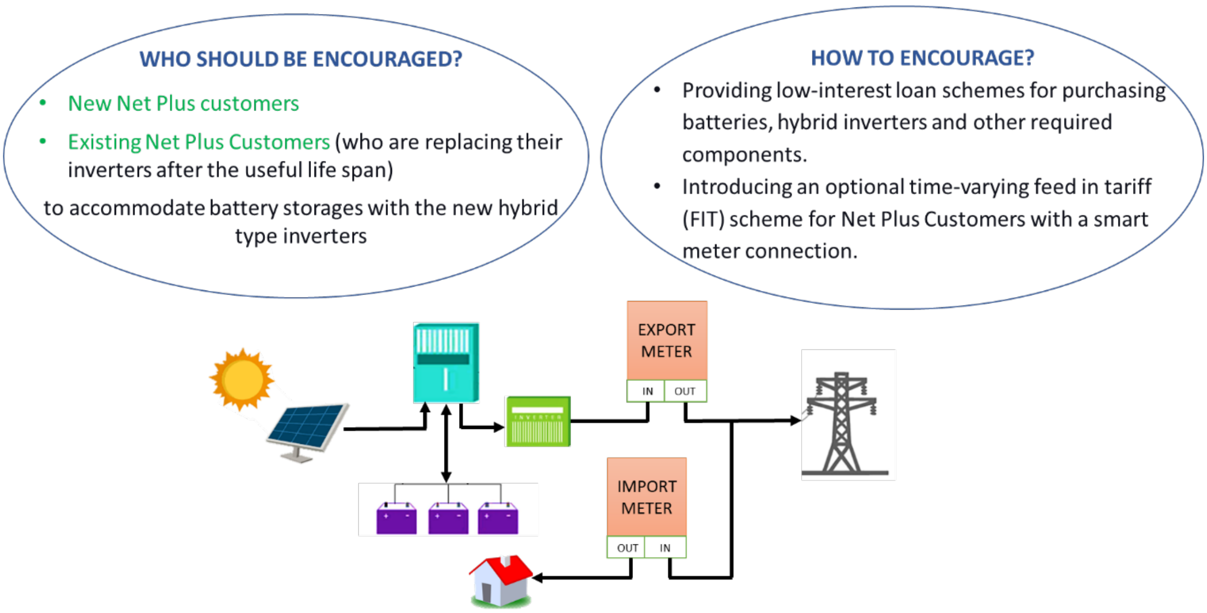


Figure 23. Solar Net Plus System with a BESS

In this proposal, upgrading the Solar Net Plus scheme to promote DR programs is considered. The main limitation is that at present, the rooftop solar facilities are ineffective in managing loads during peak hours due to the time mismatch between the peak demand and solar generation. To overcome this limitation, it is proposed to upgrade the solar net plus systems with hybrid type inverters to accommodate battery energy storage systems. This is important as battery energy storage systems can act as spinning reserves to cater for the demand in response to DR programs.

It is essential to encourage all the new Net plus customers as well as existing customers, who are replacing their grid-tied inverters after the useful life span to go with hybrid inverters to install battery energy storage systems. A low-interest loan scheme is proposed as a way of motivation to support the net plus customers who are upgrading their existing system to participate in DR programs. Secondly, an optional time-varying feed-in tariff scheme for Net Plus Customers is proposed as a financial incentive.



Time-varying Feed-in-Tariffs for Net Accounting and Net Metering customers

Unlike Solar Net Plus Scheme, both solar panels and the customer loads are connected to a single energy meter which measures the difference between the customer's total grid energy consumption and the renewable generation. Therefore, there are complications in introducing an optional time-varying feed-in tariff for solar Net Accounting or Net Metering customers.

7.3.3. Worldwide Experiences

For example, Essential Services Commission, Melbourne, Victoria, has introduced an optional time-varying feed-in tariff between 6.1 and 10.9 cents per kWh such that exported units to the grid are less valuable during off-peak periods, and more valuable during peak periods.

There are two options for the customers

1. A ‘flat rate' minimum feed-in tariff of 6.7 cents per kWh.
2. A 'time-varying' minimum feed-in tariff between 6.1 cents and 10.9 cents per kWh.

Table 49. Time-Varying Feed-in Tariff in Melbourne, Victoria

Period	Weekday	Weekend	Rate: cents per kilowatt-hour (c/kWh)
Off–peak	10 p.m. to 7 a.m.	10 p.m. to 7 a.m.	6.7
Shoulder	7 a.m. to 3 p.m. 9 p.m. to 10 p.m.	7 a.m. to 10 p.m.	6.1
Peak	3 p.m. to 9.00 p.m.	N/A	10.9

A minimum feed-in tariff is calculated by forecasting the wholesale price of electricity for the year ahead. This price varies across different times of the day due to changes in supply and demand.

In their calculation, they have also included,

- Avoided transmission and distribution losses
- Avoided social cost of carbon
- Other fees and charges

Table 50: Support Calculations when Finding Minimum FIT

Component	Off-Peak	Shoulder	Peak
Wholesale electricity prices	3.87	3.39	7.91
Market fees and service charges	0.07	0.07	0.07
Value of avoided transmission and distribution losses	0.22	0.19	0.45
Value of avoided social cost of carbon	2.49	2.49	2.49
Total	6.7	6.1	10.9

An extensive literature review was carried out to analyze the feed-in-tariff schemes in other countries around the world and some of the important details found are summarized below.

Table 51. Existing Feed-in Tariff Rates Worldwide

Country / Region	**Feed-in-Tariff Rates**	**Impact of the Feed-in-Tariff**	**Reference**
Indonesia	The consumer is paid 65% of the electricity price for each kWh exported PV energy.	The new regulation on feed-in-tariff in Indonesia aims to promote residential, industrial and commercial consumers to develop their PV systems connected to the national grid. Also, it will limit the consumer to install PV at a specific power rating.	*Optimal planning of Solar PV using a simple model for the new feed-in tariff in Indonesia. (2019)*
China	Regionally differentiated feed-in-tariff rates based on the cost of electricity generation and ranges from 0.90 to 1.00 yuan/kWh	The adoption of regional differentiation of tariffs effectively enhanced location diversification of renewable projects.	*Impact of feed-in tariff on renewable power generation in China (2020)*
Australia	Differentiated based on the states and the feed-in tariff rates within Australia and ranges from 6 AUD/kWh to 51.28 AUD/kWh.	While enhancing the diversification of Solar PV projects around the country, this scheme promotes the residential, industrial and commercial customers to get converted to Solar PV systems.	*Exploring payback-year based feed-in tariff mechanisms in Australia (2021)*
Japan	The FIT system offers two Solar PV energy options, with varying durations and fixed prices. For residential PV systems (less than 10kW), the FIT is 42 JPY/kWh for 10 years and non-residential PV systems (over 10kW), the FIT is 40 JPY/kWh for 20 years.	In the Japanese PV industry, there has been no significant reduction in the cost of PV products since the implementation of the FIT act. The high FIT price is probably the main reason for PV products to remain more expensive compared to other countries.	*The effects of the new feed-in tariff act for Solar Photovoltaic (PV) energy in the wake of the Fukushima accident in Japan (2021)*
Iran	The optimal feed-in-tariff varies from 0.0835 USD to 0.12.72 USD.	The FIT is decided based on the solar radiation potential of the different regions within the country. The system allows the investors to figure out the most economical and cost-effective regions for their investments.	*On the effect of geographical, topographic and climatic conditions on feed-in-tariff optimization for solar photovoltaic electricity generation: A case study in Iran*
United Kingdom	In 2019, the Feed-in-Tariff rate in the UK was 3.79 p/kWh. But the FIT scheme has been replaced by the Smart Export Guarantee (SEG) with effect from the 1st of January 2020.	With the currently available SEG tariff, customers get paid for any electricity they export to the grid at a flat rate of 4.1p/kWh.	*The long-term effects of cautious feed-in-tariff reductions on PV generation in the UK residential sector. (2020)*

Saudi Arabia	The feed-in-tariff rate in all regions is 0.08 SAR/kWh.	It will be necessary to increase the current rates of FIT throughout all regions of SA to allow investors to continue to receive credits throughout their contracts. (In general, 20 years)	*Development of feed-in tariff for PV in the kingdom of Saudi Arabia. (2019)*

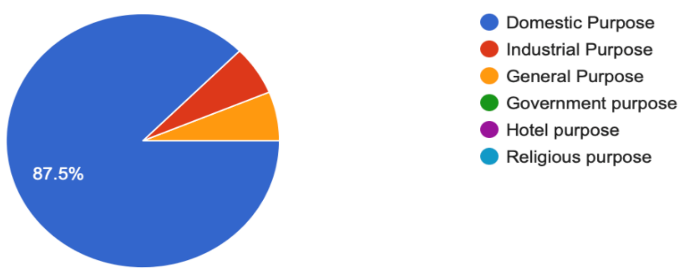
By analysing the above tariff rates in different countries, it can be concluded that the Feed-in-Tariff scheme is the most widely using tariff scheme to motivate solar power producers. Also, we can observe a trend of using a regionally differentiated FIT rate, especially in geographically expanded countries such as China, Australia, and Iran where the potential solar radiation differs from one region to another.

But when considering the Sri Lankan context, regionally differentiated tariff rates are not necessary as the solar radiation over the entire country can be taken as almost the same due to the small geographical area compared to other countries.

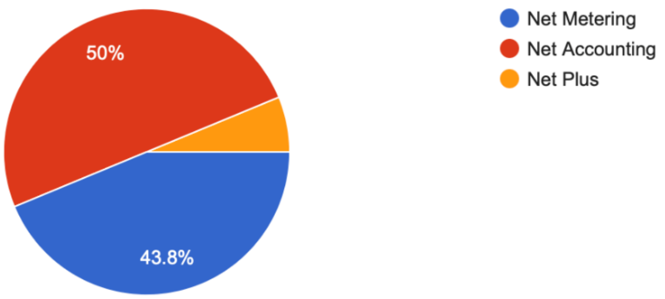
7.3.4. Survey on Rooftop Solar PV Systems

The survey on rooftop solar PV is conducted for the owners of solar rooftops with or without a residential battery storage system to identify the possibilities for the implementation of a demand response program in Sri Lanka. The questions were designed to get the ideas of customers on the existing solar billing schemes and their interest in shifting to a new Time of Use (TOU) billing scheme with their solar panels. Identifying the potential of shifting considerable electricity demand to the daytime when panels generate power, the use of residential batteries for demand response programs with financial incentives, and obtaining the idea of non-battery owners for shifting for a home battery storage in the future are the key objectives of the survey.

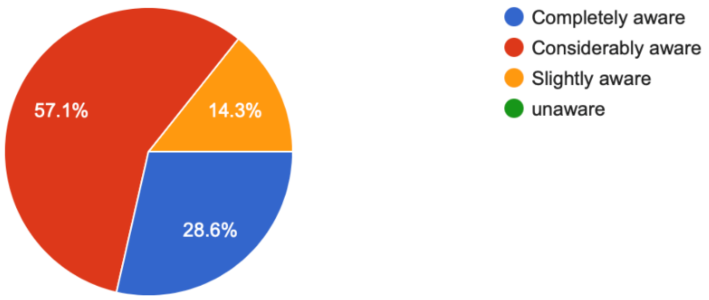
- Customer type



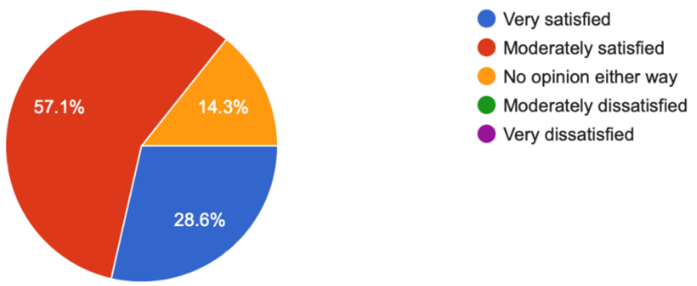
- Billing scheme



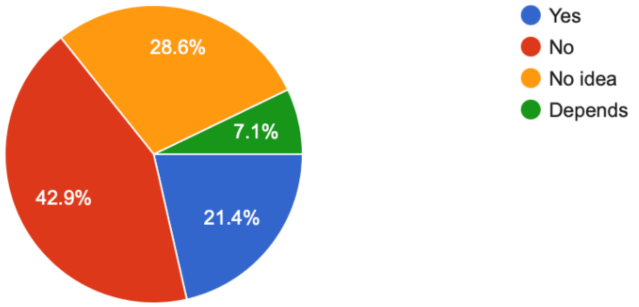
- Awareness of the billing scheme



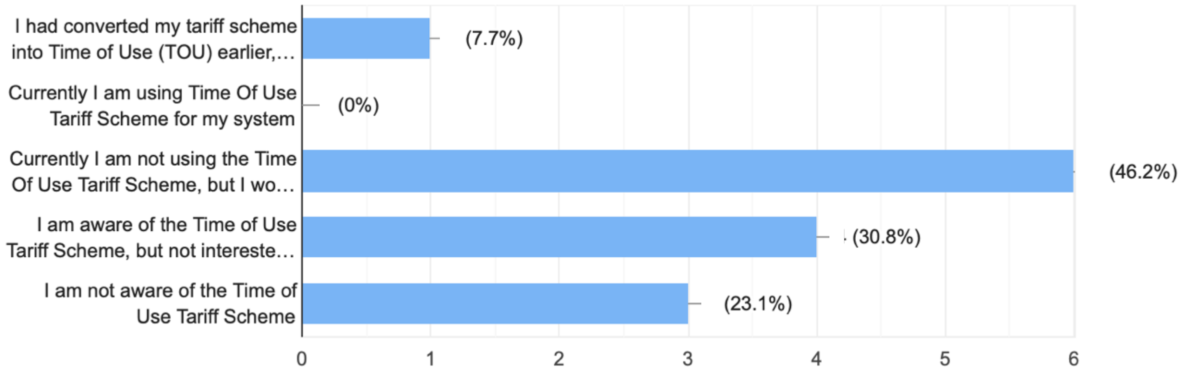
- Satisfaction with the electricity bill savings after installing solar power systems



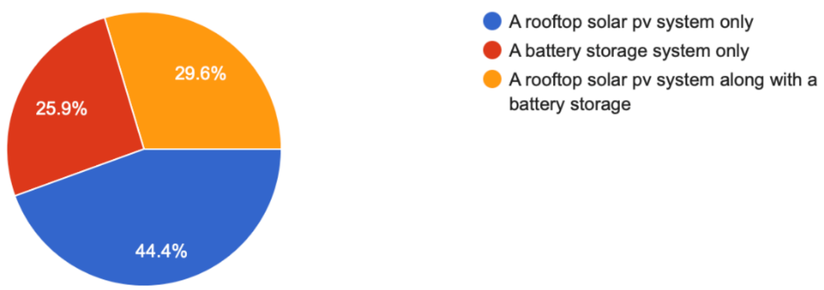
- Do you purposely use your electrical appliances more when panels are generating power / during the daytime?



- Experience with the Time Of Use (TOU) tariff incorporated with rooftop solar PV system

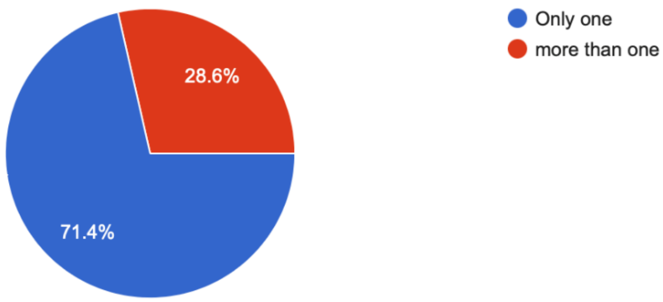


- Type of the solar PV system

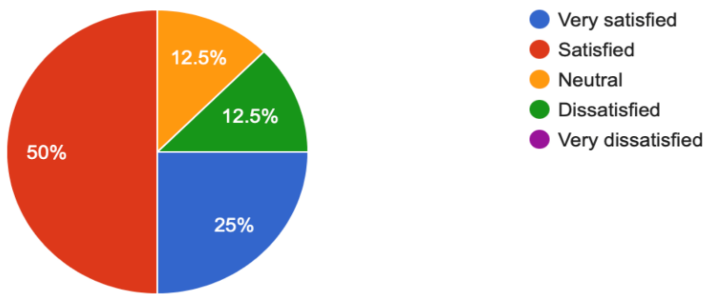


Rooftop solar system along with the battery storage (Hybrid solar system)

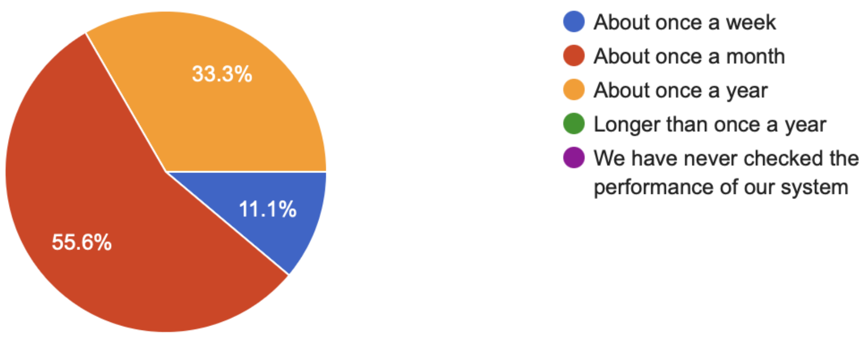
- Number of solar power systems owned by the customer



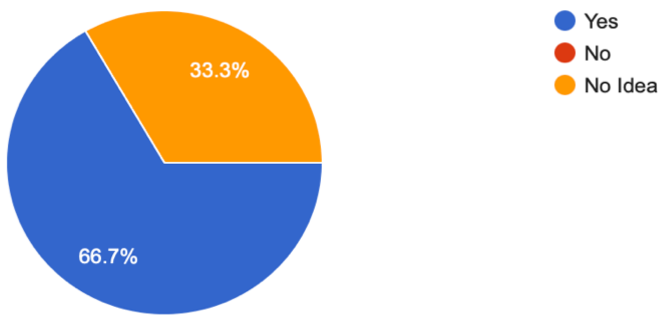
- Satisfaction with the installation of a battery storage



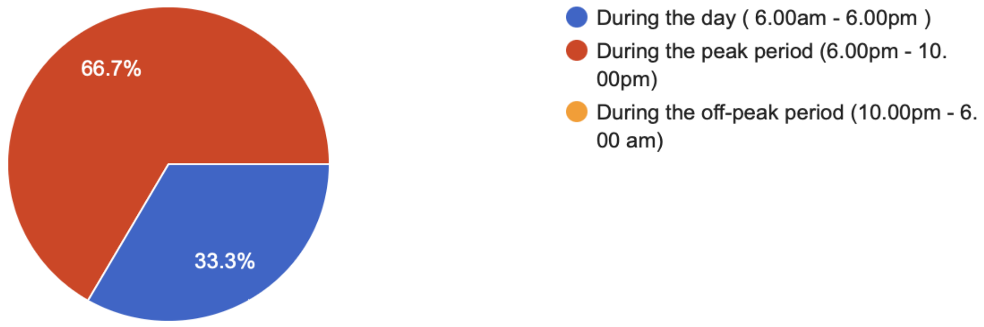
- Frequency of checking the performance of the battery system



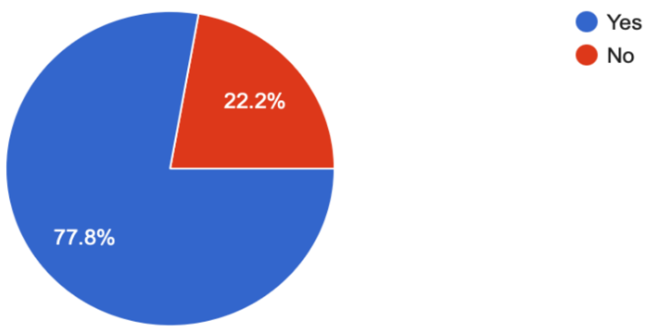
- Did the way appliances or electricity used at your premises change after installing the battery system?



- Time at which the batteries are normally discharged / used

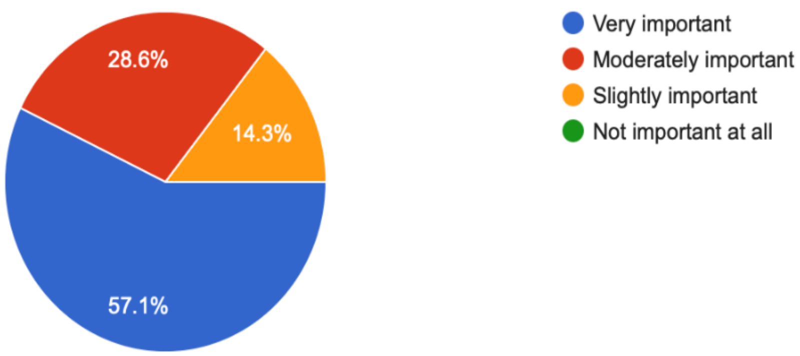


- Would you consider allowing an electricity utility to operate your battery storage system for a financial incentive in return?

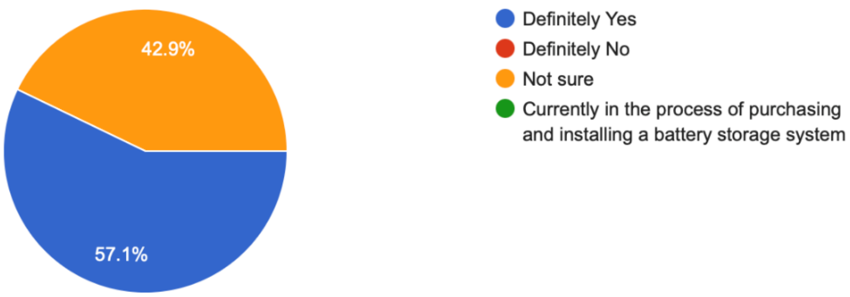


Battery storage only (UPS Only)

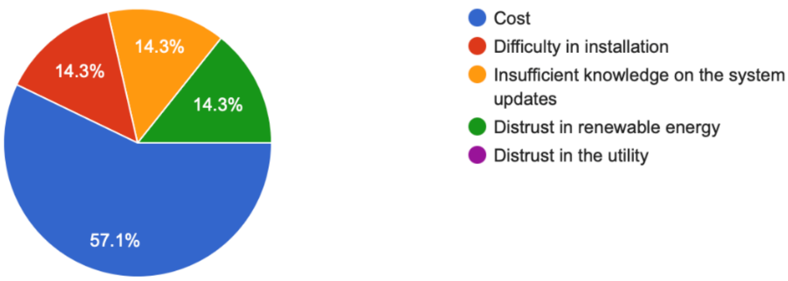
- Importance of owning a battery bank to be used in the absence of grid power



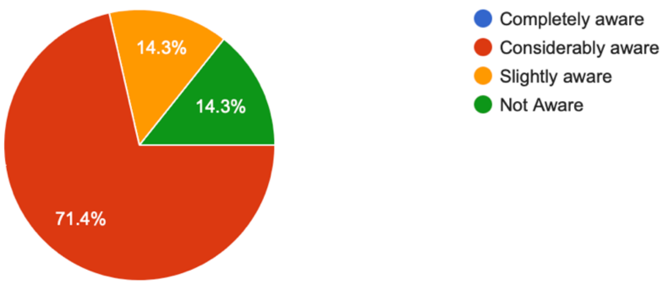
- Do you think you will invest in the next few years after the replacement of the existing inverter?



- Current hindrances in installing batteries at the customer premises



- Awareness about the incentives and benefits that can be gained from a hybrid solar PV system



7.3.5. Workshop Comments

Workshop 01 – Comments by CEB, LECO, PUCSL and DIMO

- According to the comments made by the participants, there should be a minimum feed-in tariff for investors and the point at which this proposed method is viable and profitable for both customers and investors needs to be figured out.
- Also, the need of revising solar tariffs every year was discussed during the workshop.
- Further, it was suggested that it would be more meaningful to extend the net plus scheme for domestic customers instead of the industrial customers who are already subsidized.
- Also, it was mentioned that, based on an analysis done by DIMO, the feed-in tariff can be raised to Rs.180.00 per unit of electricity and it was suggested to encourage the government to carry out these promotions.
- Based on the discussion carried out at the workshop, the implementation of large-scale battery storage can be used to facilitate the flattening of the load curve by charging the batteries during the daytime and discharging them during peak times. This approach supports the reduction of high-cost power generation during peak times.
- Since there are no properly formulated policies and regulations for off-grid solar PV systems, unregulated buyers and sellers have been involved in the process. Hence the tendency of people to install hybrid solar PV systems at their own risk was discussed during the workshop. Also, it was mentioned that these unregulated companies will tarnish the reliable image of recognized companies such as DIMO.
- It was suggested that the emerging concept of Vehicle to Grid (V2G) needs to be encouraged with a TOS tariff.

Discussion – Comments by SEA

- There is a pilot project in Kurunegala based on 20 households which belong to a scheme consisting of solar PV, battery storage, hybrid inverters and fully programmable import-export capability where the charging time and discharging time can be regulated. It was suggested that it would be beneficial if this project could be analyzed and used to implement the proposed DR program.

7.3.6. Payback period calculation of hybrid solar system

Assume a 5kW rooftop solar system with 5kWh Li-ion battery storage,

Total generated units per month (only in the daytime)	600kWh
Total saved energy in battery backup system per month (Assume 5kWh battery system can save 5 kWh units per day)	150kWh
Total energy consumption during the daytime per month	150kWh
Total energy consumption during the nighttime per month	150kWh
Total energy supply in the daytime to the grid	300kWh

Then the customers have an opportunity to use the stored energy in the battery bank at nighttime without getting power from the utility or otherwise they can sell the energy to the grid at nighttime.

Assume the time of supply tariff is introduced for the domestic customers as follows.

Table 52. The Proposed TOS Tariff for Roof Top Solar Customers

Time	Rates (LKR)
Peak Time	54
Off-peak Time	13
Day Time	25

Case-1: Use the stored energy for the consumption at nighttime

Now the customer can sell only the extra generated solar power during the daytime to the grid.

Table 53. Net Income Calculation under Case 1

Units (KWh)	Selling price (LKR)	Net Income (LKR)
300	25	7,500

Case-2: Use the stored energy for selling

Under this, customers can sell extra generated solar power during the daytime and the stored energy in the battery bank to the grid at nighttime. But in this condition, they have to get the power from the utility for the usage of nighttime.

Table 54. Net Income Calculation under Case 2

Units (KWh)	Selling price (LKR)	Total (LKR)	Total Income
150	54	8,100	
300	25	7,500	15,600
Units (KWh)	**Buying price (LKR)**	**Total (LKR)**	**Total Expense**
150	Existing Block	3043.5	3043.5
		Net Income	12,556.50

It has been seen that customers can save an extra LKR 8100.00 per month by adding a battery backup system.

Table 55. Pay Back Period Calculation

lifespan of the Li-ion battery	10 Years
Cost of the AC coupled battery- (ROSEN 48V,100Ah Lithium Powerwall, Warranty-10 years, DOD-100%)	USD 3750
Number of years need to cover the cost	9 Years

Payback period= USD 3750/ LKR 12,556.50*12 = 9 Years

According to the above calculation, it has been seen that the customers can cover their battery and inverter costs within 9 years. Even though it is not beneficial, they can get an uninterrupted power supply for the whole day. For this, a loan scheme for the customers should be introduced to buy the inverter and the battery, further, a reasonable Time of supply tariff should be proposed for them.

7.3.7. Required Policies

- A policy should be implemented with a minimum feed-in tariff for investors considering the viable and profitable points to both investors and customers.
- There is a sophisticated change in the increase of new customers getting solar PV connections each year. Hence, a policy should be implemented where the solar tariff is revised every year accordingly.
- A policy is to be implemented stating specifically to which customer category the three solar billing schemes should be extended. For example, it will be better if the Net Plus scheme is proposed for domestic customers rather than industrial customers since the industrial consumer category is already subsidized in this aspect.
- Policies in replacing high-cost power plants with large-scale battery storage systems together with solar PV to make a hybrid power system. Necessary additions to these policies should be made such as instructions to customers to flatten the load curve by charging the battery storage system during the day, discharging it during the peak period and again charging it during the off-peak period.
- Still, there are no policies and regulations on off-grid solar systems. Therefore, unregulated buyers and sellers have involved in the process and people install the systems at their own risk. These unregulated companies will tarnish the reliable image of recognized companies. Hence, necessary policies should be implemented with regard to this issue.
- Policies in implementing Vehicle to Grid (V2G) with Time of Supply (TOS) tariff scheme. (V2G power export can be encouraged with a TOS tariff)

7.4. *Proposal 4*

Use of Diesel Generators (DGs) in DR programs

7.4.1. Promotion of Synchronization Arrangements for DGs

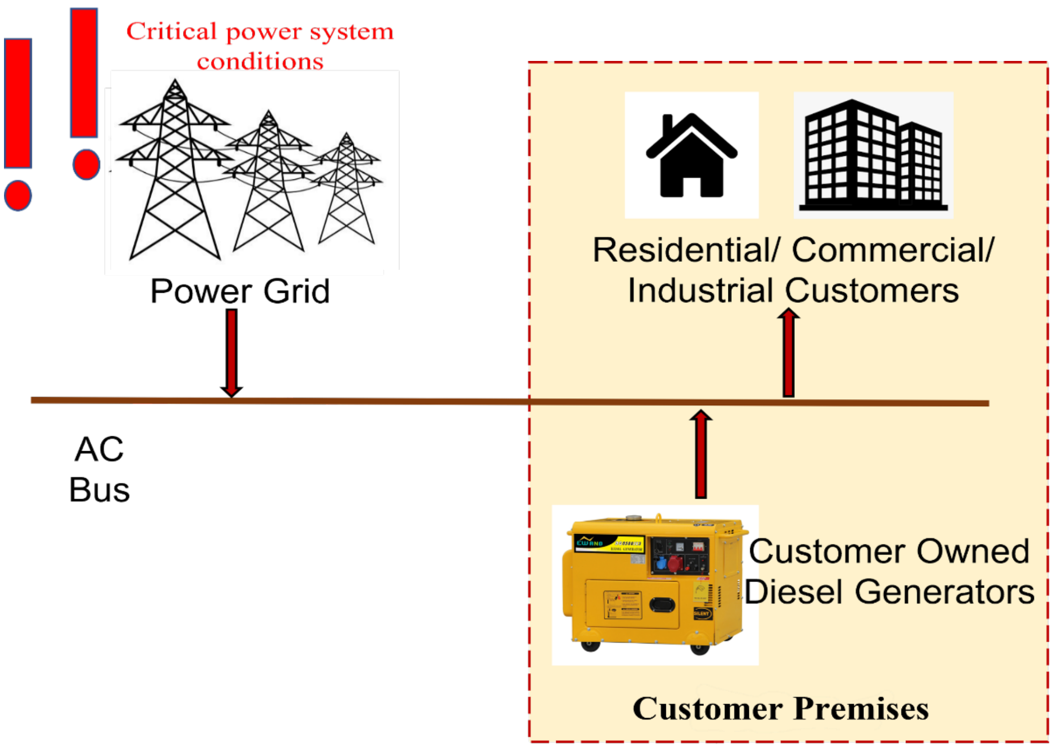


Figure 24. Connect the Customer Owned DGs With the Utility Grid

According to this proposal, all the small-scale individual diesel generators in residential areas and also large-scale individual diesel generators (1MW or above) in commercial buildings and industries can be used as a non-spinning reserve, but the problem is they don't come with a synchronization mechanism. Thus, it is necessary to update the existing generators and upcoming diesel generators with synchronization arrangements. Then the utility has an opportunity to use customer-owned DGs in system emergencies.

The following points are proposed under this.

- A Time of Supply (TOS) tariff with a new smart meter connection for customers with DGs
- Financial incentives for DG owners who upgrade their DGs with synchronization arrangements
- Polices and regulations to connect customer owned DGs as a non-spinning reserve

7.4.2. Adapting the DG Owners to DR programs

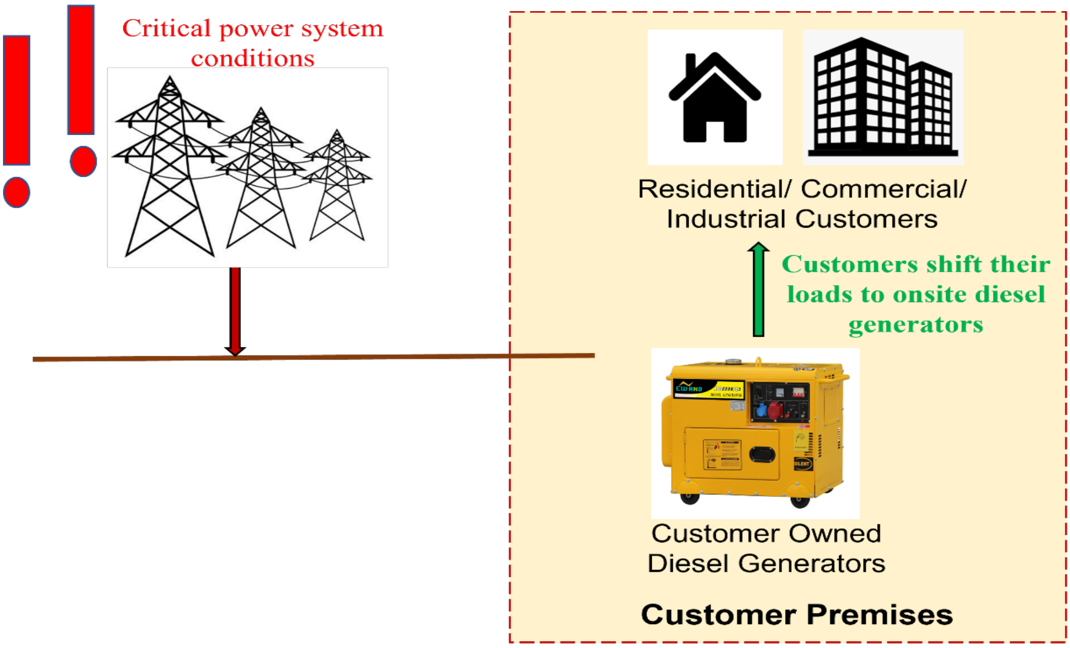


Figure 25. Shifting of Customer Loads to the On-site DGs

Here, the DG owners can participate in the DR programs. There should be an agreement between the DG owner and the utility grid and customers should reduce their electricity usage during system emergencies or peak hours by a pre-determined level by shifting their loads from the utility grid to the on-site DG sets. All the participants in this DR program will receive a credit or discount for their electricity bills in exchange for reducing the demand.

The following points are proposed under this.

- A new attractive tariff structure for the customers signed up for DR programs related to DGs
- Policies and regulatory framework to implement DR programs for customer-owned DGs

7.4.3. Communication Platforms: DG to Grid Automation

The existing standard Genset controller can be only used for short-distance communication. That means, if it is necessary to make communication with each gensets, they should be placed close to each other.

If we connect specific remote monitoring modules for the Gensets, then a dedicated common cloud can be used to store each data, and based on that, the SCADA system can be developed to give commands to the gensets when required.

Ex: Cummins Power Command Cloud 550 Remote Monitoring System

Features:

- Monitors up to (12) generators, transfer switches or expandable I/O module
- Allows for easier setup
- Allows for control from a home computer or Smart Phone App
- **Monitor Generator Data**: Annunciator, alternator and engine data for total visibility
- **Monitor Transfer Switch Data**: View source, load and switch connection status
- **Advanced Control**: Remotely start/stop generators and transfer switch tests, Remotely acknowledge and reset warning type faults
- **Built-In Notifications**: Receive notifications via SMTP (email), SMS (text) and SNMP traps
- **Icon-Based Graphical Interface**: Makes monitoring data and controlling devices an easy task
- **Additional Features:** View data logs, event logs, reports and diagnostics
- The approximate cost of this module is 700 USD.

But it is a dedicated cloud and can’t be used with all the Gensets available in the market, therefore necessary policy changes should be developed to make a common cloud which can be compatible with all the available gensets in the market in Sri Lanka.

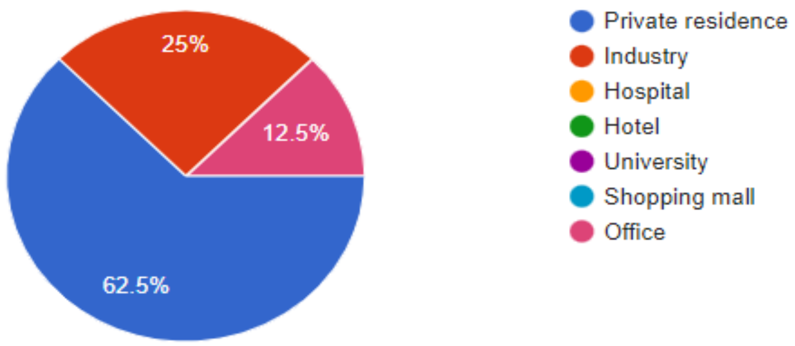
7.4.4. Survey on Diesel Generators

Demand Response (DR) programs for Diesel Generators (DG) are the programs where the customers agree to reduce their electricity usage during system emergencies or peak hours by a pre-determined level by shifting their loads from the utility grid to the on-site diesel generator sets. The participants receive credits on their electricity bills in exchange for reducing the demand during critical power system conditions.

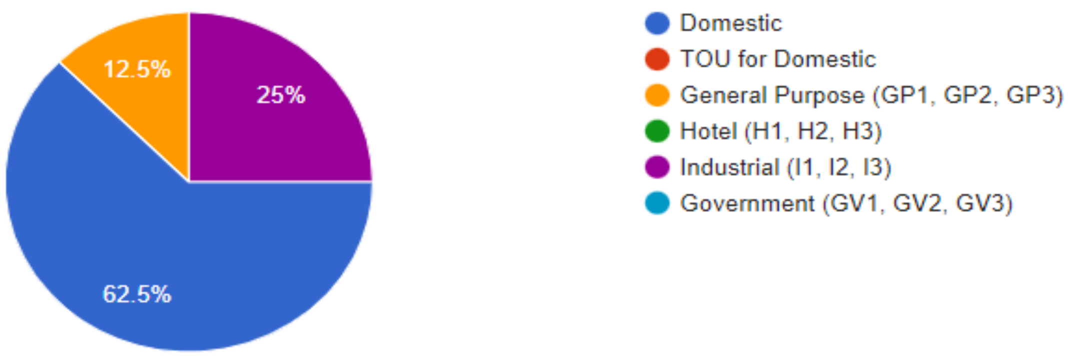
Through this survey, the availability and customer perception of the use of their DGs in DR programs were assessed.
A sample of 50 DG owners belonging to different sectors was analysed.

SECTION A - Customer information

- Type of organization/ institution



- Existing tariff category

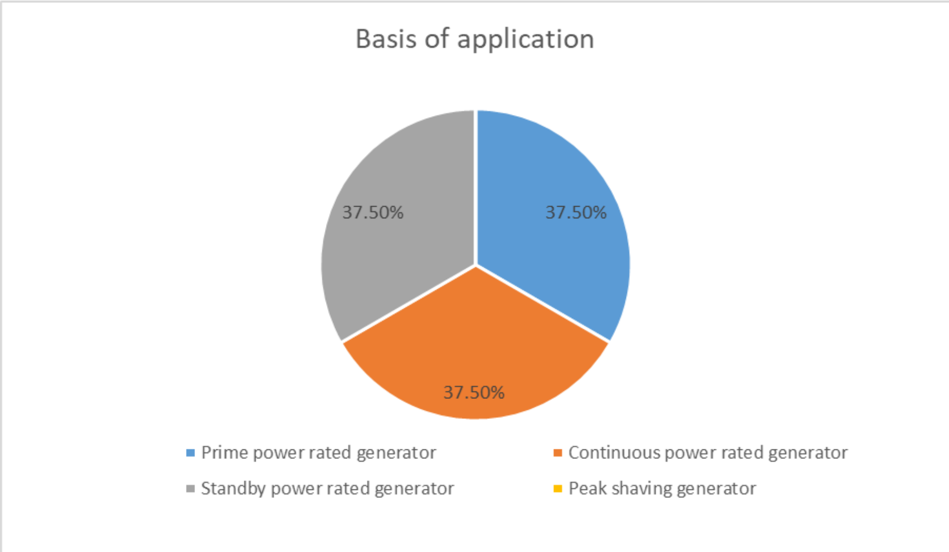


SECTION B - Information on Diesel Generators

- Number of diesel generators in use
  Mostly 1 - 2 diesel generators are used by the customers.

- Power ratings of diesel generators in use
  Domestic customers use DGs with power ratings less than 100 kVA
  DGs with higher power ratings are used by other customer categories

- Basis of application

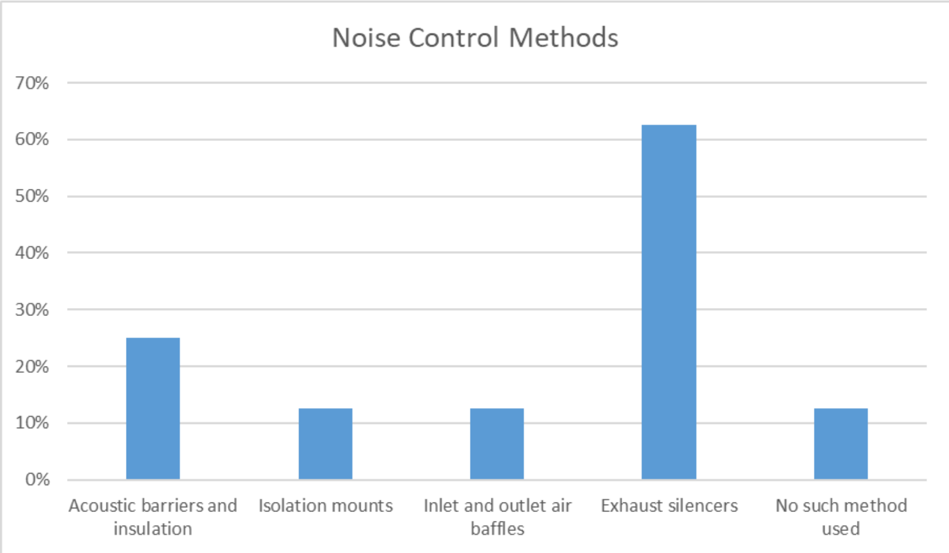


- Use of DGs by customers

  The majority of the customers use DGs during outages for emergency power backup and to ensure an uninterrupted power supply.

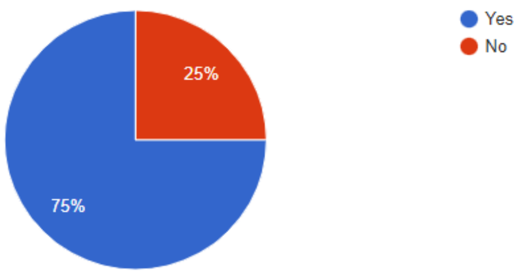
  Therefore this suggests the possibility of using the customer-owned DGs in DR programs. Customers could reduce their electricity usage during system emergencies or peak hours by a pre-determined level by shifting their loads from the utility grid to the on-site diesel generator sets. This will help the utility in balancing the demand and supply effectively.

- Noise control methods
  According to the survey, it is concluded that exhaust silences are used in most of the DGs as noise control methods. Further, some of the DGs are manufactured with acoustic barriers, insulations and inlet and outlet air baffles.



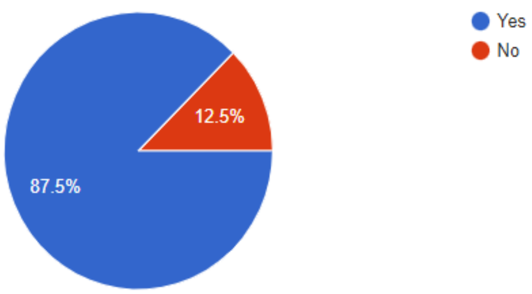
SECTION C - Customer satisfaction

- Satisfaction with the use of diesel generators for the customer needs



SECTION D - Customer opinions on diesel generators and demand response programs

- Customer perception on participating in demand response programs with the customer-owned DGs



7.4.5. Workshop Comments

Workshop 01 – Comments by CEB, LECO, PUCSL and DIMO

- More frequent maintenance is required when the diesel generators are operating below the full load. Also, it causes a reduction in efficiency and it can be challenging for the proposed systems.
- It was suggested that the viability of the proposed systems depends on their ability to reduce the peak demand by replacing expensive generations.

Discussion – Comments by SEA

- Due to the current fuel cost and since most of the generators are not prime-rated, they cannot be used for long hour dispatches. In addition to that, a very high expenditure will have to be incurred over the usage of these DGs. Therefore, the proposed method was not considered a viable option by the representative of the SEA.
- Also, participating in the captive generation program conducted by CEB with these DGs was not considered a good practice.
- Finally, the main aim of proposing the aforementioned usage of DGs was clarified by the research team as using them as non-spinning reserves in a system emergency. This fleet of DGs will supply power only for a few hours and they will not be called into operation more frequently.

7.4.6. Total Capacity Analysis in Sri Lanka

Source: Inspectorate Division, PUCSL

Table 56. List of Grid Sync Capable Generators

List of Grid Sync Capable Generators	Total (MVA)
Generators from TPL with immediate synchronizing capability with necessary controllers & relays installed	17.00
Single operated generators from TPL with necessary controller installed but without relay protection	191.46
Multiple operated generators from TPL with the capability of synchronizing but without DMC	223.22
Grid Sync ready generator list from caterpillar	119.93

7.4.7. Hardware Requirement and the Cost Analysis

Table 57. Hardware Requirement and Cost Analysis

Requirement	Hardware	Cost per unit	Availability	Approximate duration
Multiple operation up to 4 generators	DMC 2000	US$ 18,000.00	Not available in local market, need to order.	3 months for the DMC arrival, 6-8 days for installation & Commissioning
Multiple Operation up to 8 Generators	DMC 6000	US$ 34,000.00	Not available in local market, need to order	5 months for the DMC arrival, 1-2 weeks for installation & Commissioning
Single generator synchronization	G59 Relay	LKR 1,000,000.00+VAT	Normally available in the local market	2-3 days for installation and commissioning

7.4.8. Required Policies

Necessary policy and regulatory framework need to be established to govern the treatment of demand response programs and to enable them to be compensated in a manner comparable to traditional generation resources. This is essential for the successful implementation of DR programs in Sri Lanka.

Proposed policies for using DGs in DR programs are listed below.

- Regulations which allow the customer owned DGs to participate in DR programs, either by synchronizing the DGs with the national grid or by shifting the customer loads from the grid to the onsite DG sets during system emergencies or peak hours.

- Regulations on providing adequate financial incentives for the customers who actively participate in DR programs with their DGs.
    - A DR resource such as a diesel generator, participating in the energy market must be compensated for the service it provides at the market price for energy because the demand response resource can balance supply and demand at a critical system condition. The DGs have now become a more integral part of the regional resource mix, gaining the same types of economic incentives given to traditional generators.

  - Different payment schemes should be introduced for DR program participants. For example, participants of a voluntary reliability event (i.e., there are no consequences for enrolled DR resources that fail to curtail), participants receive energy payments if called, but no capacity payments for participation.

- Establishment of emission control standards for both new and existing DGs which emit sources of air pollutants, such as nitrogen oxides, carbon monoxide and hazardous particulate matter. Policies should be formulated to control the emissions of DGs and some such policies are as follows.
  - Generators that participate in DR programs must adhere to all applicable environmental regulations such as operating hours limitation and/or use of ultra-low sulphur diesel.
  - A reasonable timeframe for phasing out the participation of the oldest, dirtiest diesel engines in demand response programs must be identified.
  - For example, to participate in the programs, the diesel engines must be of the model year 1995 or newer or demonstrate that their NOx emissions do not exceed 35 pounds per megawatt-hour.

7.5. Proposal 5

Promoting microgrids in Sri Lanka to accommodate DR programs

Here,

- Ways of enhancing the awareness of the public and stakeholders on the importance of implementing a microgrid, especially at critical facilities like healthcare and industrial zones which have a major contribution to the national economy, communication and emergency services are proposed.
- Providing consultancy and technical assistance to the parties who are interested in this is suggested.
- Establishing a way of providing financial incentives/assistance by relevant authorities to carry out these projects is introduced.
- Formulating policies and regulations to legally assist the promotion of microgrids is proposed.

7.5.1. Introduction

"A microgrid is a group of interconnected distributed energy resources and loads within clearly defined electrical boundaries that operates as a single controllable entity with respect to the main grid"

Ref: US Consortium for Electric Reliability Technology Solutions (CERTS)

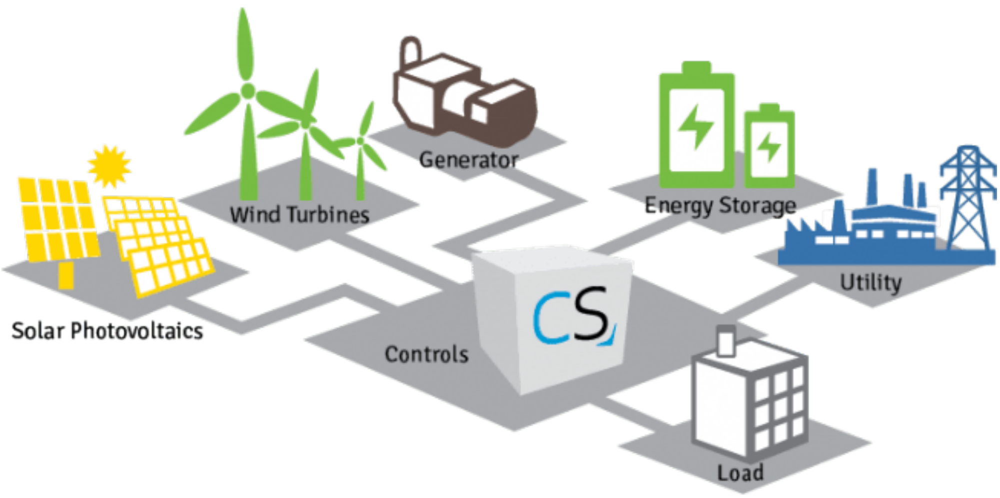


Figure 26. Microgrid Architecture

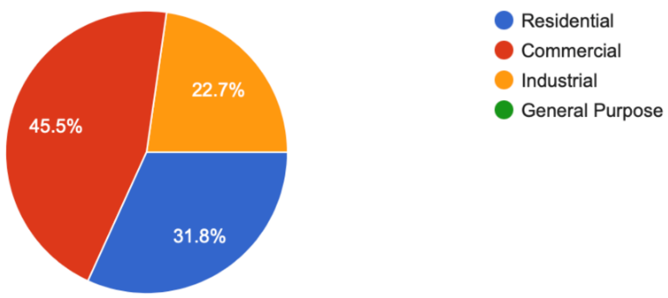
7.5.2. Contribution of the Microgrids for Demand Response (DR) Programs

- During a system emergency in the utility grid, microgrids can be operated in the **islanded mode** providing an uninterruptable power supply to the critical loads as well as reducing the burden on the utility grid until the power system restores.
- Microgrids promote the optimal usage of renewable energy sources like wind and solar and most importantly **the usage of energy storage systems like BESS**. Therefore, by implementing a microgrid platform, the energy stored in the BESS can be utilized to cater for its loads, without drawing power from the utility grid during peak hours.

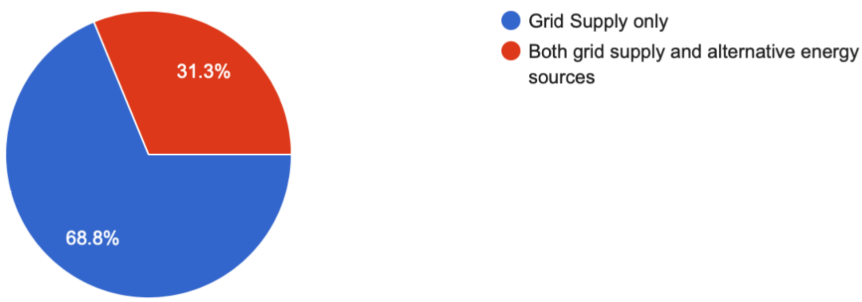
7.5.3. Survey Results

In the Sri Lankan context, a sample of customers with already established microgrids is not available. Therefore, the survey on microgrids aims at the prospective customers that might invest in microgrids to cater to their energy needs in the future. The prospective customers are mostly related to newly built housing schemes, villas, apartments, shopping malls, industrial parks, etc. According to each selected customer, the importance of investing in a microgrid should be evaluated.

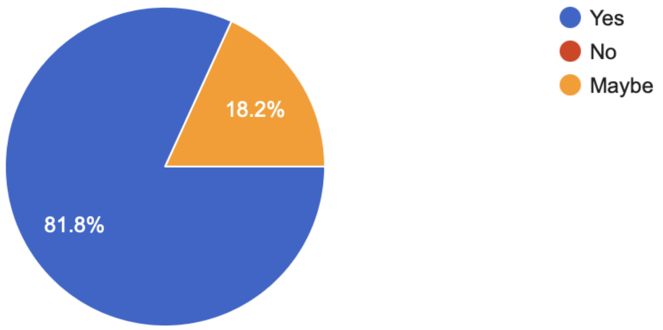
- Consumer category



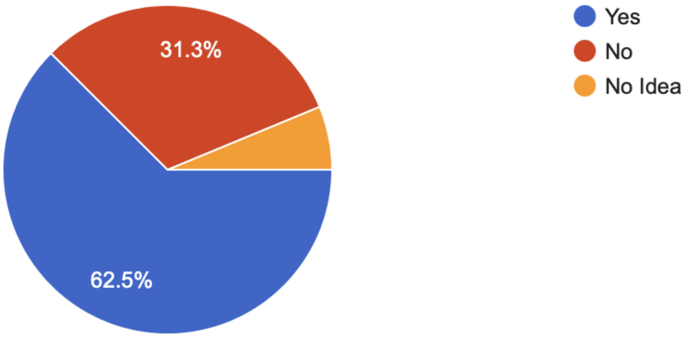
- Way of satisfying the daily electricity demand



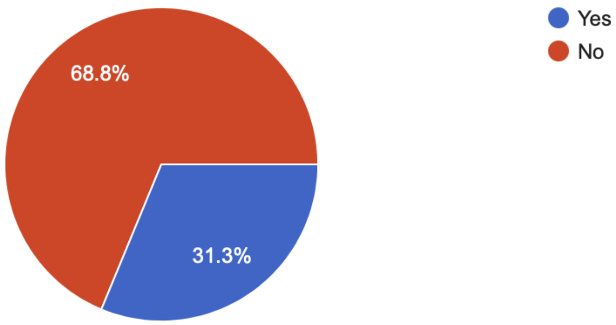
- Do you like to incorporate green energy resources such as Wind and Solar PV in catering to the demand?



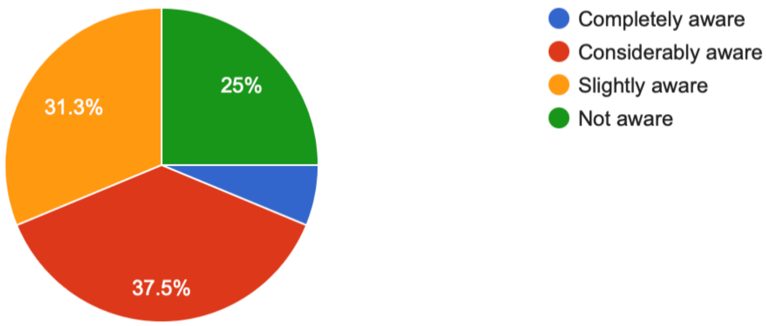
- Are there any critical/uninterruptible loads within the entity?



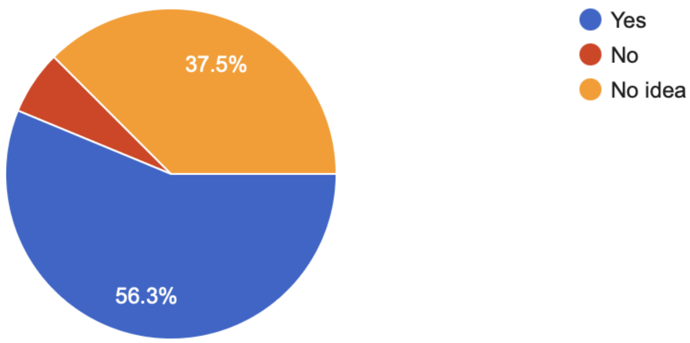
- Have you ever evaluated the overall loss related to a power interruption?



- Awareness of the concept of microgrids



- Do you think that establishing a local microgrid might have an impact on the ROI of the company? (If applicable)



7.5.4. Workshop Comments

Workshop 01 – Comments by CEB, LECO, PUCSL and DIMO

- It was suggested that it would be more beneficial if these microgrid platforms can be implemented to cater for the demand of critical loads such as hospitals, industrial zones etc. during a system emergency.
- Also, according to the comments given by participants, the “microgrid cluster” concept needs to be encouraged.

Discussion – Comments by SEA

- The SEA supported the proposal made on promoting microgrids in Sri Lanka to accommodate DR programs and the “neighbourhood microgrid” (community microgrid) concept was also considered to be a promising concept for the Sri Lankan context.

A Community Microgrid is a coordinated local grid area served by one or more distribution substations and supported by high penetrations of local renewables and other distributed energy resources (DER), such as energy storage and demand response.

The general comments provided by the representative of SEA are summarized below.

- Instead of conducting surveys to identify demand response opportunities in the country, it was suggested to declare a reward structure as a market offer, such as a kW-based demand saving reward and kWh-based demand saving reward for any customer, so that those who are interested can experiment with these offers and be benefited from these.
- When determining these reward structures, energy savings, delaying of capacity additions and delaying of grid augmentation cost needs to be considered.

7.5.5. Required Policies

Since microgrids are an emerging concept in the Sri Lankan context, new policies are required to be formulated in the following areas.

- **Establishing connections to the microgrid**
  When implementing a microgrid, both the grid-connected mode and islanded mode need to be considered. Therefore, to establish a grid connection, a proper policy should be formulated considering all the critical parameters such as voltage and frequency. Moreover, when promoting the "microgrid clusters" concept within the distribution network, corresponding policies need to be available for the interconnection of the microgrids.

- **Implementing smart devices to automate the load shifting process**

  Shifting loads from peak period to off-peak period is one of the techniques to implement demand response in a system. This load shifting process can be automated using smart devices and appliances. In order to promote these smart devices/ appliances, proper policies and regulations need to be formulated.

- **Establishing a proper regulatory framework to provide financial incentives to the parties who are interested in carrying out these microgrid projects.**
  For instance, low-interest loan schemes can be taken into consideration and the legal backup for them needs to be provided by the government through policies and regulations

- **Establishing a special purpose entity by the government for developing business models and providing technical assistance in forming microgrids or microgrid clusters.**

- **Providing legal assistance to promote the implementation of microgrids to accommodate demand response programs**
  Awareness programs, workshops and other related promotional campaigns can be considered as promotional measures. Further, legal backup is essential to carry out these programs in a proper way.

7.5.6. Investment cost calculation for different scale microgrids

The capacity cost to implement different scale microgrids are shown in the Table 58.

Table 58. The Capacity Cost of Adding Microgrids

Microgrid capacity	Item	Quantity	Unit price (USD)	Total price (USD)
40kW Solar Microgrid	Microgrid inverter 05 years warranty	2	9,100	18,200
	48V,100Ah Lithium-Ion batteries 05 years warranty	6	1,650	9,900
	Other available battery options *lead carbon battery* *12V, 200Ah 3400 Cycles @ 70% DOD* *03 years warranty*	*16*	*470*	*7,520*
	VRLA battery *12V, 200Ah 800 cycles @ 50% DOD* *01-year warranty*	*16*	*330*	*5,280*
			Grand total	28,100
175 kW Solar Microgrid	Microgrid central controller 05 years warranty Load: 160kW AC solar: 200kW AC	1	92,000	92,000
	Solar inverters 10 years warranty	2	6,750	13,500
	48V,100Ah Lithium-Ion batteries 05 years warranty	144	1,650	237,600
			Grand Total	343,100
1MW Solar Microgrid	Microgrid central controller 05 years warranty load: 200kW AC solar: 200kW AC	5	107,500	537,500
	Solar inverter 10 years warranty	10	6,750	67,500
	48V,100Ah Lithium-Ion batteries 05 years warranty 1MW x 4hrs during night peak	900	1,650	1,485,000
			Grand total	2,090,000

7.6. *Proposal 6*

Use HVAC (Heating, Ventilation, and Air Conditioning) for DR programs

7.6.1. Proposal 06-I: Shifting HVAC loads from evening and day peaks to off-peak hours

7.6.1.1. Introduction:

In this proposal, the Heating, Ventilation, and Air Conditioning (HVAC) system of Cinnamon Lakeside Hotel is analyzed to identify the potential DSM options that can be implemented. Thermal Energy Storage (TES) was selected as the DSM option to store cooling load during off-peak hours of the day when electricity is fairly cheap and used it during peak and day hours when the electricity is expensive. Technical viability and potential saving that can be achieved through TES in the hotel sector of Sri Lanka is further analyzed.

7.6.1.2. Methodology:

HVAC loads can be used in DR programs in the following ways.

Method-01: Shifting both peak and day cooling loads by using only Ice Storage Systems (Glycol Chillers)
Method-02: Shifting peak cooling load only by using Ice Storage Systems (Glycol Chillers)
Method-03: Shifting both peak and day cooling loads by using Chilled Water Storage Systems (Conventional Chillers)
Method-04: Shifting peak cooling load only by using Chilled Water Storage Systems (Conventional Chillers)
Method-05: Shifting both peak and day cooling loads by using both Ice Storage systems and Chilled Water Storage Systems
Method-06: Shifting peak cooling load only by using both Ice Storage System and Chilled Water Storage Systems

A Chilled Water Storage System (CWS) and an Ice Storage System (IS) are selected as possible load shifting methods for further analysis.

CWS is a TES using sensible heat of water to store energy during off-peak hours. Vertical cylinder tanks are the most common shape of tanks used for CWS and they can be located above ground, partially buried or completely buried depending on the location. Tank capacity depends on the amount of cooling load to be stored and temperature difference between stored chilled water and return water. Existing chillers can be used in this method.

Ice storage is a proven technology that reduces chiller size and shifts compressor load, condenser fan and pump loads from peak periods to off-peak periods, where electrical energy is less expensive.

The latent heat of fusion of water (phase change of water to ice or ice to water) is used in this process to store cooling load. Water is used as a phase change storage medium in order to take advantage of its higher storage capacity. In this method it is required to use glycol chillers and heat exchangers.

According to the following analysis, it is recommended that shifting only the peak cooling load to off-peak hours through the chilled water storage systems is the most economical solution for DR programs.
Further, it is verified by using the following case study:

7.6.1.3. Case study: (HVAC) system of Cinnamon Lakeside hotel

Average Load Profile of the Chiller Plant of Cinnamon Lakeside Hotel

Figure 27 shows the average load profile of the chiller at Cinnamon Lakeside Hotel. The average load profile of the chiller shows that there is a possibility of shifting cooling load to off peak hours as there is low demand in the off-peak hours compared to the peak and day hours.

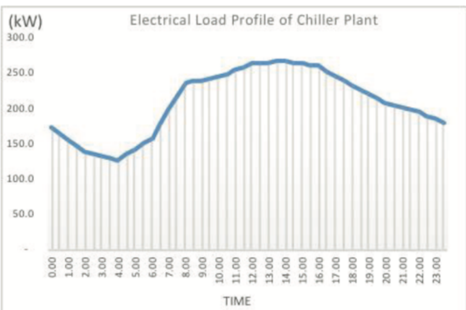


Figure 27. Electrical Load Profile of the Chiller Plant

Required storage volume for chilled water is found for different methods as follows:

Table 59. Required Storage Volume for Chilled Water

Methods	Total electrical energy consumption ($kW_e h$)			Storage volume (m^3)
	Chillers	Cooling towers	Total	
Method:01	6556.5	262.5	6,819.0	285.57
Method:02	6515.6	300.0	6815.6	58.95
Method:03	5,424.9	262.5	5,687.4	832.48
Method:04	5,109.2	300.0	5,409.2	171.86
Method:05	6,248.1	262.5	6,510.6	285.57
Method:06	5,279.2	300.0	5,579.2	58.95

The Table 59 summarises the six methods for comparison. Method 02 and Method 06 require lower storage volumes compared to other methods and Method 04 consumes the lowest energy compared to others. The required operating cost for chilled water storage for different methods are calculated as follows.

Table 60. The Operating Cost and Total Savings for Different Chilled Water Storage Methods

Methods	Storage capacity (TRh)	Chiller capacity (TR)	Cooling towers	Operating cost per day (LKR)	Total savings per year (LKR)
Method:01	6,403.7	**Glycol:**1,176.8	5 Nos. of 300 TR	60,007.00	5,802,448.00
Method:02	1,322.0	**Glycol:**436.3	2 Nos. of 300 TR	80,949.00	No savings
Method:03	6,403.7	**Conventional:**1,247.49	5 Nos. of 300 TR	50,049.00	9,437,068.00
Method:04	1,322.0	**Conventional:**448.9	2 Nos. of 300 TR	65,375.00	4,335,692.00
Method:05	6,403.7	**Glycol:**924.0 **Conventional:**241.2	5 Nos. of 300 TR	57,293.00	6,792,912.00
Method:06	1,322.0	**Glycol:**190.7 **Conventional:**390.9	5 Nos. of 300 TR	65,521.00	3,789,829.00

The investment costs for implementing different storages are calculated as follows:

Table 61. Total Investment Cost of the Chilled Water Storage System

Item	Capacity		Price (LKR)
Glycol Chiller	200	TR	13,500,000.00
Glycol Chiller	300	TR	22,000,000.00
Conventional Chiller	100	TR	7,500,000.00
Conventional Chiller	150	TR	10,500,000.00
Conventional Chiller	200	TR	13,000,000,00
Conventional Chiller	300	TR	18,000,000,00
Conventional Chiller	450	TR	26,000,000.00
Ice Storage	250	TRh	2,225,000.00
Chilled Water Storage	1	m^3	55,000.00
Heat Exchanger	200	RT	2,150,000.00
Heat Exchanger	420	RT	3,635,000.00
Cooling Tower	350	TR	2,200,000.00
Pumps	1		500,000.00
Pipe Work	1	m	10,000.00
Insulation	1	m^3	3,600.00
Total Investment Cost:			**90,278,600.00**

7.6.1.4. Benefits:

Benefits to the Industry:

In this analysis, total investment cost, savings per year, simple payback period, and the project IRR for the industry are calculated for different methods.

Table 62. Benefits to the Industry

Methods	Total Investment (MLKR)	Savings per year (MLKR)	Simple pay back (years)	Project IRR
Method:01	173.52	5.80	29.90	0.21%
Method:02	-	1.84	-	-
Method:03	106.46	9.44	11.28	6.78%
Method:04	10.53	4.34	2.43	40.76%
Method:05	146.48	6.79	21.56	1.52%
Method:06	30.70	3.79	8.10	10.78%

Utility Benefits:

In this analysis, total investment cost, savings per year, simple payback period, and the project IRR for the utility are calculated for different methods.

Table 63. Benefits to the Utility

Methods	Savings per year (MLKR)	Simple pay back (years)	Project IRR
Method:01	26,245,868.00	6.61	13.85%
Method:02	-	-	-
Method:03	28,444,737.00	3.74	26.05%
Method:04	11,855,498.00	0.89	112.50%
Method:05	26,245,868.00	5.58	16.86%
Method:06	11,401,561.00	2.69	36.67%

Other Benefits:

1. No additional chillers are required for method 04.
2. Shifting only peak cooling load to off-peak also requires less storage capacity compared to shifting both peak and day cooling loads.
3. Simple payback of 2.43 years and project IRR of 40.76% for method 04 are good financial indicators for a project. These figures will attract investors to shift the peak cooling load to off-peak hours using CWS system.
4. Ice storage systems will increase the temperature difference between return water and chilled water. It reduces the chilled water flow rate and pumps, and fan motor sizes. Further, reduce the energy consumption and investment in the HVAC system.

   Implementing the ice storage system at the initial stage of construction could give a high project IRR for method 06 which would attract investors.

5. Shifting only peak cooling load to off-peak hours at the selected hotel will reduce the utility peak demand by 205 kW. If this can be projected to 50 similar capacity buildings, the utility can achieve 10 MW peak shavings.

7.6.1.5. Solar Power in HVAC Load Shifting

According to the table 59, significant amount of power is required for load shifting in different methods. The required power can be fulfilled by using the grid power or otherwise their own generator sets. For this purpose, it is recommended to use rooftop solar power as it is available in daytime and customers have an opportunity to use low-cost grid-tied solar systems without using battery capacity because they need the power in only day hours. The following table represent the required total energy consumption and solar panel systems for different methods.

Table 64. The Required Grid-Tied Solar Power Systems

Assumption: Solar system can be operated in its full capacity for 4 hours per day.

Methods	**Total electrical energy consumption (kW_eh)**			Required solar capacity (kW)
	Chillers	**Cooling towers**	**Total**	
Method:01	6556.5	262.5	6,819.0	1704.75
Method:02	6515.6	300.0	6815.6	1703.9
Method:03	5,424.9	262.5	5,687.4	1421.85
Method:04	5,109.2	300.0	5,409.2	1352.3
Method:05	6,248.1	262.5	6,510.6	1627.65
Method:06	5,279.2	300.0	5,579.2	1394.8

It has been seen that approximately 1350 kW solar panel capacity is required for method 04 and according to the operating cost of table 60, approximately 65,375.00 LKR can be saved per day with the solar power.

7.6.1.6. Recommendations:

1. It is recommended that the shifting only the peak cooling load to off-peak hours through the chilled water storage systems is the most economical solution for DR programs.

2. Provide a credit payment or discount for their electricity bill in order to motivate the industrial/ commercial customers.

7.6.2. Proposal 06-II: Energy savings by increasing the space temperature through HVAC system

7.6.2.1. Introduction:

In this proposal, HVAC loads of commercial and industrial sites can be used to reduce the peak demand of the utilities by increasing the space temperature during peak hours. It is recommended to increase the space temperature by 1℃ at the peak time and 2.5% energy savings can be obtained according to the following analysis.

7.6.2.2. Case study: World Trade Center (WTC)

In this analysis, World Trade Center (WTC) is selected, and the energy-saving percentage was checked by increasing the space temperature of the site by 1℃.

WTC building parameters are identified as follows

Table 65. WTC Building Parameters

Building	WTC
Total AC area	65,000sqm
Occupancy	50%
Occupied AC area	52,000 sqm
Average cooling demand	1600 RT
Avg Chiller efficiency	0.54 kW/RT
Avg Airside Efficiency	0.4 kW/RT
Avg HVAC system (Overall) efficiency	1.1 kW/RT
Avg space temperature maintained	24℃
Chiller energy consumption per day	9,800 kWh/Day

Avg daily energy consumption of the building	52,000 kWh/Day
Avg Monthly enegery consumption of teh building	1,352,000 Kwh

7.6.2.3. Benefits:

Expected savings by increasing the space temperature by 1℃ are calculated as follows.

Table 66. The Expected Saving by Increasing the Space Temperature by 1℃

Expected sensible cooling load reduction/capacity unload	7 %
Expected efficiency improvement of the chiller by increasing the CHW set point by 1℃	2 %
Expected efficiency improvement of the airside for reducing the sensible cooling load	7% - 5%
Total expected energy saving per month	35,000 kwh
Expected % energy saving from the total energy consumption	**2.5%**

An increase in space temperature would result in about 2.5% energy saving from the total building energy and 6% saving from the HVAC system energy.

Note:

Overall energy saving depends on the efficiency of the HVAC system installed. However, the % saving may be in the same range.

7.6.2.4. Recommendations:

1. Encourage industrial/commercial customers to save energy by increasing the space temperature through the HVAC system.

2. Provide a credit payment or discount for their electricity bill in order to motivate the industrial/ commercial customers.

CHAPTER 8

8. Conclusion and Future Opportunities

8.1. *Conclusion*

In order to cope with the continuously increasing electric demand, governments are forced to invest in Renewable Energy (RE) sources due to the scarcity of fossil fuels (such as coal, gas, and oil), high costs associated with it, and emission of greenhouse gases. However, the stochastic nature of RE sources like wind and PV threaten the reliability and stability of the power system. Demand Response (DR) is an alternative solution to address the issues of economic constraints, integration challenges of RE, and dependency on fossil fuels. It is an aspect of Demand Side Management (DSM) that converts consumers' passive role to active by changing energy consumption patterns to reduce peak demand.

In reference to the Sri Lankan electricity network, it is seen that there are significant drawbacks in order to implement DR programs in the existing utilities. This study is mainly focused on analyzing and investigating opportunities and challenges when implementing such programs and the causes for the reluctance of consumers in changing their load requirements. In addition to that, possible and attractive win-win solutions are discussed in detail. All the solutions are presented as proposals and they are economically and technically analyzed based on the feedback provided by the experts at the workshops conducted with the collaboration of UoM, CEB, LECO, PUCSL, SEA, and some other service providers in Sri Lanka. Moreover, the surveys were conducted with the purpose of recognizing customer behavior and their perspective on the topics considered under the surveys. Based on the analyzed results of the surveys, motivation factors for the proposals were identified.

The new TOU tariff rates are introduced in the first proposal and according to the cost-benefit analysis, it will be a win-win solution as both the participant and utilities are benefited from that. The second proposal is mainly for EV customers, and they will be provided with a new TOU meter connection side by side with the existing block tariff meter connection. According to its cost-benefit analysis, it is also highly beneficial for customers and eventually, it would reduce the peak loads and that would be an advantage for the utilities also. The implementation of the hybrid solar PV systems was mainly discussed in the third proposal, and it was considered a timely option for the prevailing situation in the country. The need of revising solar tariffs annually was mainly taken into consideration with the third proposal. Also, the capability of large-scale battery storage systems to flatten the load curve was pointed out.

Moreover, for the fourth proposal, diesel generators in commercial and industrial buildings are taken into consideration for DR programs, and participants are motivated by providing proper incentives to implement synchronized arrangements and time of supply tariff. The next proposal on microgrids suggested encouraging the microgrid cluster in the distribution network while extending conventional microgrids to the most critical loads. The final proposal on HVAC suggested encouraging commercial and industrial customers to shift their cooling load from day or night peak hours to off peak hours. As a result of that, they can save significant amount of power, and also peak demand of the utility will be reduced dramatically. Finally, all the proposals are discussed in detail with technical barriers, economical constraints as well as required policies and regulations to implement the proposals in the existing utility grid.

8.2. Future Opportunities

This world is already witnessing that most governments and their utilities are particularly concerned about the challenges and opportunities of DR programs. This research is covered all the pivotal challenges in the existing utilities in Sri Lanka and all the opportunities such as available renewable and storage type resources, spinning and non-spinning reserves, and all other possible resources which can directly or indirectly connect with the DR programs. The recommendations are provided under each, and every objective and they should be investigated properly by the utilities in the future. In order to achieve the first objective, a study should be carried out to identify the available capacity of DR resources in Sri Lanka. For the second objective, it is recommended that a study should be carried out to identify the available capacities of spinning and non-spinning reserves in Sri Lanka. For the third proposal, it is recommended that smart appliances should be promoted among the participants so that they have an opportunity to reduce their energy consumption at peak hours or in emergencies by reducing their energy consumption. In the last objective, the utilities should carry out a study to identify the possibilities of expediting the execution of storage type resources such as battery storage and pumped storage in Sri Lanka.

In addition to the above recommendations, all the proposals should be taken into consideration by the utilities in order to reduce the peak demand. They have an opportunity to check the technical barriers, economical constraints as well as required policies and regulations before implementing the proposed DSM programs.

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Appendix I- Workshops

With the purpose of collecting feedback and gathering information on the policies required to implement the previously described proposals, A workshop and a discussion were conducted with the collaboration of PUCSL. A workshop was held in person at the PUCSL premises on 5th of April 2022 and the participants were representatives from Ceylon Electricity Board (CEB), Lanka Electricity Company (Pvt) Ltd (LECO) and Diesel & Motor Engineering PLC (DIMO) apart from the members of PUCSL and the research team of University of Moratuwa supervised by Prof. KTMU Hemapala and Prof. Anura Wijayapala. Another discussion was held vitually via an online platform between the Sustainable Energy Authority and the UOM research team on 18th April 2022. The participants of the corresponding authorities for the two workshops are summarized below.

Workshop- Participants List

Organization / Company	**No of Participants**
Project Members from UoM	07
PUCSL	06
CEB	06
LECO	06
Solar Power Producers (eg: First Energy, Genso Power Technologies etc)	02
Diesel Generator Suppliers (eg: DIMO)	02
EV companies (eg: VEGA)	01
Total no of participants	**30**

Discussion with SEA- Participant List

Organization / Company	No of Participants
Project Members from UoM	07
SEA	02

Appendix II- Survey Questionaries

Survey on TOU Tariff

Existing Tariff rates of CEB

Industrial, General, Hotel, Government Purpose

Customer Category- 1

This rate applies to supplies provided and metered at 400/230 Volt nominal at each individual point of supply when the contract demand is less than or equal to 42 kVA.

Customer Category- 2

This rate applies to supplies delivered and metered at 400/230 Volt nominal at each individual point of supply if the contract demand exceeds 42 kVA.

Customer Category- 3

This tariff applies to supplies delivered and metered at 11,000 Volt nominal and above at each individual point of supply.

Table 67. Industrial Purpose Tariff

Customer Category	Consumption per month (kWh)	Time Intervals	Energy Charge (LKR/kWh)	Fixed Charge (LKR/month)	Maximum Demand Charge per Month (LKR/kVA)
I-1	<301		10.80	600.00	
	>300		12.20		
I-2		Peak (18.30-22.30)	20.50	3000.00	1100.00
		Day (5.30-18.30)	11.00		
		Off-Peak (22.30-5.30)	6.85		
I-3		Peak (18.30-22.30)	23.50	3000.00	1100.00
		Day (5.30-18.30)	10.25		
		Off-Peak (22.30-5.30)	5.90		

Table 68. General Purpose Tariff

Customer Category	Consumption per month (kWh)	Time Intervals	Energy Charge (LKR/kWh)	Fixed Charge (LKR/month)	Maximum Demand Charge per Month (LKR/kVA)
GP-1	<301		18.30	240.00	
	>300		22.85		
GP-2		Peak (18.30-22.30)	26.60	3000.00	1100.00
		Day (5.30-18.30)	21.80		
		Off-Peak (22.30-5.30)	15.40		
GP-3		Peak (18.30-22.30)	25.50	3000.00	1000.00
		Day (5.30-18.30)	20.70		
		Off-Peak (22.30-5.30)	14.35		

Table 69. Hotel Purpose Tariff

Customer Category	Consumption per month (kWh)	Time Intervals	Energy Charge (LKR/kWh)	Fixed Charge (LKR/month)	Maximum Demand Charge per Month (LKR/kVA)
H-1			21.50	600.00	
H-2		Peak (18.30-22.30)	23.50	3000.00	1100.00
		Day (5.30-18.30)	14.65		
		Off-Peak (22.30-5.30)	9.80		
H-3		Peak (18.30-22.30)	22.50	3000.00	1000.00
		Day (5.30-18.30)	13.70		
		Off-Peak (22.30-5.30)	8.80		

Table 70. Government Purpose Tariff

Customer Category	Consumption per month (kWh)	Time Intervals	Energy Charge (LKR/kWh)	Fixed Charge (LKR/month)	Maximum Demand Charge per Month (LKR/kVA)
GV-1			14.65	600.00	
GV-2			14.55	3000.00	1100.00
GV-3			14.35	3000.00	1000.00

Domestic, Religious Purpose

Customer Category- 1

If the consumption is between 0-60 kWh per month the following tariffs will be applicable

Customer Category- 2

If the consumption is above 60 kWh per month the following tariffs will be applicable

Customer Category- 3

Time of Use Electricity Tariff for Domestic Consumers

TOU tariff has been introduced in Sri Lanka in 2015 for the consumers who had 3 phase connections and consumptions of 30A or above. Those customers had the capability of shifting to the optional TOU tariff. In May 2017 the same tariff was extended to single-phase domestic consumers as an optional tariff. The existing TOU tariff for domestic consumers is stated in the following table.

Table 71. Domestic Purpose Tariff

Customer Category	Consumption per month (kWh)	Time Intervals	Unit Charge (Rs./kWh)	Fixed Charge (LKR/month)
D-1	0-30		2.50	30.00
	31-60		4.85	60.00
D-2	0-60		7.85	N/A
	61-90		10.00	90.00
	91-120		27.75	480.00
	121-180		32.00	480.00
	>180		45.00	540.00
D-3		Peak (18.30-22.30)	54.00	540.00

		Day (5.30-18.30)	25.00	
		Off-Peak (22.30-5.30)	13.00	

Table 72. Religious Purpose Tariff

Consumption per month (kWh)	Energy Charge (LKR/kWh)	Fixed Charge (LKR/month)
0-30	1.90	30.00
31-90	2.80	60.00
91-120	6.75	180.00
121-180	7.50	180.00
>180	9.40	240.00

The existing TOU tariff in Sri Lanka for domestic customers

TOU tariff has been introduced in Sri Lanka in 2015 for the consumers who had 3 phase connections and consumptions of 30A or above. Those customers had the capability of shifting to the optional TOU tariff. In May 2017 the same tariff was extended to single-phase domestic consumers as an optional tariff.

The total number of domestic consumers in Sri Lanka is more than 5.7 Million. It is around 87% of the total consumers in the country. But the number of customers who have shifted to the existing TOU tariff is around 500. This indicates that the existing TOU tariff is not attractive among domestic consumers. As there is low response from the consumers, the desired outcomes of introducing the TOU tariffs have not been realized.

Requirement

The night-time peak demand drives the sector investments and hence has become a major target area for Demand Side Management programs aimed at energy conservation and efficiency improvement. Time Of Use (TOU) Tariffs are perceived as a major tool to curb the peak demand.

Further, with the growth of the usage of electrical vehicles, there is a tendency of increasing the peak demand because of the charging load. The introduction of the TOU tariff will shift the charging load to off-peak hours and the domestic consumers will get the opportunity to charge their vehicles at a cheaper rate. If the charging of electric vehicles at the off-peak hours can be encouraged, the valley in the load profile at the off-peak hours can also be filled while clipping the peak demand.

With those intentions, an optional TOU Tariff should be introduced to domestic customers of Sri Lanka in 2022 because the introduced TOU Tariff is not attractive to domestic consumers. The effectiveness of the existing TOU tariff for domestic consumers will be analysed in this study. Further, an effective TOU tariff for domestic consumers will be proposed.

QUESTIONNAIRE FOR LOAD SURVEY-TOU TARIFF

[1] Consumer Category: Choose an item.

(Domestic Purpose, General Purpose, Hotel Purpose, Industrial Purpose, Religious Purpose, Government Purpose)

[2] Please select the option(s) that corresponds to your choice(s)

- What is your electricity tariff method?

  ☐Flat tariff ☐TOU tariff ☐Other

- Do you think that the current TOU tariff rates for electricity are fair and equitable?

  If not, what suggestions you would give the CEB

  ☐Give the institutions a further subsidy

  ☐Give the small and medium income earning institutions a subsidy

  ☐Increase the rates for the higher income earning institutions

  ☐Reduce the inefficiencies and losses incurred by the CEB

  ☐Build more low-cost power plants

  ☐Different tariffs to suit different income levels

  ☐Others

3. Did you feel any specific season when the electricity demand is higher?

   If yes, what is that period?.........................

- What are the higher capacity loads in your home/industry?

  …………………………………………

- Are you using any alternative energy source against electricity load shedding?

  ☐Solar ☐Wind ☐Diesel generator ☐UPS/Battery ☐Other

[3] If you are using generators, please answer the following questions

- What type of generator you are using?

  ☐Run by Petrol ☐Run by diesel ☐Run by gas

- What is the maximum power potential of the generator?

  …………………………………….

- What was the price of the generator?

  …………………………………….

- When did you buy the generator?

  ……………………………………...

- If you are using a petrol generator, how many liters of oil are consumed in one hour?

  ……………………………………

- If you are using a diesel generator, how many liters of diesel is consumed in one hour?

  ……………………………………

- What are the environmental threats of generators?

☐Generate Smoke ☐Generate noise ☐Both

[4] If you have installed a solar energy system, please answer the following questions

- What is the power capacity of the solar energy system?

  ………………………………….

- What was the installation cost of solar energy panels?

  …………………………………

- In which month do you consume the higher amount of electricity.

  ……………………………….

- Monthly electricity consumption in units for the previous 14 months:

  November 2020……………………… December 2020……………………...

  January 2021………………………… February 2021 ………………………

  March 2021…………………………... April 2021…………………………...

  May 2021……………………………...June 2021……………………………

  July 2021………………………………August 2021…………………………

  September 2021………………………..October 2021………………………..

  November 2021……………………… December 2021……………………...

[5] If you are using a UPS, then please answer the following questions

- What was the installation cost of UPS including the battery? Please specify.

  …………………………………..

- For how many hours the UPS provides the backup facility.

  ………………………………….

- What is the normal life of UPS? Please specify.

  …………………………………..

Survey on Electric Vehicles

CONSUMER SURVEY QUESTIONNAIRE

1. Consumer name:
2. Electricity account number:

Section A – Details of the Electric Vehicle

3. Number of Electric Vehicles (EV) in use
4. Details of each EV in use
    a. Model (Please select)
        i. Nissan Leaf
        ii. BMW i3
        iii. Mitsubishi MiEV
        iv. Hyundai ….
    b. Year of manufacture
    c. Year of purchase
    d. Current Mileage

Section B – Electricity consumption of the vehicle

5. Approximate frequency of charging the vehicle (Please select)
    a. Once a day
    b. Once in two days
    c. 2 -3 times a week
    d. Once a week

6. Current typical charging period of the day
    a. 10.30 pm to 05.30 am
    b. 05.30 am to 6.30 pm
    c. 6.30 pm to 10.30 pm
7. The average time taken to fully charge the battery in the home charger (in hours)

8. How often do you use fast charging? Regularly, rarely, never (Please select)

Section C – Consumer satisfaction

9. Are you aware of the Time of Use (TOU) tariff available to domestic consumers? Yes / No

   If Yes, are you using it? Yes / No
   If "No", what is the reason for not using it (Please select)
   - Too expensive peak tariff
   - Too high day time tariff
   - Too high off-peak tariff
   - All of the above.

10. If the TOU tariff is agreeable, are you willing to charge your EV during the off-peak period? Yes / No

Section D – EVs and Demand Response programs

Demand response (DR) is the voluntary reduction or shift of electricity use by customers, which can help to keep a power grid stable by balancing its supply and demand of electricity.

11. If you are invited to participate in a DR program as an EV owner, are you willing to contribute?

    a. Yes b. No

12. Among the following, what do you see as the best solutions to promote EVs users to participate in DR programs? (Select all that apply)

    a. Introducing an affordable tariff.
    b. Promoting "Smart charging", the intelligent charging of electric car batteries to charge EVs during periods when supply from renewable energies is at its highest, thereby reducing the demand for fossil fuel-powered plants.
    c. Introducing "Workplace charging", a possible solution to managing high volumes of the intermittent renewable generation coming online during peak daytime hours, providing much-needed stability to the grid.
    d. Introducing more charging stations, so that the customers can charge their batteries frequently even during the day.

What do you think of the following statements of utilities' role for using EV batteries in DR programs?

	Strongly agree	Agree	I don't know	Disagree	Strongly disagree
1. It's better if the utilities can bring about affordable electricity rates for charging the battery if used in a DR program.					
2. More customer awareness on DR programs and tariffs for EVs will attract new buyers and will encourage existing customers to participate in DR programs.					
3. EV usage in Sri Lanka can be increased by lowering capital investment on charging infrastructure, introducing more charging stations, and providing possible opportunities for EV-related repairs and maintenance which will ultimately increase the number of vehicles in DR programs.					

Survey on Microgrid

MICROGRID – QUESTIONNAIRE

1. Provide an overview of the residential/ commercial entity.
2. How do you satisfy your daily electricity demand? Is any other generating source other than the grid supply?
3. Do you like to incorporate green energy resources such as solar PV in catering to the demand?
4. What are the barriers to incorporating green energy resources such as solar PV according to your context?
5. What is the average electricity bill amount considering the past four months?
6. Are there any critical/ uninterruptible loads within the entity?
7. If yes, please state.
8. Is it important for you to maintain an uninterrupted power supply throughout the day?
9. Have you ever evaluated the overall loss related to a power interruption?
10. Do you like to invest in mitigating power interruptions while integrating renewable generation effectively?
11. Do you aware of the Microgrid concept?
12. Do you think that establishing a local microgrid might have an impact on the ROI of the company? (If applicable)

Survey on Diesel Generators

DIESEL GENERATORS – QUESTIONNAIRE

A. Customer Information

1. Type of organization/ institution (Please select)

   Private residence, Industry, Hospital, Hotel, University, shopping mall, Other (Please specify) ....

2. Existing tariff category (Please select)

   a. Domestic
   b. TOU for Domestic
   c. General Purpose (GP1, GP2, GP3)
   d. Hotel (H1, H2, H3)
   e. Industrial (I1, I2, I3)
   f. Government (GV 1, GV 2, GV3)

B. Information on Diesel Generators (DGs)

3. Number of DGs in use ………………...
4. Power ratings of diesel generators in use

   a. 0 - 100 kVA
   b. 100 – 350 kVA
   c. 350 – 1000 kVA
   d. > 1000 kVA

5. Basis of application

   a. Prime power rated generator
   b. Continuous power rated generator
   c. Standby power rated generator
   d. Peak shaving generator

6. Annual usage of DGs expressed in hours per year (hrs/yr) ………………………
7. When do you use DGs?

   a. Emergency backup power during outages

b. During peak hours if using TOU tariff

c. Daring grid failures

d. Other off-grid applications (Please specify)

………………………………………………………………………………
………………………………………………………………………………

8. Reason for the use of DGs

a. To get an uninterrupted power supply

b. Cost savings in electricity bills

c. Other (Please specify)

………………………………………………………………………………
………………………………………………………………………………

9. Costs involved per annum

a. Initial investment (Rs) …………………….

b. Fuel cost (Rs/kWh) …………………….

c. Operation and maintenance costs (Rs/kWh) …………………….

10. Noise control method

a. Acoustic barriers and insulation

b. Isolation mounts

c. Inlet and outlet air baffles

d. Exhaust silencers

e. Other (Please specify)

………………………………………………………………………………
………………………………………………………………………………

C. Customer Satisfaction

11. Are you satisfied with the use of DGs for your needs?

………………………………………………………………………………………
………………………………………………………………………………………

12. If not, please specify the reason

……………………………………………………………………………………………
……………………………………………………………………………………………

D. Customer Opinions on DGs and Demand Response Programs

Demand Response (DR) programs for Diesel Generators are the programs where customers agree to reduce the electricity usage during system emergencies or peak hours by a predetermined level by shifting their loads from the utility grid to the on-site diesel generator sets. The participants receive credits on their electricity bills in exchange for reducing the demand during critical power system conditions.

13. Would you like to participate in demand response programs with your DGs?
    a. Yes
    b. No
14. If not, please state the reasons

……………………………………………………………………………………………
……………………………………………………………………………………………

Survey on Roof-Top Solar PV Generation

ROOF TOP SOLAR PV GENERATION – QUESTIONNAIRE

1.0 Customer details

I. Customer type – (*Please select*)

[1] Industrial purpose

[2] General purpose

[3] Hotel purpose

[4] Government purpose

[5] Domestic purpose

[6] Religious purpose

II. Billing scheme – (*Please select*)

[1] Net metering

[2] Net accounting

[3] Net plus

III. Address -

IV. District –

2.0 Solar rooftop system details

I. Solar plant's rated AC output (kW) –

II. Maximum solar power generation on a sunny day (kW) –

III. The average number of units exported to the grid on a sunny day (kWh) -

IV. The average number of units consumed per month (kWh) -

1. Present consumption -
2. Consumption at the time of installing panels –

3.

3.0 Customer satisfaction

I. How aware are you of your billing scheme?

[1] Very aware
[2] Slightly aware
[3] Neutral
[4] Slightly unaware
[5] Very unaware

II. How satisfied are you with your electricity bill savings after installing your solar power system?

[1] Very satisfied
[2] Moderately satisfied
[3] No opinion either way
[4] Moderately dissatisfied
[5] Very dissatisfied

III. Do you have any suggestions on the existing billing scheme?

[1] Yes

[2] No

[3] Comment –

IV. Do you purposely use your electrical appliances more when panels are generating power / during the daytime?

[1] Yes

[2] No

[3] No idea

[4] Comment –

V. Do you like to participate in the Time of Use (TOU) tariff with your existing solar rooftop system? or have you ever participated in a TOU tariff?

[1] Comment –

4.0 Do you own a residential solar battery system?

[1] Yes
[2] no

(Following section is only for solar battery system owners)

I. How many solar power systems do you have?

[1] more than one
[2] only one

II. In which year did you install your battery system?

III. Who is the manufacturer of your battery system?

[1] Enter the name of the battery manufacturer or brand

IV. What is the capacity of your battery storage?

V. What is the warranty period for your battery system?

VI. How satisfied or dissatisfied were you with your battery installation?

[1] Very satisfied
[2] Moderately satisfied
[3] No opinion either way
[4] Moderately dissatisfied
[5] Very dissatisfied

VII. How often do you check your battery system's performance?

[1] About once a week
[2] About once a month
[3] About once a year
[4] Longer than once a year
[5] We have never checked our system performances

VIII. Does the way appliances or electricity used at your premises change after installing the battery system?

[1] Yes
[2] No
[3] Don't know

IX. When do you charge your batteries?

[1] During the day, with excess solar generation
[2] During the off-peak period, with grid power
[3] Others- comment

X. When do you use/ discharge your batteries?

[1] During day
[2] During night
[3] Others – comment

XI. Would you consider allowing an electricity utility to operate your battery system for a financial incentive?

[1] Yes
[2] No

XII. If no, why wouldn't you consider allowing an electricity utility to operate your battery?

[1] I don't want to give over the operation of my battery system to anyone else
[2] I don't believe the incentives/ payments would be enough
[3] Others – comment

4.0 Do you own a home solar battery system?

[3] Yes
[4] no

(The following section is only for non-solar battery system owners)

I. How important is it for you to have a battery bank to use in the absence of grid power?

[1] Very important
[2] Slightly important
[3] Neutral
[4] Low importance
[5] Not at all importance

II. Have you invested in solar batteries previously?

[1] Yes
[2] No

III. Do you think you will invest in batteries in the next few years after the replacement of the existing inverter?

[1] Not sure
[2] Definitely yes
[3] Definitely no
[4] Currently in the process of purchasing and installing a battery system

IV. What are the current hindrances in installing batteries at your premises?

[1] Cost
[2] Difficulty in installation
[3] Insufficient knowledge
[4] Insufficient knowledge of system updates
[5] Distrust in renewable energy
[6] Distrust in utility
[7] Other - comment

V. How aware are you of incentives and benefits you can gain with your solar rooftop system?

[1] Very unaware
[2] Slightly aware
[3] Neutral
[4] Slightly aware
[5] Very aware