PUBLIC UTILITIES COMMISSION OF SRI LANKA

Study Report

On

Use of Battery Energy Storage Systems

For

Peak Shaving during the Time of National Night Peak

By

Reducing the Impact from Lighting Load

"Assembly Bill 2514 introduced California to energy storage in a big way. The CPUC Energy Storage decision resulting from this bill has directed the three Investor Owned Utilities to procure and deploy 1.325 GW of energy storage by 2020."

" To reject a technology by focusing only on its current cost rather than its future potential creates an artificial barrier for the technology "

LICENSING DIVISION

11/20/2015

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1 Introduction

In a typical weekday the night peak demand at generators exceeds 2050 MW while the base load remains at about 1000MW. The day peak is touching 1800 MW. This sharp night peak lasting about 3 hours exert enormous burden on utility in terms of cost as they have to keep the available system capacity to cater this short period demand, requiring capacity additions to the system.

It can be seen that, especially the domestic lighting loads are the main component responsible for said night peak. Looking at our national load curve, we can realize the provision for “peak shaving” and “valley filling” application via energy storage. Note that the domestic lighting load can only be shifted slightly in time domain with the application like day light saving. You might not remember that we are already GMT+5.30!. How can we reduce this domestic load to ease up the peaking generators and future capacity additions to the system?

One method is to reduce the perceived demand by generators. During off Peak the distributed energy storages installed at the premises of distribution transformers (Grid Edge storage) can be charged and discharged during the peak time, hence reducing the peak demand on generators. Further, storage at grid edge provides numerous fringe benefits like Power quality improvements and outage reduction.

These kind of small scale distributed energy storage systems could me easily managed by the distribution licensees reaping the monetary benefits gained by reducing the coincident peak demand and the energy arbitrage. In addition Distribution Licensees could reduce their SAIFI, and SAIDI indices. It is important to note that world trend is towards distributed energy resources and decentralized systems.

This report investigates the possibility of implementing this grid edge application through Distribution Licensees by analyzing the load curves, technologies, costs and benefits.

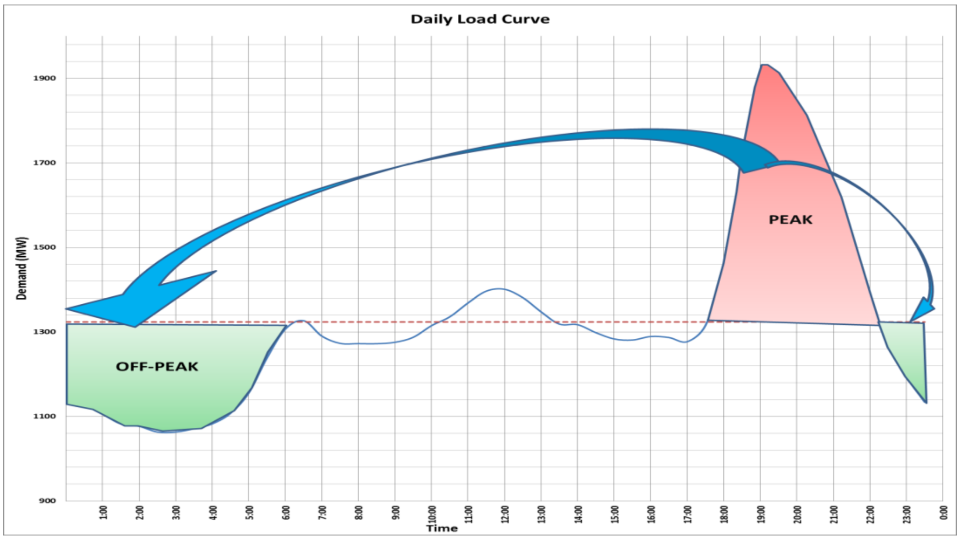

Figure 1-1 : Peak Shaving and Valley Filling

2 Analysis on Daily Load Profile

By utilizing averages of half hourly demand (generation) data from July/2015 to September / 2015 following load curves were constructed. It is clearly seen that the base load requirement is 1000MW for working day and for Sundays as well.

Further it is important to note that there is approximately 100MW of capacity contribution to night peak by the mini hydro plants operated by independent power producers. This was calculated using the data from June/2015 to September 2015 provided by CEB in their daily generation report. Therefore when constructing the load curves, a 100MW of fixed demand inserted throughout the day.

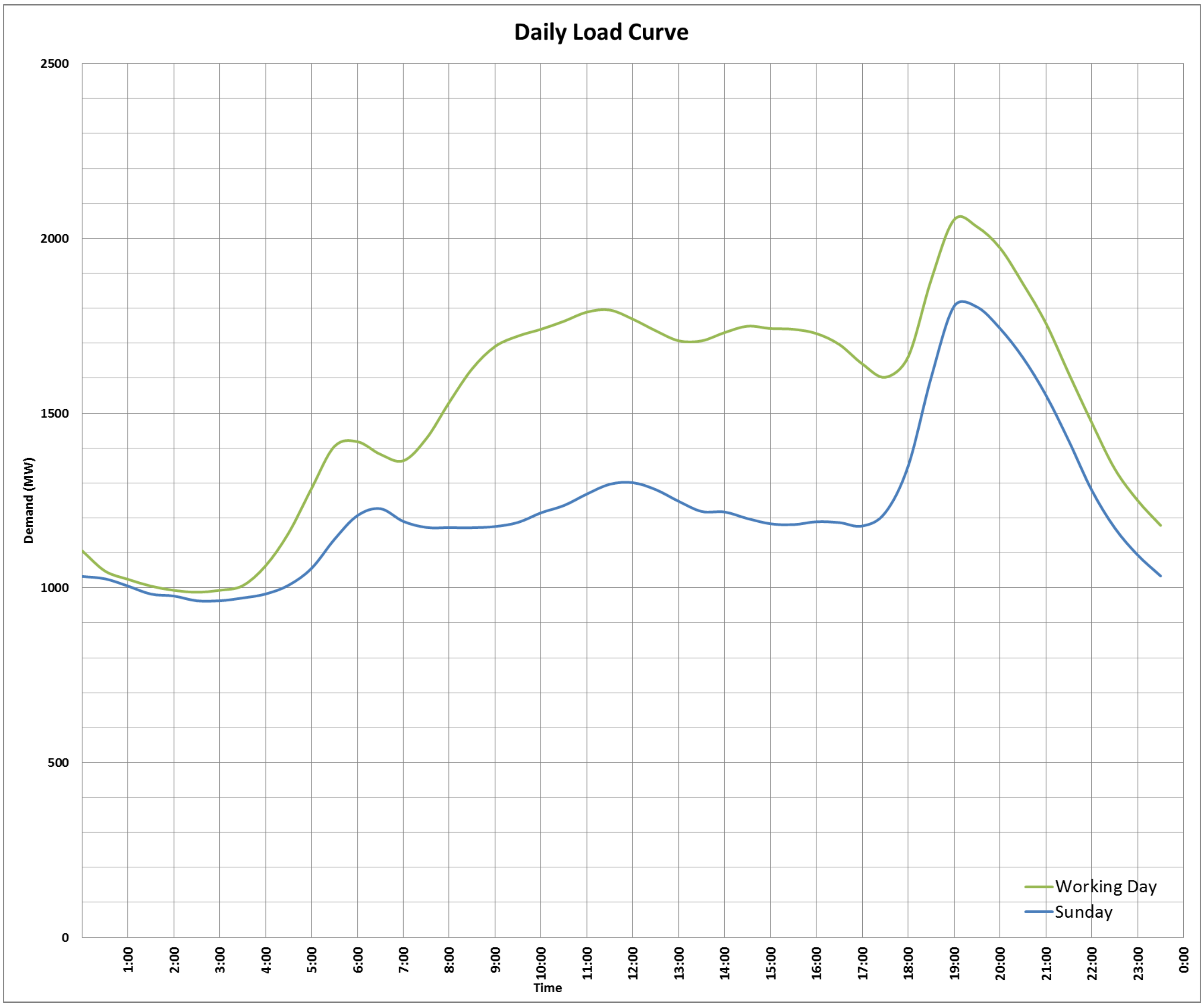

Figure 2-1 : Daily Load Curve

When analyzing the load curve with respect to the distribution substations the pattern of night peak during the Sundays can be considered since it is least polluted with demand from other categories specially the general purpose loads.

Since this study is on shaving the night peak by reducing the domestic demand (perceived), the night peak pattern of the Sunday is a good approximation for the night peak pattern that prevail at the distribution transformer.

3 The Distribution Transformer

According to the MV development plans of DLs they have employed distribution transformers with capacities from 160 kVA to 1MVA, and with loading criteria of 80% of the transformer capacity. Further it is assumed that system loss of MV distribution Network is 2% from distribution input.

The Sustainable Energy Authority has conducted a load research program (www.energy.gov.lk/pdf/Report.pdf) using sample of households connected to several distribution transformers. The loading pattern is given in the following graph. The curve with high demand is representing the loading pattern of distribution transformer while the curve below to that is represents the demand pattern by households.

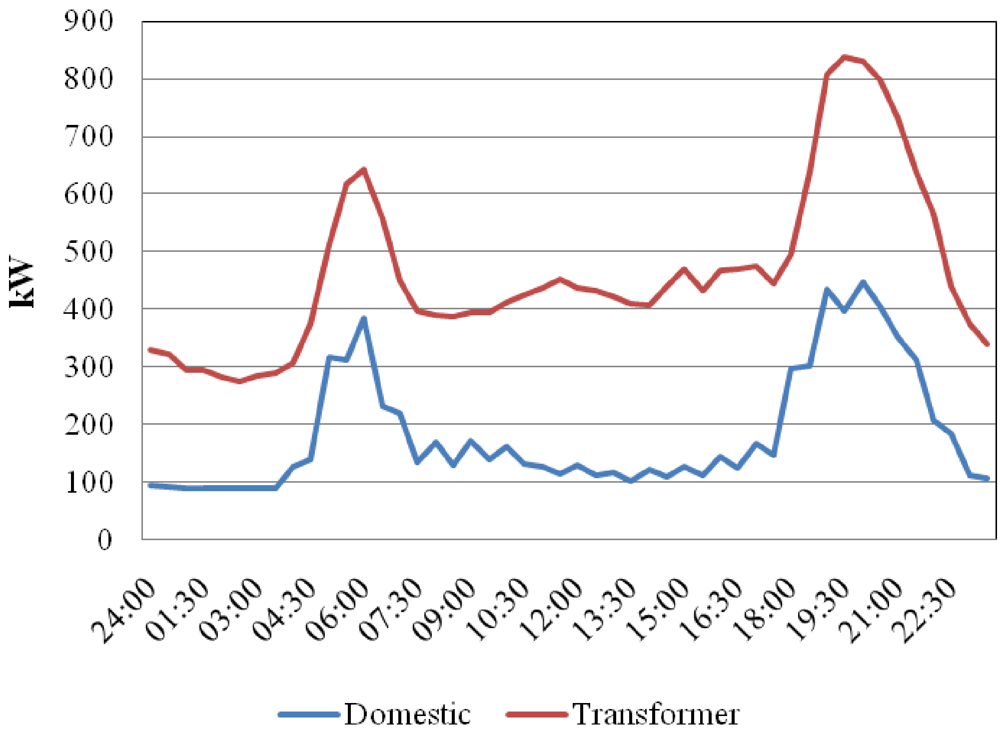

Figure 3-1: Load Curve at Distribution Transformer

In above graph it can be observed that morning and evening peak of domestic demands are in line with the respective peak of distribution transformers. Further these peaks are coinciding with the peaks in national daily load curve.

4 Household energy Consumption

Share of energy by households at evening Peak (Source: www.energy.gov.lk/pdf/Report.pdf). Note that lighting, TVs and refrigerators loads account for 44%, 21% and 17% respectively.

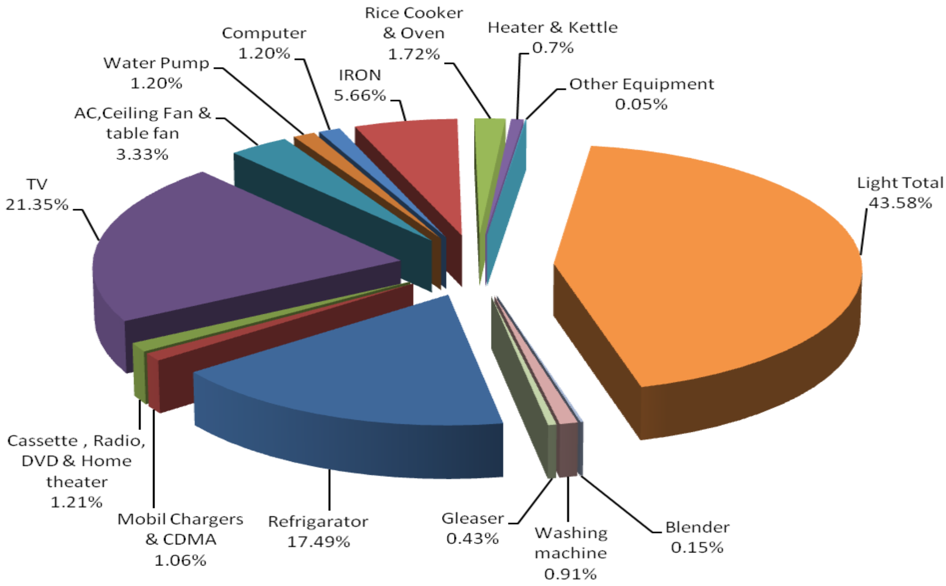

Figure 4-1: Share of Energy by Households at Peak

Since the loading of the refrigerators remain more or less constant throughout, it is the demand from lighting and television sets are the responsible loads for night peak generated by households while lighting and IRON loads are the major components of morning peak generated by households.

Following chart depicts the total annual energy consumption by each main tariff categories and it is clear that consumption by households account for 37%. The 5.115 million domestic consumer accounts (households) contribute a major portion of this national peak. For example if we assume 60W consumption by TVs, then the approximate total demand by TVs would be,

[60W of power consumption of a TV] x [5.115 Million Households] = 306 MW at national peak time.

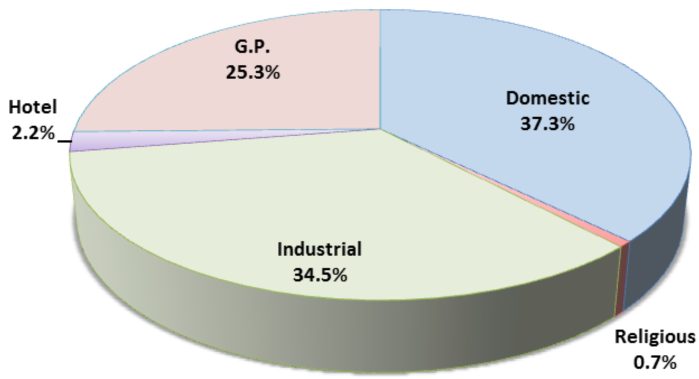

Figure 4-2 : Category wise Energy Consumption

In general it can be concluded that this national peaks can be effectively addressed if the peaks occurring at distribution level (distribution transformers) managed by peak shaving solution.

5 Battery Energy Storage System (BESS)

Why BESS over other storage technologies – Since we are looking at the kW level distributed energy storage at distribution transformer level, the footprint of the BESS has to be small. Further the storage must not have restrictions on geographical locations that it could be plugged in. Storage technologies like Pumped hydro storage (PHS) and Compressed air energy storage (CAES) are only suitable for limited number of locations, considering water and siting-related restrictions and transmission constraints. Energy and power densities of some technologies are as follows (IEC,2011).

Technology	Power Density (W/l)	Energy Density (Wh/l)
PHS	0.1 - 0.2	0.2 - 2
CAES	0.2 -0.6	2 - 6
Li-ion Battery	1300 - 10000	200 - 400
Lead Acid Battery	90 - 700	50 - 80
NaS	120 - 160	150 - 300

Table 5-1 : Power Density and Energy Density of Storage Technologies

Accordingly battery energy storage solutions are offering high energy and power densities that are suitable for utilizing at distribution transformer level. The available space at the distribution transformer setup can be used to sit the BESS. The night peak we are concerned is about 4 hours maximum and hence the discharging time required for a particular BESS is less than 4 hours. Further the rated apparent power of distribution transformers are in the range of 160 kVA, 400kVA up to 1 MVA (for rural, urban and metropolitan respectively). Therefore BESS only needs to supply a part of that capacity during maximum of 4 hours of peak time. Following figure illustrates the places different technologies have in the space having the power, energy and discharge time as dimensions (IEC 2011).

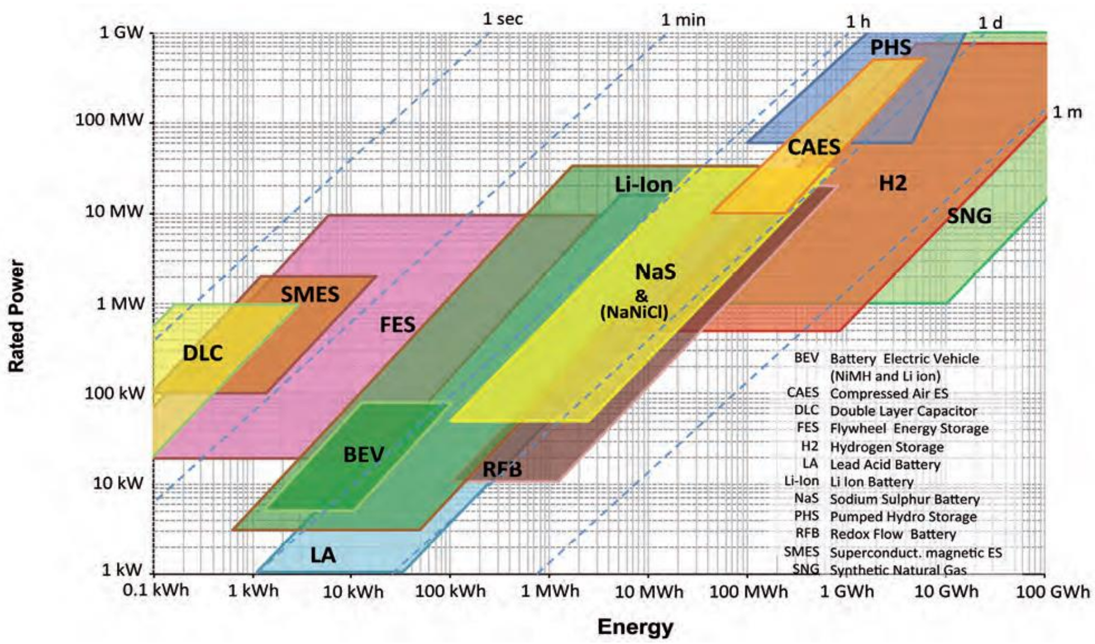

Figure 5-1 : Power, Energy and Discharge Time of Energy Storage Technologies

According to previous graph, it can be seen that BESS technologies like Li-Ion, NaS are equipped with the parameters that we are concerned. Li-ion has both a high energy density and high power density, which explains the broad range of applications where Li-ion is currently deployed.

5.1 Characteristics of a Battery Energy Storage System

Round-trip Efficiency – Indicates the amount of usable energy that can be discharged from a storage system relative to the amount of energy that was put in. This accounts for the energy lost during each charge and discharge cycle. Typical values range from 60% to 95%.

Response Time – Amount of time required for a storage system to go from standby mode to full output. This performance criterion is one important indicator of the flexibility of storage as a grid resource relative to alternatives. Most storage systems have a rapid response time, typically less than a minute. Pumped hydroelectric storage and compressed air energy storage tend to be relatively slow as compared with batteries.

Ramp Rate – Ramp rate indicates the rate at which storage power can be varied. A ramp rate for batteries can be faster than 100% variation in one to a few seconds. The ramp rate for pumped hydroelectric storage and for compressed air energy storage is similar to the ramp rate of conventional generation facilities.

Energy Retention or Standby Losses – Energy retention time is the amount of time that a storage system retains its charge. The concept of energy retention is important because of the tendency for some types of storage to self-discharge or to dissipate energy while the storage is not in use.

Energy Density – The amount of energy that can be stored for a given amount of area, volume, or mass. This criterion is important in applications where area is a limiting factor, for example, in an urban substation where space could be a limiting constraint to site energy storage.

Power Density – Power density indicates the amount of power that can be delivered for a given amount of area, volume, or mass. In addition, like energy density, power density varies significantly among storage types. Again, power density is important if area and/or space are limited or if weight is an issue.

Safety – Safety is related to both electricity and to the specific materials and processes involved in storage systems. The chemicals and reactions used in batteries can pose safety or fire concerns.

Life span - measured in cycles.

Depth of discharge (DoD) - Refers to the amount of the battery's capacity that has been utilised. It is expressed as a percentage of the battery's full energy capacity. The deeper a battery's discharge, the shorter the expected life time. Deep cycle is often defined as 80% or more DoD.

Ambient temperature - Has an important effect on battery performance. High ambient temperatures cause internal reactions to occur, and many batteries lose capacity more rapidly in hotter climates.

Following figure illustrates the important considerations for battery selection (Source : IRENA 2015).

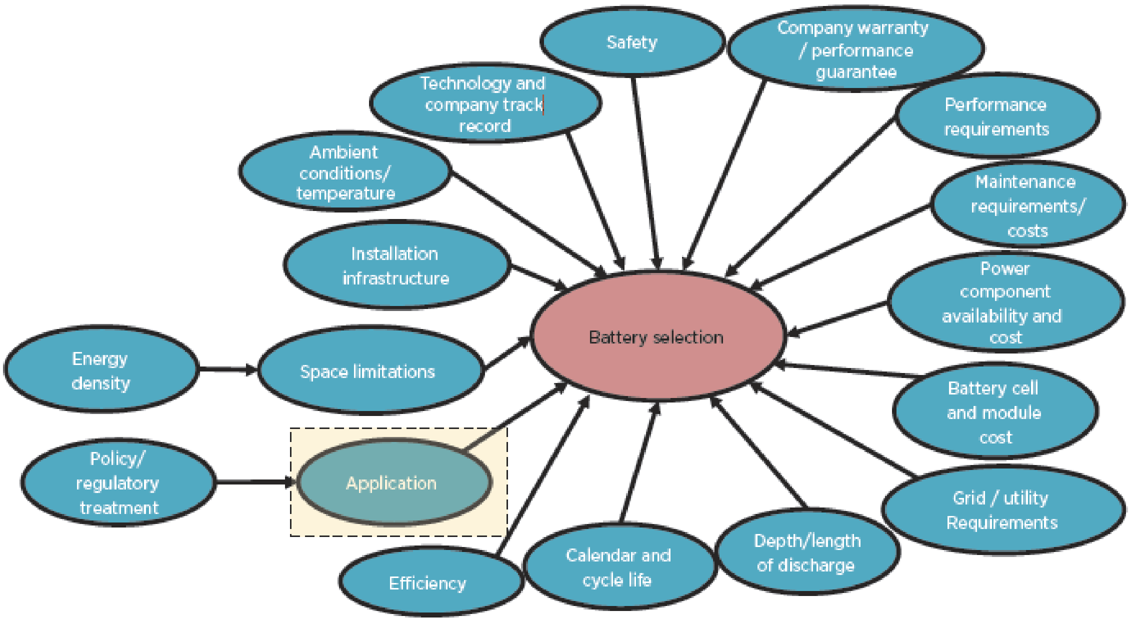

Figure 5-2 : Important Considerations for Battery Selection

5.2 Components of a BESS

Following single line diagram illustrate the components of a battery energy storage system implemented at distribution level.

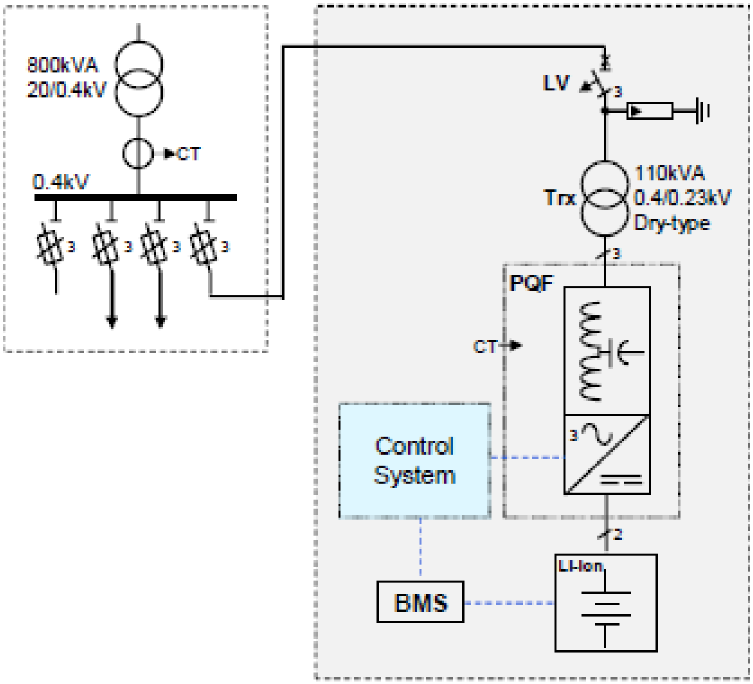

Figure 5-3 : Components of a Battery Energy Storage System

This includes,

Coupling transformer

Bi-directional converter (PQF)- acts as a rectifier during the charging of the batteries and as an inverter during the supplying of the energy from the batteries to the grid.

Battery Management System (BMS) – Manage the operation, safety and lifetime of the batteries

Batteries – For storing energy

Specification of a BESS system – a pilot project

Parameter	Value
Maximum Stored Energy	75kWh
Maximum charging/discharging rate per hour (1C)	75kW
Maximum capacity of the converter	100kVA
Voltage (via 110 kVA 400/230 V coupling transformer)	400V
Battery life span	10 years

Table 5-2 : Specification of a Battery Energy Storage System

Source : *CIRED, 2013*

5.3 Community Energy Storage (CES)

This is another kind of BESS that would be suitable for our requirement. This is a small-scale, battery-based energy storage system which is connected to the secondary of utility distribution transformers to provide backup power to customers. Several CES systems can intern provide grid-level benefits to the utility. Therefore the load levelling at the substation could be achieved (Tdworld 2011)). Following figure illustrates commercially available CES (Source: www.aeptechcenter.com/ces)

Key Parameters	Value
Power (active and reactive)	25 kVA / 25 kW
Energy	25 kWH future 75 kWh
Voltage	240 / 120V AC
Battery – Similar to PHEV	Li-Ion
Round trip efficiency	> 85%

Table 5-3 : Community Energy Storage System

Load Leveling - The CES units will be aggregated by a control hub at the substation to provide load-leveling benefit to the associated station transformer. Two schemes are available (*Tdworld 2011*) i.e. schedule based load levelling and time triggered load leveling. The former can be easily implemented by setting charging and discharging times according to a load research analysis. The latter required more complex and intelligent methods to trigger charging and discharging.

Features of CES

- *Proximity* - located closer to customers increase the reliability of the systems to provide backup power. The closer those storage systems are located to customers, the less susceptible they are to weather conditions that may damage power lines when backup power is needed.
- *As a Buffer for renewable energy*. – CES storage would help to buffer small scale renewable energy inputs like rooftop solar PV generation.
- *Smaller size*. These units will be easier to install, operate and maintain. Outages to smaller-sized units are less critical to the operation of the electric grid.

6 Economic Evaluation

In general, economic evaluation can be viewed in several angles which includes following aspects.

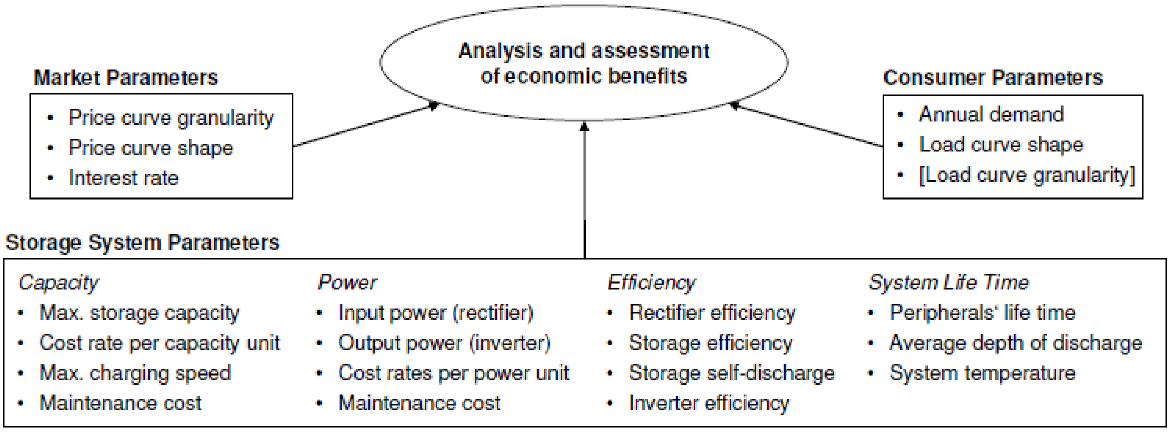

Figure 6-1 : Aspects of Battery Energy Storage Systems' Economics

Source : (Kowal, J., and Sauer, D. U. 2007)

6.1 Benefits

Benefit calculations from following aspects are important in order to have a complete economic evaluation considering the bundled benefits.

6.1.1 System Electric Supply Capacity

System electric supply capacity is the use of energy storage in place of a Gas turbine to provide the system with peak generation capacity during peak hours. Storage systems that can successfully fulfill the service requirements are compensated with the system capacity value, which is equal to the Cost of New Entry in resource balance year.

<u>Benefit Calculation</u>

System Electric Supply Capacity Benefit = Capacity Payment ($/kw) * Storage Qualifying Capacity *Capacity Derate

Qualifying capacity is a measure to make sure that the battery has the required duration to meet system capacity requirement. For example a requirement of 4 hours, means a 50-MW/2-hr battery would be used as a 25-MW/4-hr battery for this service. The qualifying capacity in this case is 25MW.

Capacity Derate, in the actual dispatch, there might be circumstances where the peak is longer than the battery capacity or the storage is doing other higher-priority services and the storage system is not able to cover all the capacity hours. In those cases, the storage system will be derated based on actual dispatch/qualifying capacity to reflect the real performance and compensation. (EPRI, 2013)

6.1.2 Electric Energy Time Shift

Electric Energy Time Shift is the use of storage to buy energy during low-price hours and sell during high-price hours. The dispatch is optimized to "buy low and sell high." (EPRI, 2013)

<u>Benefit Calculation</u>

Electric Energy Time-Shift (Arbitrage) benefit = (Energy sales) – (Energy Cost) / (Roundtrip efficiency) – (Variable O&M)

-Electricity Sales = Hourly Discharge * Hourly Energy Prices.

-Energy Cost = Hourly Discharge * Hourly Energy Prices.

-Roundtrip Efficiency (%) = The roundtrip efficiency is defined as the total energy out divided by energy in, including losses in the power electronics, balance of plants, battery, and control equipment.

-Variable O&M = Hourly Discharge * User Defined Variable O&M Cost.

6.1.3 Distribution Investment Deferral

Distribution investment deferral is the use of storage to shave transformer peak load to delay a bulky investment on the substation / feeders for a few years. The investment is deferred for as long as the storage is able to keep annual peak under the base year load peak or a defined threshold percent of base year load peak *(EPRI, 2013)*. As the apparent power demanded by the costumers increase, its peak value reaches the point where the thermal stresses caused to distribution transformers and conductors exceed the recommended levels. Incorporation of storage devices such as BESSs, located near the areas of load growth - The storage device will supply a portion of the feeder load during peak times, thereby keeping the feeder apparent power within normal operating limits.

Distribution investment deferral has the higher priority over system and ancillary services because once the storage system fails to keep the load under the load target, the investment must be made. The longer the storage system can keep the load under the load target, the more money will be saved.

Benefit Calculation -The benefit value is calculated as NPV of investment deferred by the number of deferral years.

6.1.4 Power Quality

Voltage levels at statutory requirements- BESS can maintain required voltage levels. And can compensate for line drops in upstream network.

Supporting the Low voltage side of the grid – BESS is capable of regulating the reactive power and improving the power quality, through filtration of the desired higher harmonics of current. In this case, the BESS solution will operate as an active filter for the grid.(*CIRED, 2013)*

6.1.5 Reliability

Reduction of outage time could be achieved if the BESS can supply the downstream demand during the outage time.

6.2 Case Study : A report to a Public Utilities Commission

In order to educate the reader on ground situation ,following summary of a analysis done by EPRI was extracted from*(EPRI, 2013).*

"

Electric Power Research Institute has done analyses to inform stakeholders of the California Public Utility Commission (CPUC) regulatory proceeding investigating the cost-effectiveness of energy storage in approximately 30 different cases. Cases included transmission-connected bulk energy storage, short-duration energy storage to provide ancillary services, and distribution-connected energy storage located at a utility substation. Under the assumptions provided by the CPUC, the majority of cases returned benefit-to-cost ratios of greater than one, and the majority of cases returned breakeven capital cost of energy storage ranging from $1,000 to $4,000/kW installed. These results represent an early phase of energy storage valuation analysis, quantifying the direct costs and benefits over the lifetime of the energy storage system. The results do not consider indirect impacts on the functioning of the broader electric system or environmental impacts. Following figures summarizes all cases, including those with project start years in 2015 and 2020, but all breakeven capital costs are adjusted for inflation and displayed in 2013 dollars.

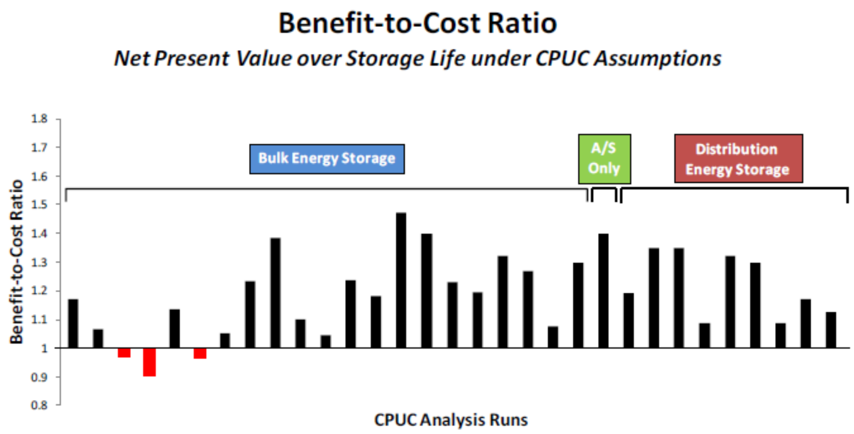

Figure 6-2 : NPV over Storage Life

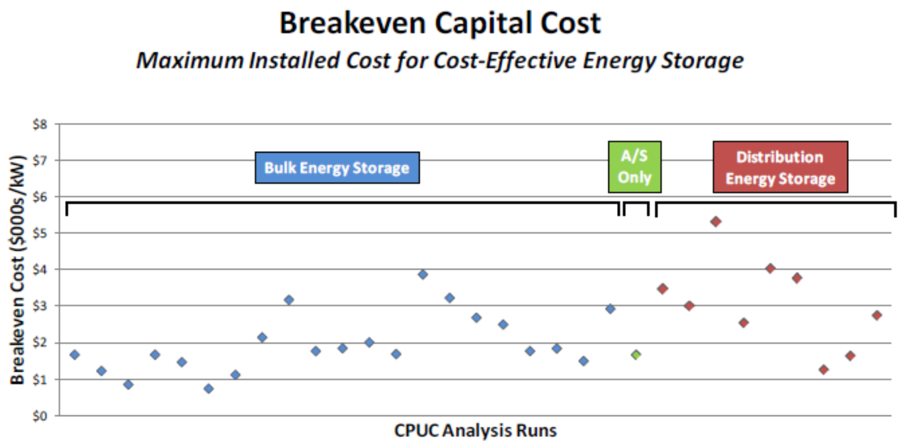

Figure 6-3 : Breakeven Capital Costs

"

6.3 Cost of Energy and Capacity for DLs in Sri Lanka

DLs pay capacity charge according to the coincident maximum demand and the energy charge according to the energy purchases during peak, off-peak and day time. Costs related to year 2014 are as follows.

	Energy Cost (LKR/kWh)						Capacity Cost (LKR/MW/Month)	
	1st Half			2nd Half			1st Half	2nd Half
	Day	Peak	Off-Peak	Day	Peak	Off-Peak		
CEB Reg 1	8.84	11.15	6.58	8.68	10.94	6.45	2,669,489.67	2,711,748.58
CEB Reg 2	5.68	7.16	4.22	5.57	7.03	4.14	2,669,489.67	2,711,748.58
CEB Reg 3	5.18	6.52	3.85	5.08	6.40	3.78	2,669,489.67	2,711,748.58
CEB Reg 4	6.31	7.95	4.69	6.19	7.80	4.60	2,669,489.67	2,711,748.58
LECO	10.41	13.12	7.74	10.22	12.88	7.59	2,669,489.67	2,711,748.58

Table 6-1 : Coincident Demand Charge and Energy Charge

Peak (18.30 – 22.30)hours Day (5.30 – 18.30)hours Off-peak (22.30 – 05.30)hours

6.3.1 Benefit from Peak time energy demand.

By introducing BESS at distribution level DLs can reduce the energy and capacity purchase costs. BESS can be charged at off peak rate (during 22.30 hours to 05.30 hours). And discharge during peak hours at where domestic demand is higher. Then money can be saved by reducing the energy demanded by DL from TL during the peak hours. Following table depict the advantage could be gained by each DL using the existing price differences in peak and off peak energy rates.

DL	Peak Charge- Off Peak Charge (LKR per kWh) for 88% Round Trip Efficiency
CEB Reg 1	3.61
CEB Reg 2	2.32
CEB Reg 3	2.11
CEB Reg 4	2.57
LECO	4.24

Table 6-2 : Price Differences Between Peak Energy and Off-Peak Energy

The typical energy demand from generators during peak hours in a Sunday is calculated to be 6724 MWh approximately. By taking the transmission losses (2.5%) in to the account the approximate peak time energy portion above the average demand line (of Sunday) can be calculated (approximately) as follows,

Total energy in the peak time duration	6724 MWh
Average capacity demand in Sundays	1324 MW
Energy portion below the average capacity demand (of Sunday)	5294 MWh
Energy Portion above the average capacity demand (of Sunday)	1430 MWh
Transmission Loss (in the year 2014)	2.7 %
Portion of Peak time energy perceived at DL/TL boundary that is placed above the average capacity demand	**1391 MWh**
Portion of capacity demanded above the line of Sunday average demand (at night peak time) Approximately	**600 MW**

Table 6-3 : Peak Time Energy Calculations

This energy portion (including transmission network losses) is depicted in the following figure.

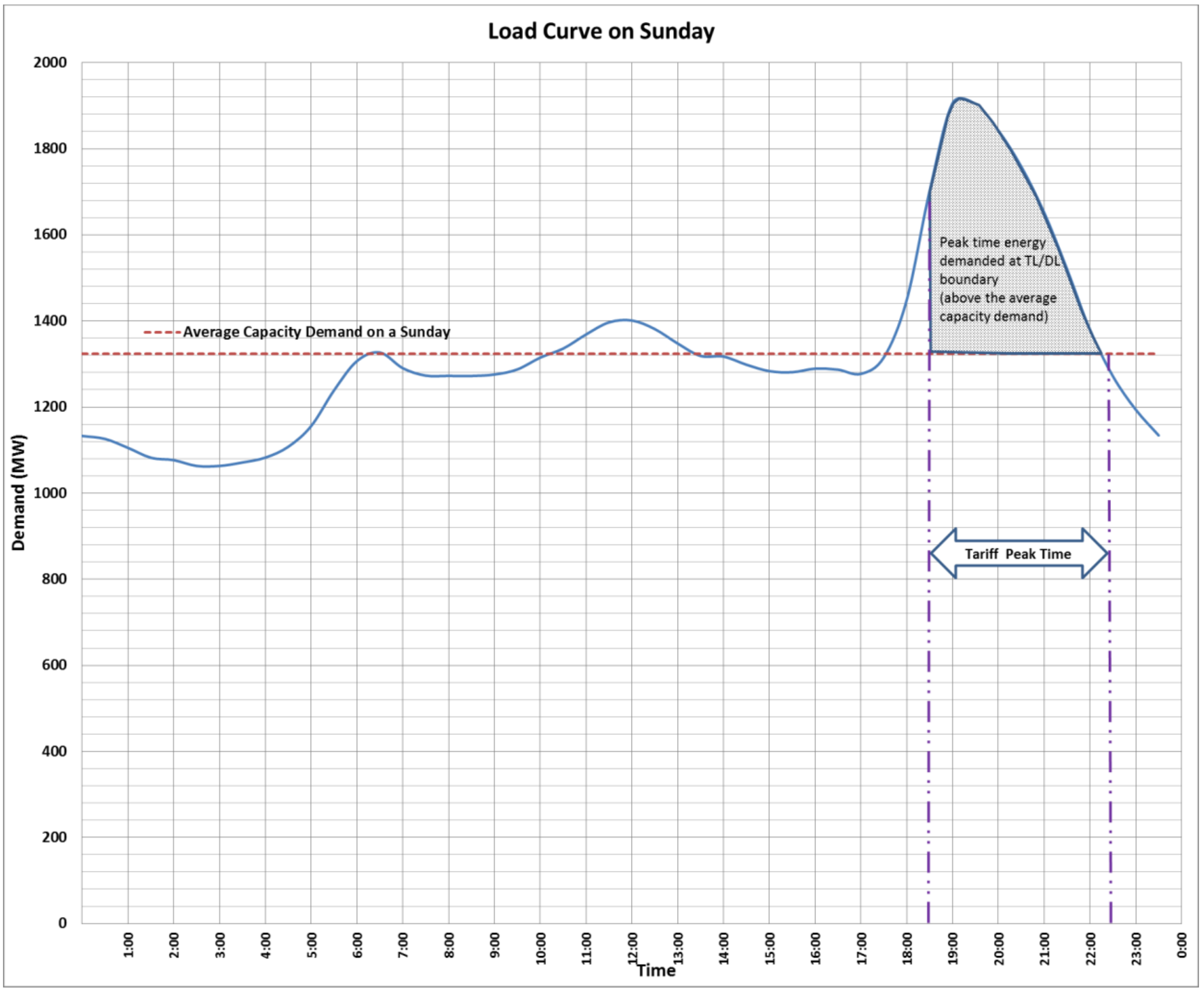

Figure 6-4 : Peak Time Energy Portion

6.3.2 Benefit from reducing the Coincident peak demand.

Coincident peak demand is the respective portion of demand incurred in a DL during the national peak (at about 19.00 hours). BESS can discharge at its maximum rate and doing so it can reduce the demand perceived by transmission licensee. Coincident maximum demand given in following table describes the demand claimed by each DL during the occurrence of national peak demand (for year 2014 in MW).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
CEB Reg 1	524	529	544	546	521	531	539	512.2	554.8	545.3	530.4	543.7
CEB Reg 2	583	557	635	618	582	572	587	547.8	564.9	573.0	561.6	566.5
CEB Reg 3	289	324	336	314	334	293	304	280.3	297.0	256.1	261.6	230.6
CEB Reg 4	271	261	274	260	286	265	277	275.3	253.4	268.0	288.8	239.0
LECO	207	211	222	221	223	212	212	207.4	214.8	209.7	216.0	214.3
Total	1,874	1,881	2,011	1,960	1,945	1,874	1,919	1,823	1,885	1,852	1,858	1,794

Table 6-4 : Coincident Peak Demand

Therefore by reducing the capacity demand of households which is responsible for night peak, approximately about 2.7 million rupees per Mega Watt per month can be saved by DLs. This could be achieved by utilizing BESS at distribution transformer level.

6.4 Tangible Benefit Cost Analysis (DL's point of view).

A benefit- cost analysis was carried out considering only the tangible benefits that could be achieved by the DLs considering the present tariff structure and regulatory regime. Hence monetary benefits from reduction of coincident peak demand and electrical energy arbitrage were taken into consideration. Benefits from outage reduction, improved power quality and distribution investment deferral are not included.

For this analysis project data of eight BESS plants (implemented as distributed energy storage) were used as references (*Sandia, 2015*).

Total Plant cost of BESS (8 plants)	1	2	3	4	5	6	7	8	*Ref*
Net Capacity (kW)	25	50	50	50	25	25	25	25	*Sandia, 2015 - Survey Year 2010*
Hours of Storage	2	4	2	3	1.1	3	1.2	3.2	
Energy Capacity (kWh) at rated DOD (80-85%)	50	200	100	150	28	75	30	80	
Round Trip Efficiency (%)	89	89	93	80	85	85	90	90	
Capital cost of power USD/kW	1,994	1,407	1,407	1,896	1,994	1,994	1,994	1,994	
Capital cost of Energy (USD/kWh)	846	846	1,581	542	1,882	1,553	1,725	1,222	
Total Plant Cost (USD)including equipment and installation	92,129	239,468	228,475	176,150	101,600	164,850	101,600	147,600	
Operating Expenses									*Ref*
Fixed O&M (USD/kW per Year)	37.2	26.8	26.8	26.8	37.2	37.2	37.2	37.2	*Sandia, 2015 - Survey Year 2010*
Replacement Battery Cost (USD/kW)	735	1,471	1,375	578	900	2,000	900	1,700	
Variable O&M (USD/kWh)	0.0027	0.0014	0.0027	0.0018	0.005	0.0018	0.0046	0.0017	
Lifetime									
Battery replacement years	8	8	8	8	8	8	8	8	
Plant Life	15	15	15	15	15	15	15	15	

Table 6-5 : Analysis of Battery Energy Storage Plants

From Above Information following can be deduced,

Item	Value
Total Capacity (kW)	275
Total Plant Cost including installation(USD)	1,251,872
Average cost per kW (USD/kW)	4,552
Maximum fixed O&M Cost (USD/kW per Year)	37
Average Replacement Battery Cost (USD/kW)	1,207
Average Variable O&M (USD/kWh)	0.0027125
Average Round Trip Efficiency (%)	88

Table 6-6 : Analysis of Battery Energy Storage Plants – Unit Costs

The storage costs are trending down and hence following costs could be considered from year 2020.

Storage costs in year 2020		*Ref*
Battery replacement Cost (USD/kW)	250	*EPRI, 2013*
Capital Cost (USD/kWh)	500	*EPRI, 2013*

Table 6-7 : Storage Costs in Year 2020

6.5 Producer Price Index for Utility Engineering Projects

The project costs given in Sandia 2015 is refered to year 2010. Hence this costs has to be transferred to present (2014) prices. Therefor PPI index for utility engineering projects and PPI for equipment repair and maintenance were taken into account. Following figurs depicts the PPI increase over the period of consideration.

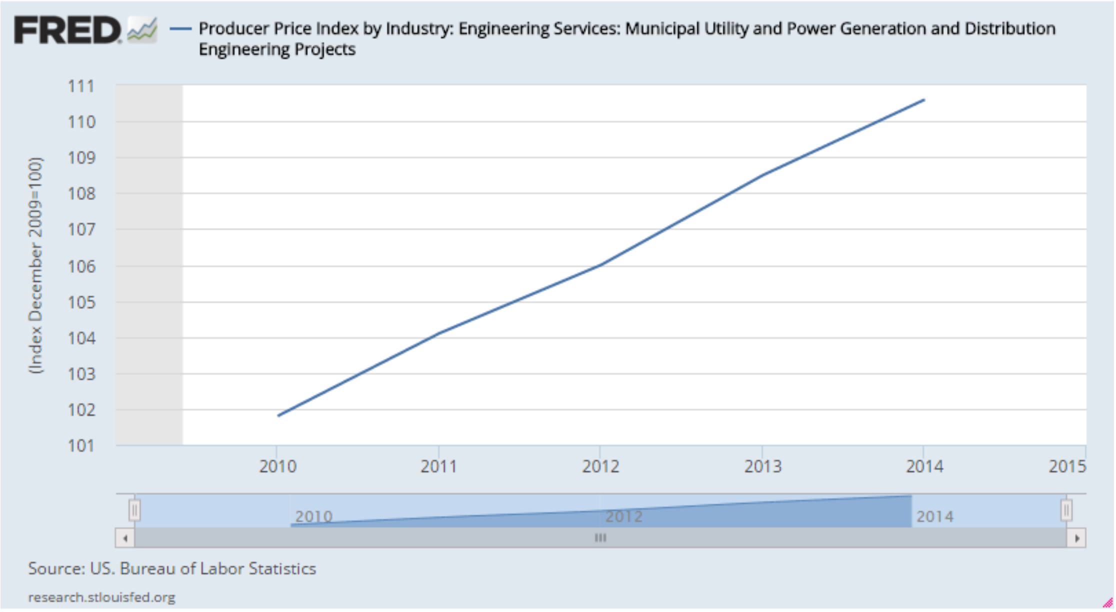

Figure 6-5 : PPI – Power Distribution Engineering Projects

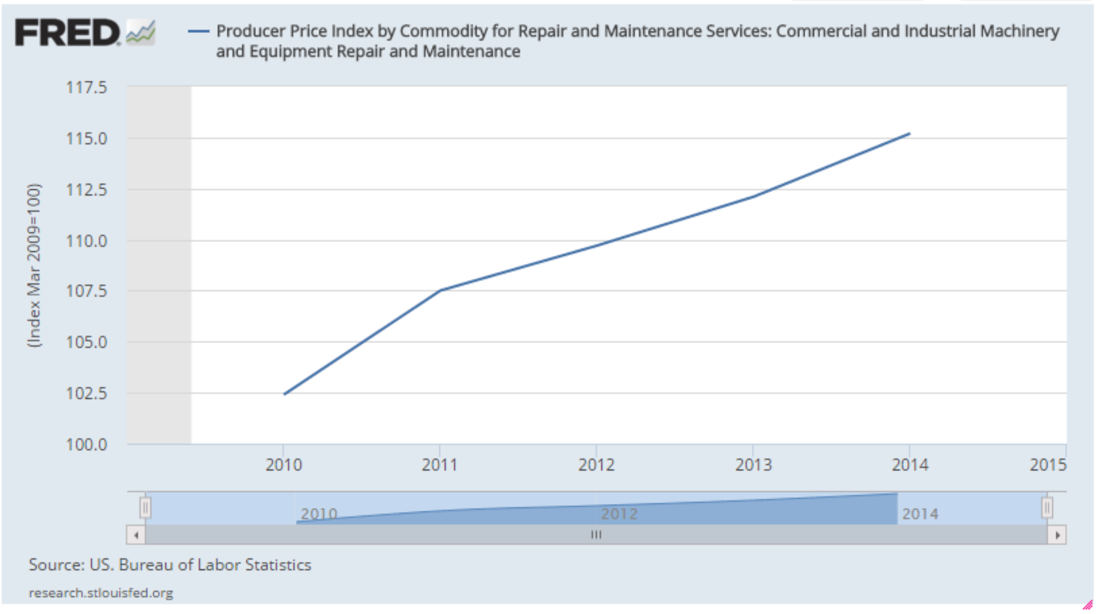

Figure 6-6 : PPI – Repair and Maintenance Services

Using the trend given in above graphs following PPI figures were estimated , which is required for the financial evaluation of BESS projects.

	Year	**Utility Projects**	**Repair & Maintenance**
PPI	2010	101.8	102.4
	2014	110.6	115.2
	2015*(Trend)*	112.8	118.44
	2016*(Trend)*		121.46

Table 6-8 : Estimated PPI Figures

6.6 Net Present Value – at Current Prices.

A simple cost-benefit analysis carried out using the highest arbitrage (with LECO) for a BESS system having 25kW/100kWh rating. According to the analysis given under section 6.4, the total investment for 25kW BESS plant can be calculated as ***4552.262 USD/kW x (PPI$_{2015}$/PPI$_{2010}$)$_{Eng\ Projs.}$ x 25kW =126,104 USD*** at year 2015.

	Costs					Savings				
year	Investment (USD)	O&M Fixed (USD)	O&M Variable (USD)	Battery Replacement Cost (USD)	Total Cost (USD)	Reducing Coincident Peak Demand (USD)	Time shifting of Energy demand [Arbitrage] (USD)	Total Tangible Savings* (USD)	Net Savings (USD)	Present Value @ 10% discount rate (real)
0	(126,104)				(126,104)				(126,104)	**(78,211)**
1		(1103.10)	(117.43)		(1,221)	5,766	1,107	6,872	5,652	
2		(1103.10)	(117.43)		(1,221)	5,766	1,107	6,872	5,652	
3		(1103.10)	(117.43)		(1,221)	5,766	1,107	6,872	5,652	
4		(1103.10)	(117.43)		(1,221)	5,766	1,107	6,872	5,652	
5		(1103.10)	(117.43)		(1,221)	5,766	1,107	6,872	5,652	
6		(1103.10)	(117.43)		(1,221)	5,766	1,107	6,872	5,652	
7		(1103.10)	(117.43)		(1,221)	5,766	1,107	6,872	5,652	
8		(1103.10)	(117.43)	(6250.00)	(7,471)	5,766	1,107	6,872	(598)	
9		(1103.10)	(117.43)		(1,221)	5,766	1,107	6,872	5,652	
10		(1103.10)	(117.43)		(1,221)	5,766	1,107	6,872	5,652	
11		(1103.10)	(117.43)		(1,221)	5,766	1,107	6,872	5,652	
12		(1103.10)	(117.43)		(1,221)	5,766	1,107	6,872	5,652	
13		(1103.10)	(117.43)		(1,221)	5,766	1,107	6,872	5,652	
14		(1103.10)	(117.43)		(1,221)	5,766	1,107	6,872	5,652	
15		(1103.10)	(117.43)		(1,221)	5,766	1,107	6,872	5,652	

Table 6-9 : Analysis on Net Present Value

It can be seen that the project is having negative NPV due to higher cost of BESS system (including storage). It is important to note that the above Benefit-Cost analysis cares only about direct monetary savings but excludes the indirect savings attainable from outage reduction, improved power quality, distribution investment deferral and economic benefit by avoiding peaking plant capacities. At these rates the breakeven for this type of 15 year running BESS project occurs when the BESS total plant cost is about **1600 USD/kW** approximately at current prices. This type of BESS projects definitely going to be producing positive NPV by year 2020 due to the continuous reduction in BESS capital costs.

Important: The total cost of storage systems, includes mainly the cost of subsystem components such as storage (batteries), battery management system, bi-directional converter and the cost of installation, and integration. It is true that the storage (battery) costs are going down, but the storage component still constitutes only 30% to 40% of the total system cost, thus the focus needs to be on the entire system (*DOE, 2013*).

In the following table which illustrates the break even scenario of the BESS project, the investment of USD 40,072 includes the total cost of the storage system (including all the costs of sub systems, cost of installation). So that the break even plant cost per kilowatt (1600 USD/kW) also includes the total costs involved (not only the storage, i.e. battery cost). The base cost components are given in the table 6-6.

	Costs					Savings				
year	Investment (USD)	O&M Fixed (USD)	O&M Variable (USD)	Battery Replacement Cost (USD)	Total Cost (USD)	Reducing Coincident Peak Demand (USD)	Time shifting of Energy demand [Arbitrage] (USD)	Total Tangible Savings* (USD)	Net Savings (USD)	Present Value @ 10% discount rate (real)
0	**(40,072)**				(40,072)				(40,072)	
1		(1103.10)	(117.43)		(1,221)	5,766	1,107	6,872	5,652	
2		(1103.10)	(117.43)		(1,221)	5,766	1,107	6,872	5,652	
3		(1103.10)	(117.43)		(1,221)	5,766	1,107	6,872	5,652	
4		(1103.10)	(117.43)		(1,221)	5,766	1,107	6,872	5,652	
5		(1103.10)	(117.43)		(1,221)	5,766	1,107	6,872	5,652	
6		(1103.10)	(117.43)		(1,221)	5,766	1,107	6,872	5,652	
7		(1103.10)	(117.43)		(1,221)	5,766	1,107	6,872	5,652	
8		(1103.10)	(117.43)	(6250.00)	(7,471)	5,766	1,107	6,872	(598)	**0**
9		(1103.10)	(117.43)		(1,221)	5,766	1,107	6,872	5,652	
10		(1103.10)	(117.43)		(1,221)	5,766	1,107	6,872	5,652	
11		(1103.10)	(117.43)		(1,221)	5,766	1,107	6,872	5,652	
12		(1103.10)	(117.43)		(1,221)	5,766	1,107	6,872	5,652	
13		(1103.10)	(117.43)		(1,221)	5,766	1,107	6,872	5,652	
14		(1103.10)	(117.43)		(1,221)	5,766	1,107	6,872	5,652	
15		(1103.10)	(117.43)		(1,221)	5,766	1,107	6,872	5,652	

Table 6-10 : Analysis on Breakeven Net Present Value

Note: 40,072USD / 25kW x 112.8/101.8 = 1602.88 USD/kW

6.7 Cost of generation during the national peak times.

6.7.1 Generation Options Used at Night Peak

A analysis has done using the data of 71 days in the months of July, August and September to identify role of major plants during the national peak. Capacity contributions from following thermal (oil) plants during above mentioned period revealed that these plants do not operated like peaking plants.

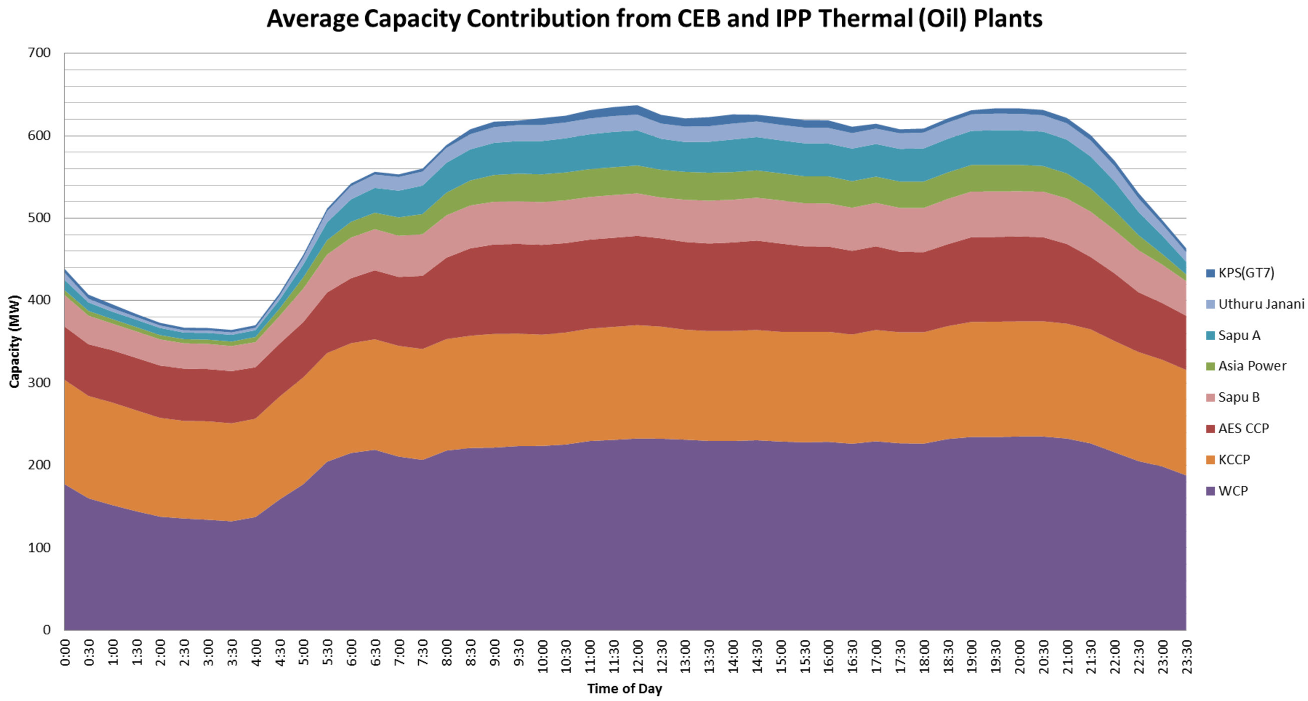

Figure 6-7 : Capacity Contribution from Large Thermal Plants

By analyzing the difference between the capacities contributions at off peak time and peak time it was identified that following major hydro plants has been operated as peaking plants.

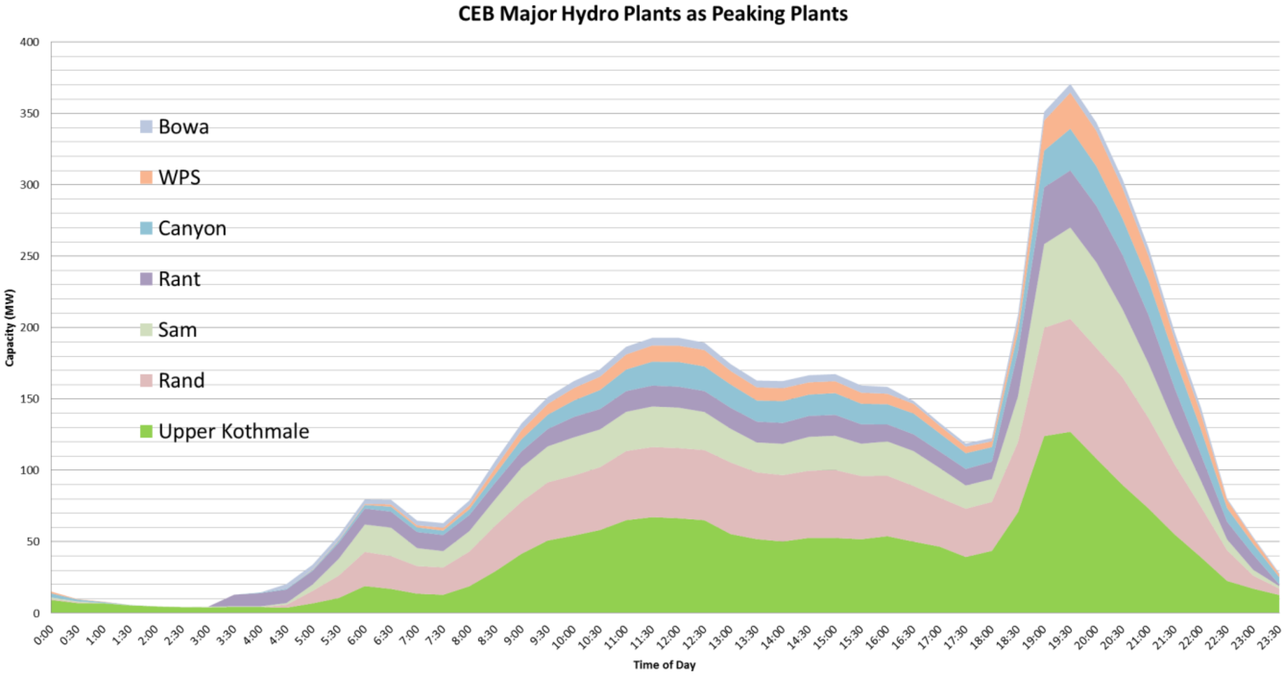

Figure 6-8 : CEB Major Hydro Plants as Peaking Plants

6.8 Value of BESS To Differ Investments on Peaking Plants

The value of an energy storage system is governed by the cost of the next best alternative means of providing the required service like peaking. In Sri Lankan context the peaking power is provided by cheap hydro plants. Therefore direct benefit such as removing a portion of peak capacity required by expensive Gas Turbine cannot be considered in the prevailing situation.

Typical Gas Turbine plant of 35MW is having a total unit cost of 784.9 USD/kW, and the specific cost for such plant can vary from 38 USCts/kWh to 29USCts/kWh according to the plant factor *(LTGEP, 2015)*. For GT7 the average unit cost was 44.66 LKR/kWh considering the fuel costs and energy generation from January to May 2015 *(System Control, 2015).* Therefore the energy and demand reduction via distributed BESS during peak hours would have higher economic value in case where hydro storage is not adequate for peaking period (during draught) or/and in case when peaking requirement is to be catered by GTs having high specific cost.

6.9 Possible Emission Reduction

In case where BESS is charged with portion of energy produced from major hydro/renewables which are operating during the off peak hours (typically in rainy seasons), and BESS is discharged during peak hours where it avoids portion of peaking energy otherwise produced by GTs, then there is a case for possible emission reduction in following quantities.

If the portion of energy supplied per day by BESS instead of GTs by using the stored energy from Hydro and renewable sources is E (in MJ) then the emission reduction would be (*Source for Emission factors: LTGEP 2015*),

$$NOx\ Reduction = E \times 0.28 \times 365\ g\ per\ Year$$
$$SO_2\ Reduction = E \times 0.453 \times 365\ g\ per\ Year$$
$$Particulate\ Reduction = E \times 0.005 \times 365\ g\ per\ Year$$

7 Recommendations

It is recommended to advice Distribution Licensees **to carry out detail evaluation on technical and economic viability** of integrating Battery Energy Storage Systems at grid edge, i.e. at LV level and also in MV level.

MV development plans are prepared by DLs once in two year, with 10 year planning horizon. It include current issues and problems in existing network such as low voltage situations, inadequate system capacity, low level of reliability and critically loaded equipment, etc. Integrating BESS at grid edge is a prospective solution to aforementioned issues. In addition direct monetary benefit could be earned by way of energy arbitrage and coincident peak demand reduction. Therefore it is recommended **to instruct DLs to consider grid edge technologies like BESS, as input to distribution system development proposals**. In this regard, DLs would be able to evaluate the benefits of distribution system upgrade deferral (investments for increasing system capacities) by including BESS projects.

Instruct Distribution Licensees **to initiate pilot project to integrate several BESS systems** at selected distribution transformers (out of 26000+ distribution transformers) and evaluate/monitor the technical and economic performance. This would make DLs ready to jump start BESS projects around year 2020 when the storage costs are expected to be 500 USD/kWh. and reap the benefits identified in this report.

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