

A Mathematical Model to Improve National Electricity Load Profile of Sri Lanka

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Abstract: In the daily demand profile of the Sri Lankan power system, it can observe a significant-excessive peak in the evening from 6.30 p.m. to 10.30 p.m. and another between 5.30 a.m. and 6.30 a.m. It is revealed that two peaks in the daily load profile had been caused due to the usage of the domestic sector. Since level off this daily electricity demand cycle, by flattening the peak & filling the valley is a necessity. Suggestions to introduce a low-cost battery storage system which will get charged during off-peak hours and use this stored energy during peak demand time will be a low-cost option to reduce the matter. The present study proposing a mathematical model to level off the daily load profile in Sri Lanka by utilizing concept of storing energy gathered from the main grid during the off-peak hours and reusing it during the on-peak hours.

To develop the model three types of the household were selected based on the monthly consumption of 90 units, 150 units, and 180 units. Analysis of the household load profile of an average middle-class house utilizing 180 kWh, 150 kWh and 90 kWh per month shows that during peak hours, it will utilize around 3 kWh, 2 kWh and 1 kWh per day respectively. This can be stored in a low-cost battery by charging it during off-peak hours (say from 11.00 pm to 5.00 am) & can be utilized during peak demand time of 6.30 pm to 10.30 pm. As a storage device, a novel household battery technology will be introduced with 160 Ah (~2kWh) and 250 Ah (~3kWh) capacity. The model house that we have considered uses 3 kWh per day during the peak demand time, therefore proposed, 3 kWh storage battery to be installed with charging & inverter circuits. This house will not draw electricity from the national grid during peak hours. This energy saving option, even though it will not generate electrical energy by way of installation of a solar panel or any other renewable option, this will be a low-cost option to the household while saving a massive cost to the nation. This will also maximize the capacity utilization of all existing generation plants.

Keywords: Mathematical model, load control, Load-profile balancing, clip the peak.

1. Introduction

There is an unprecedented increase in demand for energy sources in South Asia because of growing economics in all countries. Hence, for South Asia, energy security arises according to the imbalance between energy demand and ability of supply from indigenous resources. As a result, it increases import dependence^{1,3-6}. In South Asia, the drain on national resources to satisfy rising energy import expenditures is a serious political and social challenge. As a result, each South Asian country seeks to ensure reliable, sustainable, and economically price for energy supplies in order to meet the people's and economies' growing aspirations^{4,7}.

In South Asia, the electricity consumption varies low of 19 units per year in Afghanistan to over 540 units in India and Pakistan. In most nations, power consumption is expanding at a pace of 7% per year, except for Afghanistan, Bhutan, and the Maldives, where growth rates of over 13% are predicted in the first decade to meet rural electrification needs⁸. In the Sri Lankan context, strong policy initiatives and decisions were taken by the government to secure the nation with energy. As a result, it shows that access to electricity in Sri Lanka is almost 100% while maintaining above 500 kWh/annum per capita electricity generation (Figure 1).

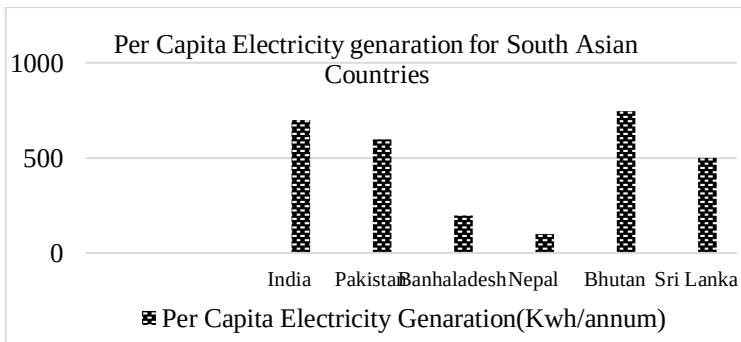


Figure 1. Electricity scenario of India, Pakistan, Bangladesh, Bhutan and Sri Lanka per capita electricity generation(Kwh/anum)

Energy has been identified as a key issue in all sustainable development agendas in Sri Lanka. The proposed targets are aiming to reduce the reliance on fossil fuels, increase energy efficiency, improve access to energy, energy storage and increase the use of renewable energy. Sri Lanka is striving geared to be the energy hub of the region. In order to accomplish this goal, the country will focus on harnessing its own indigenous resources as well as low-cost energy options to fulfill the present and future energy demand. One of the main challenges facing the Sri Lankan government is to meet the demand

while diversifying into low-cost energy generation to provide a sufficient energy supply at an affordable price to the people. In the case of power supply, the government focuses on ensuring energy security at the lowest cost while diversifying energy sources and promoting energy production through cleaner, indigenous sources such as hydro, wind, and solar. The generation mix in Sri Lanka is dominated by thermal and hydro resources. However, in addition to this, there are other energy resources like wind, solar, and biomass, which also contribute to power generation. The generated electricity is being used by households, industries, commercial establishments, government officers, etc. The Sri Lankan daily electricity demand also varies at a predictable pattern, which is called the daily load profile. Fig.1 shows the daily load profile of Sri Lanka.

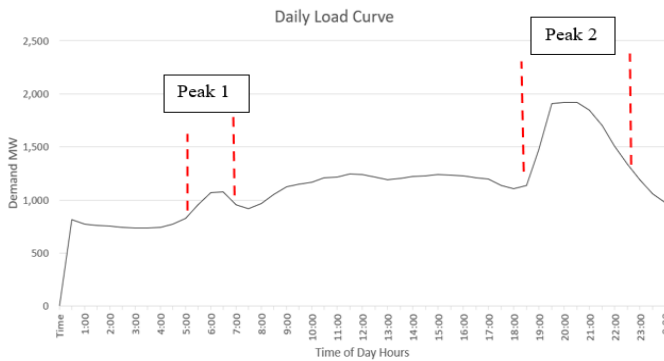


Figure 2. Typical daily load profile of Sri Lanka

As shown in Figure 2, the daily demand for power can be graphed against time. The initial peak (between 5.30 a.m. and 6.30 a.m.) is caused by early morning electricity usage. At this hour, both working people and schoolchildren are at their busiest. Around 7:00 a.m., as households leave for work or school, the peak begins to fade. Because most individuals commute to work or school around 7.30 a.m., electricity usage in businesses is modest. The subsequent slow peak, which lasts until 9.00 a.m., represents the first working hours of a typical day. The commercial working load begins at 9.30 a.m. and lasts until 6.30 p.m., during which time the electricity consumption is higher.

The significant rise about at 6.30 p.m. is due to domestic electricity demand during the evening and night. This is referred to as 'peak demand,' and it ends at 10.30 p.m. The primary sources to this peak consumption are household cooking, lighting and television watching.

The significant rise about 6.30 p.m. is due to domestic electricity demand during the evening and night. This is referred to as 'peak demand,' and it lasts until about 10.30 p.m. The primary sources to this peak consumption are household lighting and television watching [10]. Those two main peaks will create an imbalance in the main grid and to supply electricity for those two peak demands, Sri Lanka currently uses thermal power that will incur extra cost for Ceylon Electricity Board (CEB) and that has become quite a burden to the Treasury. As such, few sustainable energy harnessing methods are promoted and requested to be practiced by the electricity consumers by the Ministry of Power and Energy, CEB, and Sustainable Energy Authority (SEA) in Sri Lanka. They are,

1. Energy efficient lighting practices (CFL or LED)
2. Usage of electric cars and charging them in the off-peak hours (1 a.m. to 4. 30 a.m.)
3. Efficient usage of the electric equipment/peripherals
4. Net Metering

As a result, if we can persuade consumers to install such systems with the ability to go off the grid during peak hours utilizing battery storage, they will be making a significant contribution to the CEB and the nation. According to 2012 CEB figures, there are 997,000 home consumers who use more than 90 kWh per month. If just half of these customers sign up for the proposed program, peak load can be decreased by 1.525 GWh or 500 MW, which is equivalent to the projected sample coal power station⁹. This study presents a comprehensive model for reducing the load profile's night peak, as well as the current state of creating an indigenous/local energy storage system in Sri Lanka to address this issue.

2. Methodology

The research framework was developed to mitigate the two peaks that can observe in the national load profile in Sri Lanka. This methodology includes discussions, surveys, and observations.

Participation in the seminars and open discussions with experts in the field were done prior to the data collection. Furthermore, the impact of daily household electricity usage on national energy demand was examined and verified.

Discussions with various groups of electricity-using households in Sri Lanka as a first step in the data gathering procedure. Then, to collect primary data, three average households in Colombo district, Sri Lanka were identified

depending on monthly electricity usage. Selected households were typical middle-class homes that consumed 180 kWh, 150 kWh, and 90 kWh per month. As secondary data sources, energy annual reports were analyzed before examining the households. Ceylon Electricity Board and Sustainable Energy Authority annual reports, journal papers, periodicals, websites, research articles and publications were used to examine the analyzed tariff system in Sri Lanka.

3. Results and Discussion

Authors have proposed a model to flatten the peak of the daily load profile, which takes place at the night. Calculations have shown that in Sri Lanka, the requirement is a smaller battery system that has a capacity of around 250 Ah (~3 kWh) units to manage the peak load in a typical household.

After looking at the daily energy consumption profile of the model house (180kWh monthly usage), it's evident that there are high surges around 6.30PM and 10.30PM, as well as 5.20AM and 7.30PM. Similar patterns can be seen in the monthly usage of 90 kWh and 150 kWh households.

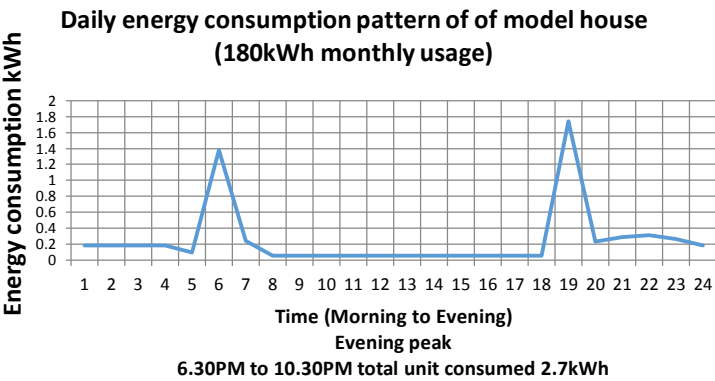


Figure 3. Daily energy consumption pattern of model house (180kWh monthly usage)

We understood that even those with monthly consumption of 180 kWh and 150 kWh could find a system with such storage economically viable. Refer to Table 1 and Table 2 for 180 kWh calculations and Table 3 and Table 5 for 150 kWh calculation. Table 2 shows the electricity bill without the energy storage option of 180 units.

It is obvious from table 1 if total monthly usage is less than 60 units, the unit cost is Rs.7.85. However, the number of units consumed increases, the value per unit increases as shown in the column 2. Since the unit cost the next 30

units is Rs.10.00 and the unit prize charge for the following 30 units is Rs.27.25, resulting in a total cost of Rs.832.50. When it consumes more than 120 units, it charges Rs.32.00 per unit, leading to Rs. 4003.50 as electricity bill.

Table 1. Model house with 180 units consumption

Monthly Consumption kWh	Unit charge (Rs/kWh)	Units	Fixed charge	Total = Unit Charge X Consumed Unit Rs.
			(Rs/month)	
0-60	7.85	60	0	47100.
61-90	10	30	90	300.00
91-120	27.75	30	480	832.50
121-180	32	60	480	1920.00
>180				
		180	Total Bill	4003.50

After consideration to the data uthorshave proposed a tariff structure for domestic customers who plan to use the battery pack. If 2.7 kWh (Table 1) is used for the peak hours, then number of units that will be drawn from the grid is 81 kWh.

Number of units that will be drawn from the grid during off peak hours per month = $2.7 \times 30 = 81$ units.

These 81 units shall be calculated at say Rs.7.00 per unit as at present CEB unit in off-peak hours for industrial users. This is Rs.6.99 per unit and is taken as Rs.7.00 for ease of calculation. It is only fair that the benefit of shifting the consumption from the peak hours to the off-peak hours should be shared with the consumers and hence charge them for this quantum of energy at the off-peak industrial rate.

Therefore 81 units utilized by this household shall be calculated at Rs.7/- per unit = $81 \times 7 = \text{Rs.}56700$.

Then CEB must work out an equation to how balance 99 units shall be calculated. This remain units will be calculated based on the current tariff structure. The following Table 3 showed final electricity bill for this household, which will equivalent to Rs. 2067.75.

Total electricity bill without energy storage option = Rs .4003.50

Therefore, saving per month = Rs .1935.75

Payback period for the household of 180 kWh will be approximately 31 months based on 3 kWh battery cost of Rs 60,000.00.

Table 2: Model house with 180 units consumption-Proposed tariff structure

Monthly Consumption kWh	Unit charge (Rs/kWh)	Units	Fixed charge (Rs/month)	Total Rs.
0-60	7.85	60	0	47100.
61-90	10	30	90	39000.
91-120	27.75	9	480	729.75
121-180	32	-	480	0
>180				0
	7	81	0	56700.
		180	Total Bill	2067.75

Table 3: Model house with 150 units consumption-Proposed tariff structure

Monthly Consumption kWh	Unit charge (Rs/kWh)	Units	Fixed charge (Rs/month)	Total Rs.
0-60	7.85	60	0	471
61-90	10	21	90	300
91-120	27.75	-	480	0
121-180	32	-	480	0
>180				0
	7	69	0	48300.
		150	Total Bill	125400.

Table 4: Model house with 90 units consumption- Proposed tariff structure

Monthly Consumption kWh	Unit charge (Rs/kWh)	Units	Fixed charge (Rs/month)	Total Rs.
0-60	7.85	42	0	329.70
61-90	10	-	90	30
91-120	27.75	-	480	0
121-180	32	-	480	0
>180				0
	7	48	0	33600.
		150	Total Bill	665.70

Table 3 and Table 4 illustrate the cost and proposed tariff structure for 150 units and 90 units domestic houses. Above calculation procedure was repeated for those calculations.

Total electricity bill without energy storage option = Rs .304300.

Therefore, saving per month = Rs1789.00 .

Payback period for the household of 150 kWh will be approximately 28 months based on 2 kWh battery cost of Rs 50,000.00.

Total electricity bill without energy storage option = Rs861.00 .

Therefore, saving per month = Rs196.00 .

Payback period for the household of 150 kWh will be approximately 77 months based on 1 kWh battery cost of Rs 15,000.00.

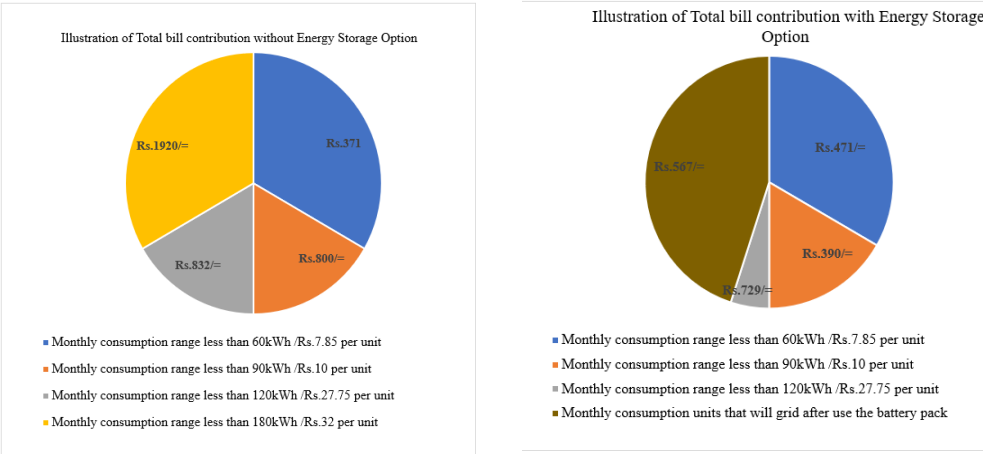


Figure 4. Comparison for Illustration of total bill contribution with an without energy storage Option

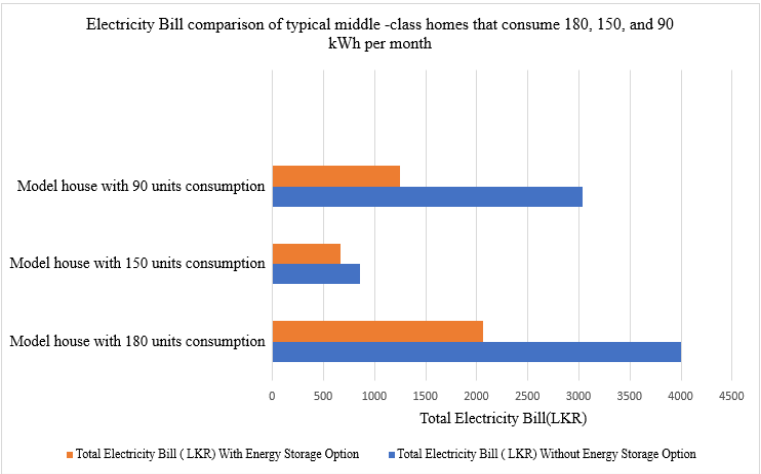


Figure 5. Electricity Bill comparison of typical middle-class homes that consume 180, 150, and 90 kWh per month

Figure 4 depicts a comparison of residential power usage of 180 kWh with and without energy storage. It can be seen that the unit consumption for the 121-180kWh class is reduced to a lower value as a result of the units that are connected to the grid after utilizing the battery pack. Furthermore, it can be concluded that the introduction of energy storage options will lead to a reduction in electricity bills for three households (Fig 5)

Analysis of the household load profile of an average middle-class house utilizing 180 kWh, 150kWh and 90 kWh per month shows that during peak hours, it will utilize around 3 kWh, kWh 2and 1 kWh per dayrespectively . This can be stored in a low-cost battery by charging it during off peak hours (say from 11.00 p.m. to 5.00 a.m.) & can be utilized during peak demand time of 6.30 p.m. to 10.30 p.m. new concept call Day time metering system (DTMS) need to be introduced for households using this energy storage option & the benefit of utilizing of peak hour energy consumption need to be passed onto these customers. This needs to take into account that the cost of generation to the CEB during the peak hours is substantially over the average cost of generation of about Rs 20.00 per unit. Thus, the DTMS should offer a much higher tariff during the peak hours and a tariff much lower than the present during the off peak. This is the greater incentive for consumers to be off the grid during the peak hours. This is the common practice used for the industrial consumers even now. As a result, the savings to the consumer will be further enhanced and the payback period reduced.

Above calculation, based on CEB's present tariff system to industrial users & domestic users, has been done which will give benefit to consumer while the country would make a substantial saving by way of avoiding a future coal power plant, as well as saving on fossil fuel cost of existing plants.

6. Conclusion

Model house that we have considered uses 3 kWh per day during the peak demand time, therefore proposed, 3 kWh storage battery to be installed with charging & inverter circuits. This house will not draw electricity from the national grid during peak hours. This energy saving option, even though it will not generate electrical energy by way of installation of solar panel or any other renewable option [2], this will be a low-cost option to the household while saving a massive cost to the nation. This will also maximize the capacity utilization of all existing generation plants.

A 3kWh battery will be equivalent to 250 Ah battery. At the moment, 200 Ah Lead Acid battery is available in the market at a price of around Rs.35,000/-.

If a locally produced inverter circuit & a charging circuit is incorporated to make it a complete system, it would be possible to supply a complete package from Rs.50,000/- to 60,000/- for average domestic users.

As per the development process of the Sri Lankan own battery system is unpredictable, since our objective of the concept is to clip the peak presently available conventional Lead Acid battery can be suggested as an immediate action.

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