Scenario Analysis of Future Load Profile of Sri Lanka Considering Demand Side Management Initiatives

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***Abstract*—As a result of technology development, expansion of industries and improvement of living standards, the electricity demand increases rapidly. It is the responsibility of the utility to supply uninterrupted, reliable and good quality power to customers. Basically, it is the balancing of supply against the demand. Building new power plants to match the supply to increasing demand may not always be economically viable. The trend now is to control the demand with demand management initiatives. This study evaluates the reasons for changes in day peak and night peak in the electricity load profile, to study the feasibility of making the load profile smoother using Demand Side Management (DSM) initiatives. After analyzing several types of customer categories, it was identified that Chilled Water Storage (CWS) systems and Electrical Vehicles (EV) can make a significant change in the load curve. By constructing storage tanks to store chilled water during the off-peak tariff period, and using the stored chilled water to meet the peak-time cooling demand will reduce the demand at peak time. A mathematical model was developed for demand forecasting, incorporating DSM.**

I. Introduction

Generation, Transmission and Distribution licensees, regulated by the Public Utilities Commission of Sri Lanka (PUCSL) perform their respective functions. CEB is the only transmission licensee, and CEB, Independent Power Producers (IPPs) and Small Power Producers (SPPs) are the main generation licensees. The transmission licensee dispatches power plants, buys electricity from power plants and sells electricity to distribution licensees.

Five distribution licenses have been issued and four of them are owned by CEB and the other license is owned by Lanka Electricity Company (LECO). The five Distribution Licensees (DLs) own and operate the relevant distribution networks and supply services to customers.

The five DLs are different in terms of their customer base and volume of sales. All DLs sell at the Uniform National Tariff (UNT). If the Bulk Supply Tariffs (BST) for the sale of electricity by the TL to DLs is fixed, then DLs would be required to sell electricity to their customers at non-uniform rates.

The demand for electricity initiates at the customer end the utility, has and the System Operator (CEB) has to match this demand with the supply. Since demand increases, the utility has to dispatch higher cost power plants to match demand. Since the power plants are dispatched in the order of ascending marginal cost, energy from the plants that come online to meet the system peak is the most expensive. In addition, the utility has to possess adequate capacity to meet the varying peak demand, which requires the utility to pay for ongoing availability of peaking plants that may only be dispatched for a few hours per day or month. The sharp evening peak justifies the analysis and implementation of Demand Side Management (DSM) in the country.

The shape of the Sri Lankan load profile has changed significantly over the past two decades. Simply we can identify that the increase in electricity use is the core reason for the change in the shape of load profile. However, there are some other possible reasons as well which require further. Study.

- Increase in demand for electricity
- Changes in demand patterns of different consumer categories
- Economic growth of the country and structure of the economy

The normalized load profile for some selected years is shown in Fig. 1.

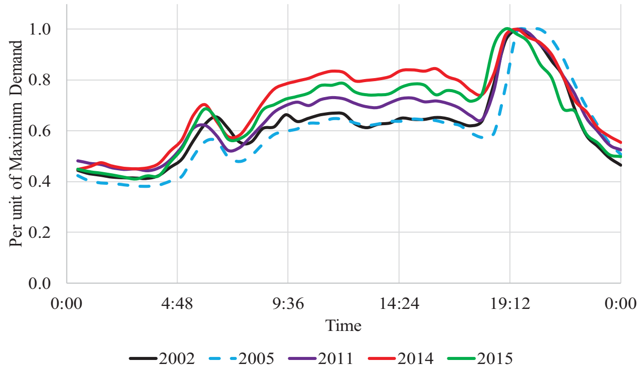


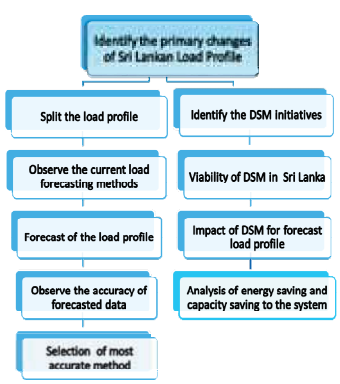
Fig. 1. Variation of load curve over selected years

As an indication, 970 MW of peak demand at 1995 increased to around 2100 MW by 2015. Energy consumptions too increased. The significant change in the daytime peak demand and the night peak demand.

The regulator for the economic, technical and safety of electricity industry in country PUCSL. The commission has conducted a study [4] to analyse the load profile and look for ways to shift the system peak towards a flat load profile. The study used the system load profile data published by Sustainable Energy Authority (SEA) for 1997 to 2010, load profile data for 2011 and 2012 obtained from Transmission Licensee, the Ceylon Electricity Board (CEB), and the electricity consumption data of Time of Use (TOU) consumers obtained from all distribution licensee [4]. The research focused on the key methods of Demand Side Management (DSM), their applicability for the country and the initiatives, recommended feasible ways to control and shift the system peak. As our research is also based on the key initiatives of DSM, this report helps to identify how DSM can be used to shift the system peak and to identify the contributing factors for the high evening peak demand. It is found that this report has limitations; it only considers one DSM technique for peak reduction. Thus, the report did not include analysis of other DSM options, or the structural change in country's economy.

II. Methodology

The methodology followed in this study is shown below Load forecasting and DSM scenario analysis are the main two segments of this approach.



A. *Load Forecasting*

Load forecasting methods have several categories, each categories using different mathematical models to predict the demand.

Short term load forecasting

- Regression
- Time series analysis
- Artificial neural network with back propagation

Long term load forecasting

- End-use models
- Statistical model based learning

A multiple regression model to construct the shape of predicted load profile was developed using MATLAB. With the available data, the model was constructed using the following input variables.

- wnd: weak day or not (1 or 0)
- pd: demand at previous time slot

Results of MATLAB model fitter are as follows.

Linear regression model:

$$\text{Dnormalized} = C + A\,(\text{wnd}) + B(\text{pd}) \qquad (1)$$

- A = -8.179e-05
- B = 0.9759
- C = 3.485e-05

The value of Dnormalized was used to calculate the actual Demand. In order to construct the complete load profile, the actual demand was calculated using the standard deviation and the mean of each time interval which used to normalize the data. The load profile was predicted for a typical weekday and weekend (Saturday, Sunday).

$$\text{Dactual} = (\text{Dnormalized} * \text{Standard Deviation}) + \text{Mean} \qquad (2)$$

B. *DSM Scenario Analysis*

In this step, the existing DSM initiatives were identified and comprehensively studied for their capability to change the system load profile. By studying the available DSM techniques, the way forward for introducing the new DSM techniques was identified.

Even though it was identified that the DSM techniques were cost effective, have lower gestation periods, it is necessary to analyze the viability of DSM in Sri Lanka. In this step, the need and potential of DSM was analyzed.

The impact on the forecast load profile by the suggested DSM techniques evaluated in order to identify whether the suggestions are reaching the project objectives or not. DSM Scenario Analysis has done basically in two case studies.

1) *Chilled Water Storage for Bulk Customers*

Chilled water storage systems work by cooling water overnight or during the off peak period and then using that chilled water during the day or peak period to cool the building. This results in less electricity usage throughout the day when rates are the highest. [9]

Chilled water storage systems rely solely on the sensible (i.e., no phase change or latent energy) heat capacity of water and the temperature difference between supply and return water streams going to and from the cooling load. As a result, the storage volume required is greater than for any of the ice or eutectic salt options. However, using water eliminates the need for secondary coolants and heat exchangers and standard water chillers can be used without significantly degraded performance or capacity. [13]

The potential energy saving that can be achieved through CWS was derived by selecting a sample from the group of General Purpose and Hotel category customers General Purpose (GP2 and GP3) and Hotel (H2 and H3) category was selected this consist 5488 GP customers and 327 hotel category customers. [15]

Customers with higher contract demand will have central air conditioning systems installed in their premises, this assumption was made in order to filter out the data. Accordingly the selected data sample was filtered as follows,

- Sample 1: GP3 customers and GP2 customers with contract demand above 1000 kVA (127 customers)
- Sample 2: H3 customers and H2 customers with contract demand above 300 kVA (100 customers)

Then the selected two samples were analyzed to filter which may have CWS installed in their premises. This gives the sample of customers who has potential to implement CWS within their premises. Daily TOU average consumption of each customer was then calculated. Based on their daily average consumption, their percentage consumption for each time period was calculated.

After filtering the samples, the sample was categorized into two, based on the peak time consumption of each customer.

- Category A: This category consists of customers with their peak time consumption 11% or above. The sample consists of 159 customers.
- Category B: This category consists of customers with their peak time consumption below 11%. The sample consists of 35 customers.

The basis of 11% was taken to divide the two categories. The customer who has considerable consumption in peak time will always be above the ceiling. This analysis was done in [1].

2) Chiller Demand Before & After

For each customer belonging to category A and B, the daily TOU energy consumption was calculated using the monthly TOU energy consumption data. The daily energy consumption data was used to calculate their demand for each time period in the TOU tariff, for all the customers in the sample.

The ratio between the total demand and the chiller demand calculated above was used to calculate the chiller demand for each customer in category A and B. As per the assumption the chillers will be switched off in peak for four hours and switched on for cooling requirement for the peak period will be generated in the off peak period over seven hours for category A and for the category B chillers will be switched off first seven hours during the day time as their peak occurs at that period and the cooling requirement of that time period will be generated in the off peak period when the chillers were usually switched off. Depending on the above assumption the new chiller demand was calculated for each customer and the effect from the CWS to the total demand was observed. This calculation was done to observe the total saving to system by implementing the CWS system.

The sample that was selected is representing the entire group of customers in CEB who has a potential to implement the CWS system in their premises. Since the assumption was made that the behavior of each categories are same the saving to the system can be calculated. The total saving can be achieved in the peak and the demand is increasing in the day time period and off peak period.

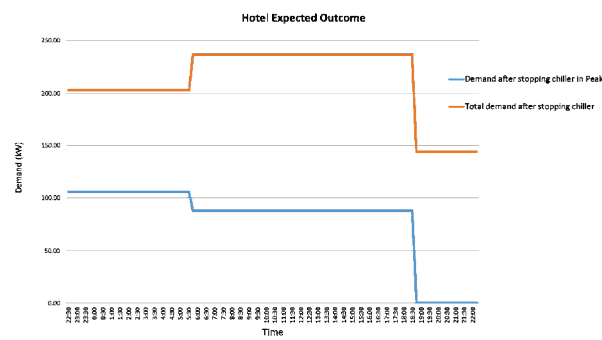


Fig. 3. Expected Outcome for Category A Customer

It can be seen that by implementing the CWS the off peak power and also the energy consumption was increased. The idea behind the DSM is not to reduce the energy consumption but to shift the peak time consumption to off peak. The advantage of shifting the demand to off peak from the consumer side is that their electricity charge will be reduced sine they are not consuming in peak which has a higher tariff. And for the utility benefits in two ways; through the energy reduction in the peak and day time period, also it will gain from the reduction in peak time capacity required. [1]

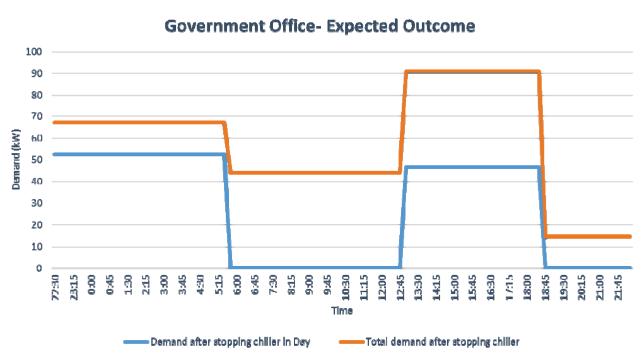


Fig. 3. Expected Outcome for Category B Customer

The savings to the section A and B can be archive are listed in table 1. [1]

TABLE I Demand Saving Results [1]

Category	Peak demand saving (kW	Day demand saving (kW)	Off peak demand increase (kW)
A	20,790	-	13,200
B	154	8291 (from 0530 - 1230)	9311
Total	20,944	8291	22,511

3) Electric vehicles for household customers

In this case, the ordinary vehicle and electric vehicle has to be compared by collecting data calculating the energy saving and cost saving to the utility and the consumer.

For this case study, we have selected a typical petrol car (Micro MS 7) user and one week data on fuel consumption and fuel expenditure. As the sample electric car, Nissan leaf was selected. The reason for this selection is the moderate purchasing cost. Therefore, middle class people can buy this type of car according to their income level. In the other words, the potential market for these two cars is significantly large.

Petrol car

- Occupation of petrol car user: Doctor
- Type of car: Micro MS 7
- Average riding distance for a typical week ` = 600 km
- Average fuel cost per week = LKR. 6000.00

Electric car

- Type of car: Nissan leaf
- Energy of battery = 24 kWh
- Charging time by 240V supply = 5.0 hrs
- Possible distance of traveling after one charging = 100 km

In this case we are suggesting to charge the car at off peak time (from 10.00 PM to 05.30 AM). Therefore consumer can get more economical benefit using Time of Use (TOU) tariff system.

The benefits to the consumer and utility also has to be addressed, basically the consumer will be benefited by reducing their consumption and the utility will also benefited through the energy reduction in the peak and day time period, also it will gain from the reduction in peak time capacity required.

According to our plan the investment for the DSM initiatives will be done by client, utility and also from the government. As the investment is really high for DSM, motivating consumers to involve in DSM will be our duty as an intermediate group between utility and consumers.

III. Results

A. Load Forecasting

The model was developed to get the typical week day profile and typical week end day profile separately. The both models we observed have and error percentage of 5% when it compare with the actual demand.

B. Financial Evaluation of CWS

The financial evaluation of CWS was observed under two categories.

1. Savings due to system peak reduction
2. Saving due to energy saving

The savings can be calculated with the value of Bulk Supply Tariff values and the average capacity cost. The tariff applicable to the utility was taken from the Bulk Supply Tariff (BST) for sale of electricity from the Transmission Licensee (TL) to the Distribution Licensees (DLs). The tariffs with effect from 1st April 2017 were taken for calculations.

TABLE 2 Bulk Supply Tariff

Day time (0530;1830)	11.82 LKR
Night Time (1830;2230)	15.47 LKR
Off Time (2230;0530)	7.04 LKR

1. Benefit from system peak capacity reduction
   - Peak Capacity reduction = 20.94 MW
   - Capacity Charge = LKR 2,553,632.36
   - Peak Capacity saving per year = mLKR 642.00
2. Benefit from system energy saving
   - Total peak time energy saving per month = 2,513.38 MWh
   - Day time energy saving by Category - B customers per month =1,741.32 MWh
   - Total off peak time energy increase per month= 4,727.43 MWh
   - Saving on Energy Cost per year = mLKR 314.00
   - Total Saving per year = mLKR 956.00

From the utility point of view the benefit is not only from the above considered energy and capacity saving. There are more benefits from the DSM project. Some of them are listed below.

- The investment on new power plants will be delayed since DSM can manage the existing generation to meet demand increment.

- Transmission and distribution investment also will be delayed since no new network needed.
- Efficiency improvement of the base load power plants during the off peak time interval through the increased demand.

C. Financial Evaluation of EVs

1) Benefit to utility

The benefit utility can be addressed in term of the valley filling. Since the valley is filling the complexity or the variation in off peak can be minimized.

TABLE 3 Valley Filling Results from EVs

Average valley during 12.30 AM to 05.30 AM (MW)	645
Average EV consumption 12.30 AM to 05.30 AM (MW)	462
Average % of Filled Valley	79

2) Benefit to consumers

It was assumed that average consumption above 60 kWh unit have the potential to move to EVs.

Time of Use Tariff

- Consumption above 60 kWh per month
- Block 3: 91 – 120 kWh
- Charge per unit (LKR): 27.75Cost calculation

Since the user travel around 600 km per week, let assume he is charging his car in everyday at off peak time.

TABLE 4 Savings from EVs

	Per Week	Per Month
Fuel Cost (LKR)	6000.00	24000.00
Electricity Cost (LKR)	4660.00	18650.00
Money Saving (LKR	1340.00	5350.00

IV. Conclusion

It can be concluded that forecasting of load profile can be done under two scenarios as short term and long-term forecasting. And by our research work we observed that the short-term prediction model the load will mostly correlate with the previous demand and respective time slot and also the day (weekday or weekend day). For the long-term forecasting is was observe that for long term scenario the consumer behavior has to analyze and the prediction had to be done separately according to the type of consumer category and finally add them all to observe the complete model. Both models we observed have an error percentage of 5% when it compare with actual demand. The two case studies under the DSM it was given that the CWS and EVS are viable project for the country. It was observed that 20.9 MW in the peak interval and 8.2 MW in day inter power can be saved and it can be accommodate during the off peak interval by adding 22.5 MW. Not only to utility can the consumers also be benefited through DSM since they don't need to pay additionally for the peak demand since they are using off peak energy. Utility can invest on this since utility gains and energy cost saving as well as a capacity cost saving by stopping the unnecessary starting of some power plants just to cater to the peak time energy requirement. Electrical vehicle is also a good solution to reduce the load profile variation on utility point of view and on consumer side it will be beneficial as we observed that in the financial evaluation since the cost for consumption is less compared with the cost for fuel. Further this study can be extended to more DSM scenario analysis and observe the viability. The predicted load model and the results of those scenario analysis can be used model a reliable dispatch model to the Sri Lankan Power system which will have higher economic benefits.

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