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Demand Management at Households in Sri Lanka through Dynamic Pricing and Demand Information Systems

Alfered Canistus G[1], Sakthivelnathan N[2], Thiruparan N[3], Jayasinghe D.H.G.A.E[4] Tilak Siyambalapitiya[5]
Department of Engineering Technology University of Jaffna., Sri Lanka[1,2,3,4]
Resource Management Associates (Pvt) Ltd[5]
Email: kanistas32@gmail.com[1], sakthi24.nathan@gmail.com[2], Thiruparannagenthiran@gmail.com[3], jakila@tech.jfn.ac.lk[4], tilak@rmaenergy.lk[5]

Abstract

In electrical power systems, expensive peaking power plants need to be operated to serve the peak demand. In Sri Lanka, the peak usually occurs late in the evening, caused by household demand. Peaking power plants are expensive to operate, compared with baseload power plants. Therefore, any electric utility desires to reduce the peak demand using demand management techniques. Demand management efforts in Sri Lanka are limited to mandatory time of use pricing for medium and large institutional customers. Household customers, the dominant customer category in terms of electricity sales, require to be brought into the time of use pricing regime. The main objective of this research was to conduct case studies to examine whether household customers are sensitive to price incentives. Financial incentives and information about their electricity demand were provided to a selected number of household customers to encourage them to reduce electricity use in the peak period. It was found that the approach has caused a reduction of the peak-time demand in all the selected households. This demand management technique may be refined and expanded to achieve a significant change in the load curve. The paper provides the mathematical formulation of a potential approach to dynamic pricing. The utility CEB may further analyses and implement this demand management approach.

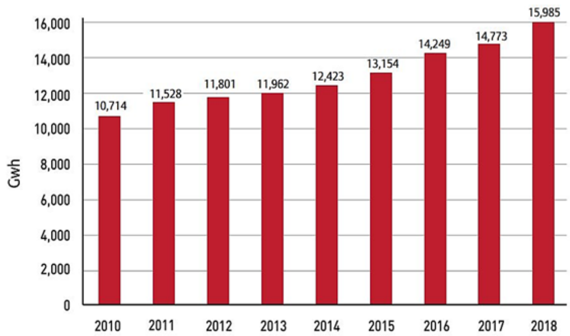
Keywords—dynamic pricing, peaking power plant

Introduction

Electricity today is an essential service for economic development and for the enhanced living style of the people. People use electricity mainly for lighting, heating, cooling, and refrigeration and for operating appliances, computers, electronics, and machinery. Today with the growth of technology and developments in industries, demand for electricity continues to increase. Electricity consumption increases along with economic growth and increasing population. According to the annual report of CEB [1],

by the end of that year, 5,543,137 households were provided with electricity, which is higher than the households served in the previous year (5,425,060). The average per capita electricity consumption which was at 626 units (kWh/person) at the start of the year had ended at 650 units by the end of the year. The number of new electricity connections provided during the year was 161,180, reflecting an average of 13,429 new customers per month, in CEB. LECO too sees increase in the number of customers. The overall electricity consumption of 13,431 GWh was recorded in 2017 increased to 14,091 GWh in 2018 (4.9% growth). By the end of the year, the total electricity generation was 15,985 GWh which is 8% more than the previous year with the generation of 14,773 GWh. Figure 1 shows the variation in generation in Sri Lanka.

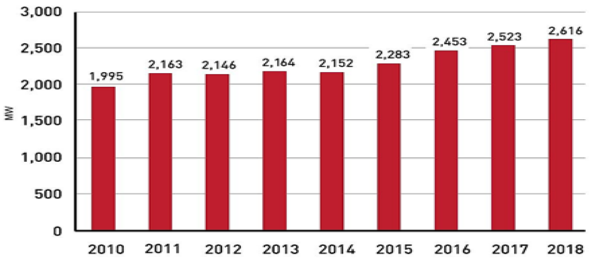
Figure 1: Variation of Gross Generation (2010-18) [1]



The maximum demand too, increases along with increasing consumption. The maximum demand of 2,523 MW recorded in the year 2017 increased by 3.7% in 2018 to 2,616.MW.

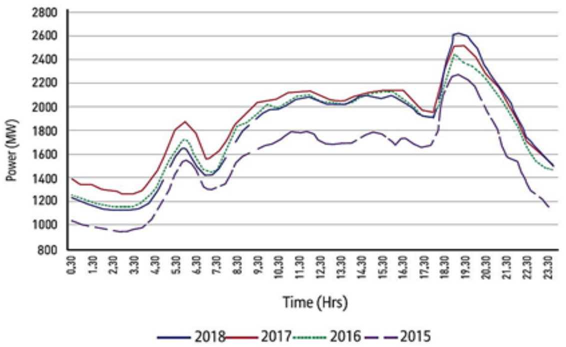
This increasing demand is the key element of this research. The most flexible, yet un-substitutable form of energy is electrical energy. It has been a critical resource for all nation-building activities which keep the countries' wheels in progress and economy to prosper. Therefore, the demand for electricity is ever increasing. The Figure 2 shows the growth of maximum demand.

Figure 2: Variation of Maximum Demand (2010-18) [1]



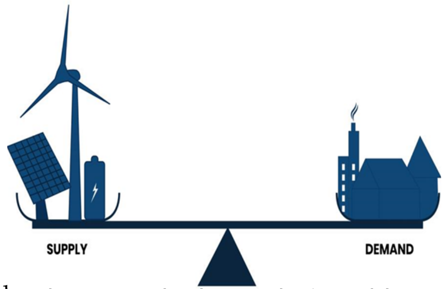
The load curve which shows the demand variations has a close relationship with human behaviour and other economic activities of the country. It has a morning peak of shorter duration, day peak of a relatively longer duration, and a sharp night peak, which is the maximum of all. Even though it is desirable to have a flat load curve, due to this behavioural impact, the curve has rather large variations. The extent of variation is so substantial that the maximum demand is about 2.24 times the minimum demand [2]. The ratio between the maximum and the minimum has increased from 44% to about 50% over 2012-2018. Increasing use of electricity causes the maximum demand to increase. Figure 3 shows the changes in the Sri Lankan load profile over the past years.

Figure 3: Variation of Load Curve (2015-18) [2]



In electricity generation, it is always a challenge to supply the varying demand. It is the responsibility of the utility to match its electricity supply to demand and maintain the balance between the demand and the supply. Figure 4. shows the illustration for the supply-demand balance.

Figure 4: Illustraion for Supply-Demand Balance



Baseload power plants are designed to operate throughout the day, whereas peaking power plants are usually operated only during peak hours. It is not always economical to balance the supply and the demand by constructing new power plants. Since the peaking power plants are expensive to operate compared with baseload power plants, the Ceylon Electricity Board (CEB) desires to reduce the peak demand using many techniques.

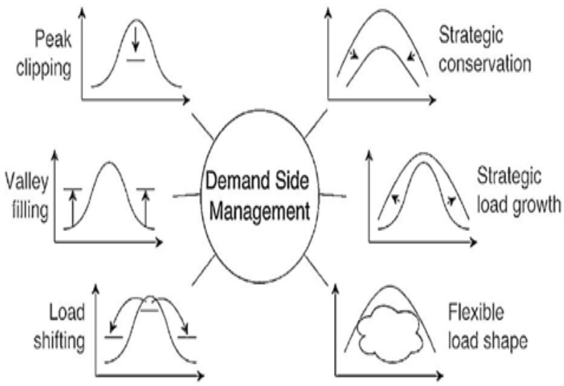
Household customers, the most dominant share in the Sri Lanka's electricity demand profile, are the key target in this research. The main objective of this research is to encourage a selected number of household customers to reduce electricity use during peak hours by providing financial incentives and demand information.

Demand Side Management

Demand Side Management (DSM) is the group of activities by the utilities to shape up the load curve, by influencing the customers on their use of electricity [3]. DSM consists of measures taken by utilities to influence the amount and timing of customer demand, to use scarce energy resources and power delivery infrastructure efficiently [4]. The main aim of DSM is to encourage customers to consume less power during the peak period or to shift their loads to off-peak period to smoothen the load curve. This allows the utility to reduce the use of peaking power plants which are more expensive.

DSM has been considered since the early 1980s. It targets to accomplish one or several load shape objectives, such as peak clipping, valley filling, load shifting, strategic conservation, strategic load growth and flexible load shape [5]. Figure 5 shows the basic load shape objectives. DSM means that the electricity demand is adjusted to generation and the availability of electricity in the grid and it both refers to reducing electricity demand and avoiding peaks [6].

Figure 5: Basic Load Shaping Techniques [5]



Related Work

DSM is a mechanism through which the demand for electricity of selected customers is managed (i.e., reduced or shifted to a different time period) in response to certain conditions [7]. DSM was introduced by Electric Power Research Institute (EPRI) as a concept that includes series of activities which government perform to increase social welfare and minimize the needed investment in the electricity industry in the 1980s [8]. There are numerous DSM approaches tested and applied over the past decades. The high contribution by household customers to Sri Lanka's total electricity consumption as well as the daily peak, caused the researchers to focus on DSM for households. A few DSM approaches are discussed below.

- Load priority
- Peak shaving and valley filling
- Differential tariff

Zhang and team [7] provide an implementation of a simple demand side management control strategy on the domestic customers, which is to reduce the coincident peak demand at LV feeder level by high power appliances. This was achieved by temporally stopping the turning-on by consumers of high-power appliances that are not already in use. This demand side management scheme can be deployed using wireless architecture. Consumer's inconvenience is the main research gap identified in this approach. The domestic load profile contains peaks, and peak shaving is achieved by controlling the equipment responsible for the peaks. Valley filling is achieved by allowing the customers to operate their appliances in the low load periods of the supply system. This will improve the efficiency of the system and flatten the load curve [9].

The study presented by Wang and Wang [10] describe the peak shaving and valley filling using a vehicle to grid (V2G) system. Electric vehicle battery charging in the low demand period is their strategy. Udrene and Bazbauers [11] state that the V2G system is able to support "peak shaving" by supplying up to 700 MW of electric capacity back to the grid, which is about 11% of the capacity of all the V2G cars connected to the grid. The battery life and charging time are major constraints in a V2G system.

In the study presented by Rahman and team [12], tariff selection for the household on three different tariffs was tested. Two of the tariffs are time of use (TOU) tariffs which were Power Shift (PS1) and Smart Home (SM1) tariffs, and the third one was a flat tariff identified as Home Plan (HP1). PS1 was divided into three time periods namely super-peak, peak, and off-peak periods. SM1 has four different time periods to consider, namely, peak, off-peak, weekday shoulder and weekend shoulder. HP1 is a flat tariff. The consumer gets charged a flat rate of their electricity consumption regardless of the time of use of electricity or how much they use. In this study, one typical residential consumer's electricity usage was evaluated in those three tariffs using power tracker. It concludes that according to the consumer's ability to shift appliances, the appropriate tariffs can be recommended.

Sri Lanka offered TOU tariffs to bulk customers (not households) since 1986, as an option to flat tariffs. Since 2011, TOU tariffs are mandatory for bulk customers. Since 2015, households are offered an optional TOU tariff. Sri Lanka Energy Balance [13] shows that the average selling price of electricity in Sri Lanka increased over time. Only around 200 household customers migrated to the TOU tariff offered to encourage at specific electricity use, as the peak time tariff was quite high.

Nevertheless, this offer will continue to benefit electric vehicle users in the future.

Malviya and team [14] present a prototype home electric volatility framework to monitor electricity usage. Control is achieved through a wireless sensor network and android mobile. Absence of physical display to provide demand information to customers is the major gap in this device. There are many studies on DSM are available. Here are a few specific literatures representing the studies on demand side management.

Sachdev and Singhe [15] highlight that DSM guides to regulate the customer demand through peak clipping and load management. DSM will be effective only by combining the aspects of energy efficiency with an incentive-based demand shifting. Additionally, information and communication technology help to change the end-use pattern of electricity.

Khanna and team [16] provide a conclusive statement that DSM measures have major contribution to electricity use behavior of consumers. That study was covered 1450 households in China. Their DSM measures were electricity pricing, energy labelling program, and information feedback. Results show that DSM measures have reduced the electricity consumption in the household sector of China.

Mayakrishnan [17] summarized that the household customers who belong to lower-income groups, use less efficient electrical appliances owing to the higher costs. The study says that the income level of customers is a key factor that influences the aspect of energy efficiency. DSM helps to reduce the peak demand.

Considering the literature and the relevant studies, it is very clear that there is a pressing need for a stronger DSM strategy, to improve the demand profile of Sri Lanka. The success of DSM techniques in other countries motivate the scope of this research.

Research Methodology

A random preliminary survey was carried out to determine the knowledge level of household customers regarding the DSM approaches. Then the power monitoring process was started with the selection of six number of houses for power monitoring. A pair of houses were selected under three categories of energy consumption, 120-150, 150-180, above 180 kWh.

Power Monitoring

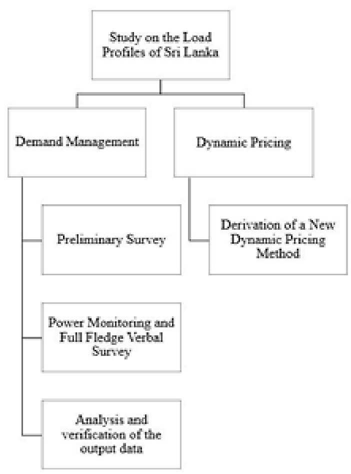
The Fluke 435 series II power quality and energy analyzer was used in this research. Electricity use of each household was monitored comprehensively over two days. On the first day, the usual usage pattern of the customer was monitored. On the second day, the analyzer monitored the consumption pattern of the customer responding to financial incentives offered in the study and to the availability of demand information. The load curve of day 1 illustrates the demand information of the customers. The financial incentive for each customer was to provide an incentive according to their level of participation in this proposed DSM strategy. As it was told to the customers, the additional financial incentive was provided by calculating the peak demand reduction from day 1 and day 2. For every one percent reduction 10 LKR was provided along with the fixed amount of 1000 LKR. The overall financial incentive which was provided for every household customer is shown in Table 1.

Table 1: Financial Incentives Provided

Home No.	Reduction (%)	Incentive (LKR)
1	60	600 + 1000
2	44	440 + 1000
3	81	810 + 1000
4	20	200 + 1000
5	48	480 + 1000
6	43	430 + 1000

The methodology followed is shown in the figure 6.

Figure 6: Methodology Followed



Dynamic Pricing

In this section, the proposed incentive to household customers is explained. The basic principle is that households will receive an incentive if they improve on their own demand profile, by moving away from the peak period.

I_i = Incentive factor in the interval i

P_i = Price with incentive in the interval i

Where, $i = 1$ to 48, each interval representing 30 minutes

P = Published price of electricity in the tariff

Then, let us define the price with the incentive to be,

$$P_i = I_i \times P \qquad (1)$$

To determine the incentive factor, the national demand profile on the peak day can be used. On the day where the annual peak demand occurs,

D_i = System demand in the interval i

D_{max} = System peak demand

$$I_i = \frac{D_i}{D_{max}} \qquad (2)$$

Accordingly, the incentive factor will be 1.0 at system peak, and the minimum value will be at the minimum demand interval. The demand profile of an individual customer is different to the demand profile of Sri Lanka. If the incentive calculated above is applied to a customer without adjustment, it is possible that the customer can be financially benefited by reduced electricity bills, even without shifting demand away from the peak period.

Therefore, the incentive factor was adjusted upward in such a manner that the customer's electricity bill will not change unless the customer shifts demand to off-peak periods. In the customer demand profile, where

D_i^j = Demand of customer j in interval i, before implementing the incentive

C^j = Electricity cost for a day of customer j, without incentive

C_I^j = Electricity cost for a day of customer j, with incentive applied

Without an incentive

$$C^j = P \times 0.5 \times \sum_{i=1}^{48} D_i^j \qquad (3)$$

With an incentive implemented, the customer demand profile remains the same,

$$C_I^j = 0.5 \times \sum_{i=1}^{48} P_i \times D_i^j = 0.5 \times P \sum_{i=1}^{48} I_{ix} D_i^j \qquad (4)$$

Since,
$0 < I_i \leq 1$,

$$C_I^j < C^j \qquad (5)$$

However, for no change in customer demand profile, it is required that $C_I^j = C^j$.Therefore, to ensure the above, the incentive factor may be multiplied by an adjustment factor. The adjustment factor is derived from successive approximation where $A^j > 1$. Therefore, the adjusted price of electricity for customer j will be:

$$C_I^j = 0.5 \times P \times A^j \times \sum_{i=1}^{48} I_{ix} D_i^j \qquad (6)$$

The adjusted incentive factors for customer j in the form of $I_i^A = A^j \times I_i$ will be unique to the customer, and he will be informed about the factors. Depending on the type of meter (basic electronic or smart meter with online access), the factors will either be pre-programmed into the customer's meter or will be remotely applied.

Results

The analysis of both days' load curves is the measure that can determine the participation level of the customer in demand management which is the main objective of the research. The involvement of the customers can be seen in the results. The day 1 profile is for the usual use of the household and the day 2 profile is for the same household with their participation in our DSM approach. The following figures show the comparison between day 1 and day 2 load profile of each household.

According to the survey, Home 1 customer has heavier loads such as a washing machine, water pump, refrigerator, electric iron, and ceiling fans. Even though there are heavy loads, only a few of them can consider as the shiftable loads. They are the electric iron, water pump, and washing machine, because the refrigerator needs to run throughout the day and ceiling fans need to run depending on the weather. This customer shifted his demand from (6.30 PM - 10.00 PM) to (8.00 AM - 10.00 AM).

Figure 7: Comparison of Demand Profiles (Home 1)

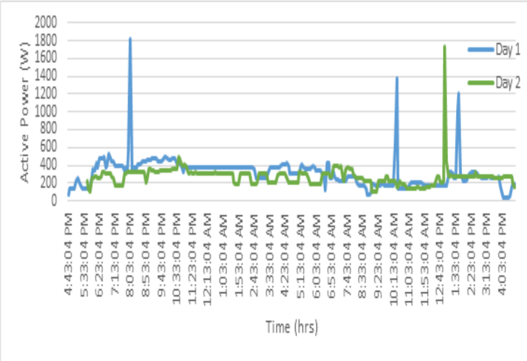
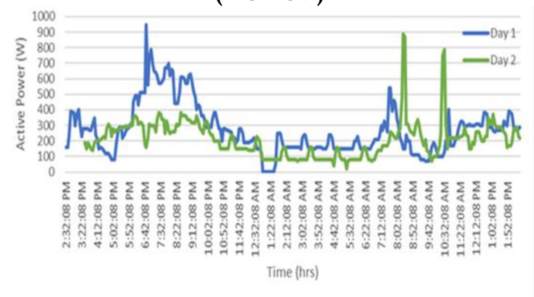
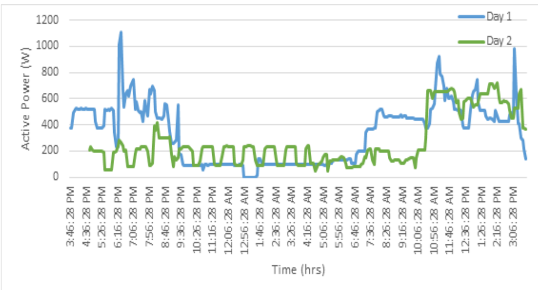


Figure 8: Commparison of Demand Profiles (Home 2)



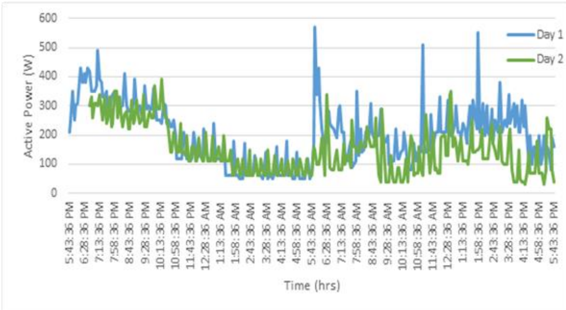
According to the survey, Home 2 customer has heavy loads such as a grinder, refrigerator, microwave oven, washing machine, water pump, exercise machine (treadmill), and electric iron. Even though there are heavy loads, only a few of them can consider to be shiftable loads. They are the electric iron, water pump, exercise machine, and washing machine because the grinder and microwave oven need to run as per the requirement. However, the customer can avoid using the grinder and the microwave oven at the same time to avoid a high peak. This customer shifted his demand from (6.30 PM – 9.30 PM) to (10.00 AM - 3.00 PM).

Figure 9: Comparison of Demand Profiles (Home 3)



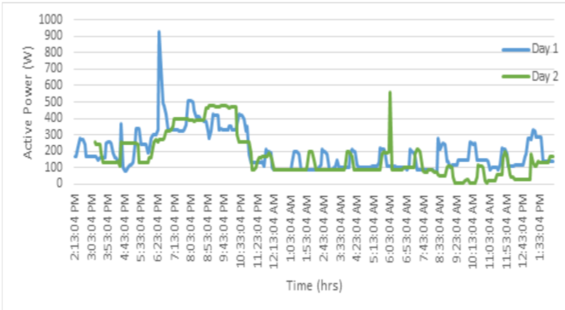
According to the survey, Home 3 customer has heavy loads such as a grinder, electric hot plate, microwave oven, refrigerator, water pump, and electric iron. Even though there are heavy loads, only a few of them are shiftable loads. They are electric iron, and water pump because the grinder and electric hot plate need to run when required. The customer can avoid using the grinder and the electric hot plate at the same time to support demand management. This customer shifted his demand from 8 PM to 1 PM.

Figure 10: Comparison of Demand Profiles (Home 4)



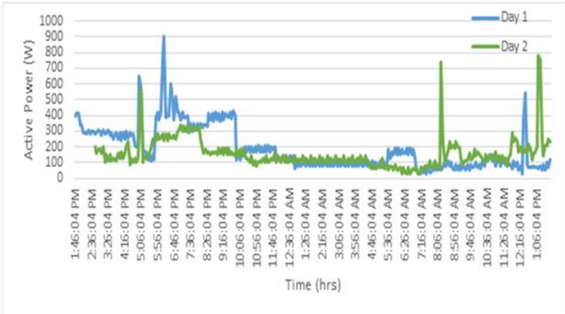
According to the survey, Home 4 customer has heavy loads such as refrigerator, ceiling fans, electric iron, and water pump. Only the lectric iron can be considered to be a shiftable load because the refrigerator needs to run whole the day and ceiling fans need to run required. This customer does not have a significant potential to shift some of his loads. However, he reduced his demand and overall energy to respond to the financial incentive.

Figure 11: Comparison of Demand Profiles (Home 5)



According to the survey, Home 5 customer has heavy loads such as a water pump, refrigerator, electric kettle, electric iron, and a toaster. Even though there are heavy loads, only a few of them can are shiftable loads. They are the electric iron and the water pump. This customer shifted his demand from 6.30 PM to 6.00 AM.

Figure 12: Comparison of Demand Profiles (Home 6)



According to the survey, Home 6 customer has heavy loads such as a water pump, refrigerator, washing machine, electric iron, and a toaster. Even though there are heavy loads, only a few of them are shiftable loads. They are the electric iron and water pump. This customer shifted his demand from (6.00 PM – 7.00 PM) to (8.00 AM – 9.00 AM).

Table 2 gives the comparison peak demand and energy use between day 1 and day 2, of all the six households.

Table 2: Peak Demand and Energy Usage Comparison

Home No.	Peak Demand		Energy Usage	
	Day 1	*Day 2*	*Day 1*	*Day 2*
1	950 W	380 W	6.5 kWh	4.8 kWh
2	750 W	420 W	8.1 kWh	6.1 kWh
3	1810 W	350 W	7.6 kWh	6.3 kWh
4	490 W	390 W	4.8 kWh	3.4 kWh
5	930 W	480 W	4.8 kWh	3.9 kWh
6	600 W	340 W	4.5 kWh	3.5 kWh

Conclusion

A comprehensive demand management strategy to encourage household customers to reduce their peak-time electricity use was implemented at six households by providing a financial incentive and demand information. Through this strategy, all six customers have reduced their peak demand in response to the financial incentives and demand information. This indicates that the selected household customers are sensitive to price incentives. The result of this approach clearly shows that the main objective of the research was achieved successfully.

The financial incentive needs to be replaced by the proposed dynamic pricing, to implement this strategy throughout Sri Lanka. It can be concluded that dynamic pricing for household customers will be a better demand management approach. We suggest this dynamic pricing to CEB., to be implemented after a fully-fledged island-wide survey and a pilot project.

Further, this research can be extended to a greater number of households for longer durations and observe the viability of this strategy in Sri Lanka. The result of six households can be used as the basis for further research. Even though this demand management approach is viable and cost-effective, the customer will be reluctant to participate, because of the lack of knowledge about DSM. Future research may focus on strategies that can provide basic knowledge of DSM to customers in a more effective manner. The utility too, can support its customers through arranging an awareness program, which will provide a good understanding the consumers about demand management approaches and the status of the country's electricity supply.

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