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Demand Side Management using Dynamic Pricing: A case study in Civil Homes-Dhapakhel, Nepal

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Abstract
Effective and efficient use of electrical power has always been a topic of discussion of modern world. Not only energy utilities but also a end consumer can make efforts to make smart use of electrical power. Demand side management is a group of such actions which helps in optimizing the energy consumption pattern of the end user. As power demanded by consumer varies, different load consumption pattern may be noticed with respect to time. In residential buildings, power demand is high in evening and morning time whereas power demand is low in other time of the day. Conventional meters are independent of energy consumption pattern and charges flat retail electrical prices to consumer. However, smart-meters can make records of energy consumption and able to send information to the utility.In this study, survey of the Chapagaun distribution feeder in colony area under Lagankhel substation, Kathmandu is conducted.With sample size of 63 consumers from 75 consumers, 16 appliances are noted and are categorized under shift able and non shift able loads.Shift able appliances are separately scheduled to solve inconvenience of manual switching bu using Energy Consumption Scheduler (ECS) called smart meter to reduce peak loads. Peak to Average ratio of ECS system demand is minimized in our study which is achieved by changing the consumer behaviour and by changing electricity price with respect to demand of power.i.e for lower demand electricity charge is low and charges is high for high demand which is also called dynamic pricing.From optimization results peak load was successfully reduced to 68.32kW from 86.59kW and also a significant improvement in load factor from 25.52% to 32.34% is obtained.

Keywords
Appliance scheduling, Demand Side Management, peak clipping, Dynamic pricing, Energy consumption pattern

1. Introduction

Traditional power grids face many existing and potential problems, such as power outages. In this context, there is increasing demand of electricity from residential customers in the recent years[1]. Therefore, there is a great need of energy efficiency and demand reduction program for the effective and sustainable operation of the power system. The majority customers nowadays are charged flat retail electricity prices though the electricity prices fluctuate accordingly to the generation cost. Consequently, the customers do not have the incentives to shift their electricity use from peak time to off-peak time [2].

Compared with building more power plants to meet the growing needs of customers, demand response is a better choice to solve the above problems[3]. Demand response is defined as end users' changes in way of consuming electricity in response to changes in electricity prices over time, or payment of incentives to introduce less electricity usage prices during peak periods of the wholesale market [4]. Real-time pricing is one of the incentive programs that encourage consumers to personally and voluntarily manage the demand provided by electricity providers[5]. Electricity prices under vary at different times of the day, reflecting the real-time cost of generating and transmitting electricity. As prices varies with load rates are high at peak and low at off-peak time therefore, consumers are encouraged to shift their consumption to off-peak hours[6]. The peak clipping and valley filling activities are being done automatically to achieve the flatter load curve thereby decreasing the peak to average ratio of electricity consumption.Since the purpose of the study is to provide a schedule for the energy consumption of each user's device, a binary program is solve the problem to achieve the best results[7]. Thus, a binary variable 0 or 1 represents appliances conditions of the on and off state. MATLAB-based modeling system is used for this optimization. MATLAB is a useful tool as it uses object oriented programming where we can include class, virtual scheduling, packages inheritance, semantics, this languages of syntax and calling convention are rarely used in other software [8]. The optimal load scheduling program can be determined using a Gurobi optimization that provides a cost-effective way of consuming scheduling vector for each user autonomously controlled by smart meter. It communicates the information to the consumer for greater clarity of consumption behavior, and electricity suppliers for system monitoring and customer billing[9].

The proposed model is being used to find the scheduling of equipment for a single-phase user in a colony area deployed in Civil Homes, Dhapakhel, Nepal in a 100 kVA auxiliary distribution transformer.

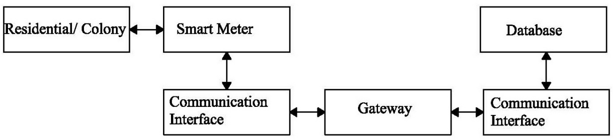

Figure 1: Smart Meter System

2. Problem Formulation

2.1 Model Parameter

1. Variable: Appliances(16), Total hours(96), Number of consumers(63)
   - All variables are worked in binary system.
2. Objective Function: Maximization of Load Factor
3. Constraints:
   (a) Operating time of all appliances of each consumers should be same.
   (b) Non-shift able appliances are not optimized.
   (c) Optimization shifts the appliances to permissible time slot which are shift-able.
   (d) Cost of electricity should not exceed the existing cost.

Consider a power system with distribution lines connected with a appropriate means of transmission [10].

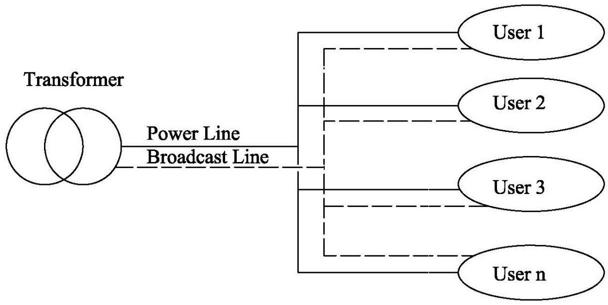

Figure 2: Radial network

Without loss of generality, the granularity of time is taken as quarter hour. The total load across all users at each quarter-hour of the day $t \in$ T an be calculated as,

$$kW_t \equiv \sum_{n \in T}^{n} kW_n^t \tag{1}$$

The maximum and average demand are calculated as,

$$kW_{peak} = max(kW_t) fort \in Tand \tag{2}$$

$$kW_{avg} = \frac{(\sum_{n \in T} kW_t)}{T} \tag{3}$$

$\therefore$ the PAR of the system is,

$$PAR = \frac{kW_{peak}}{kW_{avg}} \tag{4}$$

$$LF = \frac{1}{PAR} \tag{5}$$

The simulation setup considers 63 users served by a utility company. Each user consists of 16 appliances, divided into shift-able and non-shift-able devices.

Table 1: Non-shift able and Shift-able Appliances

Non-shiftable device	Shiftable device
Lighting	Induction Heater
Refrigerator	Hot Plate
TV	Oven
Phone Charging	Washing Machine
AC	Water Pump
Electric Geyser	
Space Heater	
Computer	
Router	
Laptop	

Table 2: The average Power consumption of appliances

Appliances	Wattage(kW)
Lightning	0.05 to 0.5
Induction Heater	1 to 2
Hotplate	1 to 2
Oven	1 to 2
Space Heater	0.4 to 1.2
Washing Machine	0.5 to 0.75
Laptop	0.04 to 0.2
Refrigerator	0.05 to 0.08
Router	0.01 to 0.02
Water Pump	0.75 to 1.5
Phone Charging	0.01 to 0.06
Computer	0.16 to 0.24
TV	0.05 to 0.25
AC	1 to 2
Electric Geyser	1 to 2

A developed model consists of 63 users with 16 devices. Each consumer operates their devices all day over their intended time. Thereafter, the energy consumption schedule in the spreadsheet for each user in a slot is 96 times daily in a slot. The spreadsheet file is then entered in MATLAB to process data. At MATLAB, the load curve is extracted from every user and the system.

ECS assumes an separate control of the power consumption of any shift-able device. The appliance is variable to switch on or off time for optimization. So the problem is scheduling by using Gurobi optimization for maximizing load factor.

2.2 Proposed Strategy

The goal of the proposed system is to maximize the Load factor and reduce the peak demand.

maximize (LF)

3. Methodology

3.1 Case Area

This study is considering Civil Homes, which is part of the colony area of the Kathmandu Valley. The reason is that it is a purely residential area. Since this secondary distribution feeder has not connected commercial and industrial loads, the load can be identified as a full residential load and used for sheltering . The area of Civil Homes is selected as to avoid the effects of other commercial and industrial loads and their building design are particularly same.

(source: Google Earth ©2021)

Figure 3: Case Study area in map

3.2 Dynamic Pricing

Conventional electricity rates are block rates. Nepal Electricity Authority charges energy bills at various prices depending on the number of energy blocks. In order to allow consumers to participate in DSM, the block fee rate has been changed to a dynamic price based on system demand. The proposed pricing scheme charges electricity usage at different prices at different times of the day, depending on the demand of the system. Change block rate rates to dynamic price rates.A linear demand function has been proposed for costs. The existing NEA tariff is Rs 4 to 12 for various energy consumption for residential consumers.

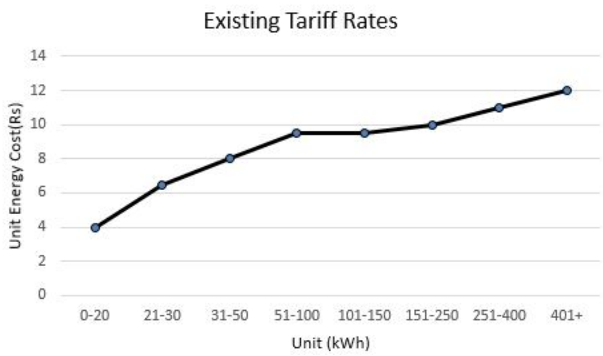

Figure 4: Block Meter Rate Tariff [11]

For setting the flexible cost of the product or services we can use dynamic pricing. It is also called real time pricing which aids in business by setting the cost as services by adjusting price according to demand.In order to change the behavior of consumers switching equipment for system health, the consumer must increase the load usage during off-peak times and at the peak of more charging than usual to discourage the addition of a working device. . Therefore, the real-time price is considered in the study as the electricity rate depends on the system load[12]. For model development, the simplified cost function considered in the optimization problem is: Because consumers can benefit from participating in DSM, is chosen so that the total cost of the system does not exceed the before optimization cost. Program than if you did not participate in the DSM program [11]. Based on these price gap, a price has been set from Rs. 4 to Rs. 12 for minimum and maximum demand respectively over a day representing a linear function.

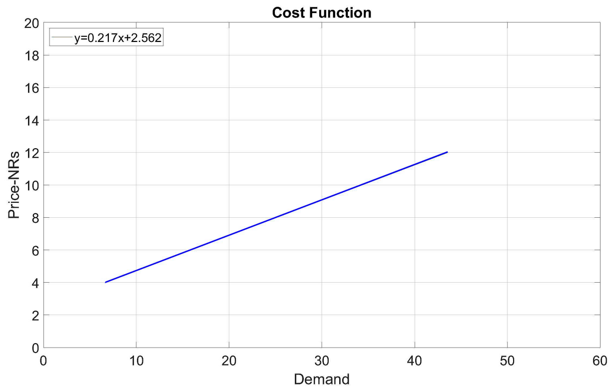

Figure 5: Price vs Demand

3.3 Data Collection

The Questionnaires were prepared and distributed to each of the domestic consumer of the secondary distribution substation which consists of 75 users. Household survey was based on personal interview as well as their previous data which is collected by civil homes. As the number of users connected to this secondary substation is only 75, but the data was collected from 63 users. Out of 75, only 63 users are considered using random sampling method. From the survey, the different appliances, their wattage, operating schedule and their electricity bill were collected of all four seasons of the year.

3.4 Load Factor

The load factor measures the efficiency of your home's electrical energy usage. It is calculated by dividing the total power (kWh) used in that month by the peak demand (kW), multiplied by the number of days in a billing cycle and the total number of hours in a day.

$$LF = \frac{\text{Average Load}}{\text{Peak Load}} \tag{6}$$

4. Results and Discussion

The program is simulated in MATLAB software. In the simulation, the secondary distribution grid is assumed to consist of 63 real-world residential users servicing from the utility. Non-Shift able home appliances refer to loads such as refrigerators and lighting, and loads such as water pumps and washing machines are classified as shift able loads. For loads that cannot be moved, assume that the refrigerator,router operates all day long. Other loads must behave exactly as consumers do before subscribing to the ECS service. Suppose you have a little flexibility to operate cooking equipment such as induction heaters, hot plates and ovens. With time delays or traditional tariff systems, before consumers want. Meanwhile, water pumps and washing machines are scheduled to optimize energy use for flexibility that allows them to switch at any time, except from 10:30 PM to 4:00 AM at midnight to avoid the inconvenience of switching.

4.1 Determination of Existing and New Demand Profile

The load profile of the existing system was observed too unevenly. The peak appeared twice a day. On the other hand, demand was low. This can be clearly seen in Figure 5. This load profile has a low average power demand and a high peak value. The peak of the system reaches 86.59 kW at 6:00 PM 7:00 pm. The system has a load of 4.99 kW at night (12 AM to 4 AM).

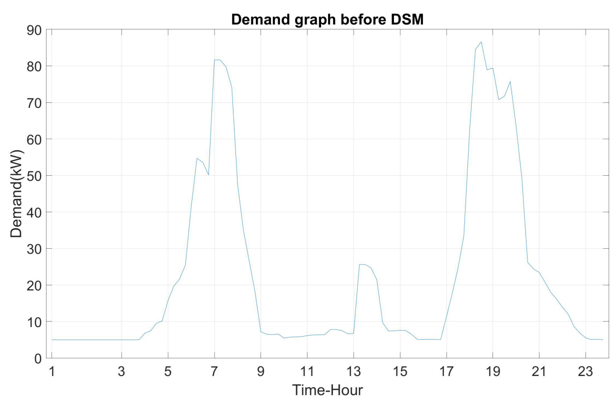

Figure 6: Electrical energy demand profile before DSM

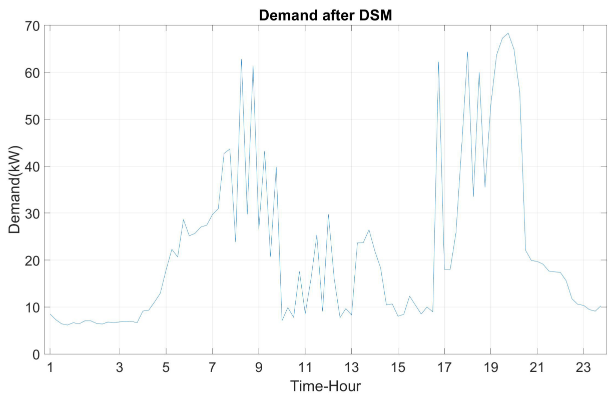

Figure 7: Electrical energy demand profile after DSM

The loads are dramatically re-programmed to form a softer load curve. Peak and valley are full of considerable amounts. The maximum load decreased from 86.59kw to 68.324 kW, which is a decrease of 26.73%. The valley did not fulfill a lot of power that was occupied by a small amount of energy. In other words, the load is effectively displaced to the average demand 22.096kW.

Table 3: Energy Demand Analysis

SN	Parameters	Before DSM	After DSM
1	Demand	86.59 kW	68.324

4.2 Electrical energy demand deviation

The energy demand deviation chart is obtained by subtracting the demand after DSM from the demand before DSM at different times of the day. A negative value represents an increase in load. It's daytime here, starting at 10 o'clock in the morning, the load has being shifted from other time except 1:00 PM to 3:00PM, which effectively helped achieve the goal of DSM. Positive kW is also an index for adjusting the load ratio. the main cuts can be seen both in the morning and in the evening as in figure 8. The reason behind this is that 96% of households use motor pump, and households use washing machines. Their current operating hours are random but concentrated in the morning and afternoon. The simulation model allows you to change the operation at any time of the day, except midnight (10pm to 4am).

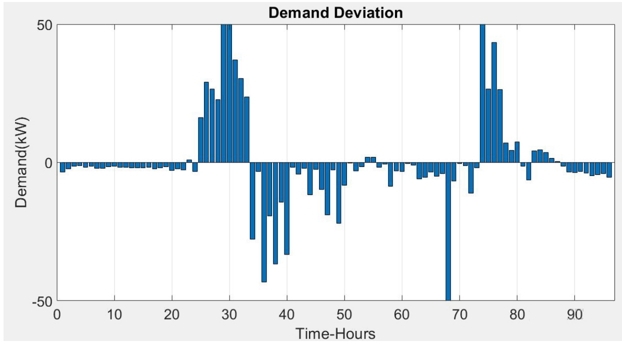

Figure 8: Energy-Demand Deviation

4.3 Assessment of Electrical Cost

The electricity cost considered by traditional electricity prices is taken from the annual average electricity cost provided by public utility companies for its consumers across the country, and is calculated as NRs. 9.52 and charge per kilowatt-hour of energy consumption. Calculating the electricity cost is to simplify the calculation, taking the average of the monthly electricity bill and the total energy consumed.

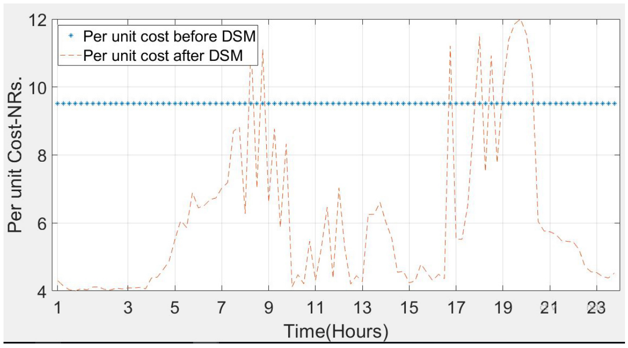

Figure 9: Per unit cost comparison

Because the main goal of demand-side management is to maximize Load Factor. Since appliances are reprogrammed to reduce peak system demand, as long as the total operating hours of any appliance does not decrease, the peak-to-average ratio should be reduced to keep the average value the same as the existing one. Therefore, the LF value should increase with the maximum load. PAR dropped significantly after running optimization. The load factor is the reciprocal of PAR, which reflects the cost of services provided by the utility company, which is a significant increase of 25.52% from 32.34%. Increasing the load factor is a direct benefit for the company, because the peak period has been reduced and the valley has been filled. The cost of stopping and starting the generator is reduced, and the installation of new equipment is avoided as the cost increases index.

Table 4: Load Factor Analysis

SN	Parameters	Before DSM	After DSM
1	Load Factor	25.52 %	32.34%

Conclusion

This document establishes an optimization model for home appliance programming based on demand-side management. The model uses the energy consumption data of 63 residential users. This has led to a significant increase in energy use and energy use efficiency. The scale of benefits for consumers and utilities can be adjusted by changing the cost function of the system. Therefore, DSM measures, such as the appropriate dispatch of demand response equipment, can be an effective option for the protection system to realize the economical and stable operation of the power system.The simulation results show that the proposed DSM strategy can reduce the energy cost benefits of NR and reduce the average peak demand at night from 86.59 kW to 68.32 kW.Variable prices in the range of 9.52 to NRs. (4 to 12), with average NRs. 6.05. The load factor increased significantly from 25.52% to 32.34%.

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