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Flattening of Load Curve in Smart Grid using Heuristic Approach

S. S. Kasar
Post Graduate Student
All India Shri Shivaji Memorial Society College of Engineering, Pune, India
V. N. Gohokar
Professor at Electrical Department
All India Shri Shivaji Memorial Society College of Engineering, Pune, India

ABSTRACT

From the very outset, Energy has played a vital role in development of civilization. Degree of energy used is a symbol of progress of country, and as the progress increases, corresponding utilization of energy also increases. To fulfill these increasing demands, it is essential either to increase the electricity generation or to use available energy effectively. The conventional generation models and electric grids are therefore expected to radically change their behavior and becoming "Smarter." Out of number of techniques of making existing power grid Smart, Demand Side Management is found as more effective technique. Demand side management allows consumers to know their own energy usage and suggest the ways to control their usage and reduce their energy bills. Through demand side management utilities also get rid of peak demands and peak hour stresses on the system. A consumption scheduling mechanism for load management in smart grid using Integer linear programming along with Heuristic optimization, gives a new automated Demand Side Management technique. We are aiming at flattening of load curve by shifting the loads from peak duration to off peak duration. The proposed mechanism is able to schedule the load in terms of both, the optimal time and optimal power, by identifying Time-Shiftable and power Shiftable appliances respectively. This optimization of load is based on combine effect of 'Linear Programming' and 'Heuristic approach.'

Keywords

Demand Side Management, Linear Integer programming, Heuristic approach, time based optimization and power based optimization of load.

I. INTRODUCTION

The infrastructure of electricity consumption has changed to greater extent from the same during the electricity had been invented. Now days, with modernization of peoples' life style, means of electricity usage are also getting advanced. Though such advanced use of electricity leads to luxurious life of society, it also leads to the challenges in terms of environmental issues, security and utility management, etc. Power industries now aiming at developing the next generation of power grid as a reliable and intelligent system as well as a "Green Grid" system, and pursuing with this aim, number of techniques for power system management are introducing and developing. To make our power greed green, it is essential either to enhance the generation of electricity or to manage the load on power system. Smart grid allows massive integration of unpredictable and intermittent renewable energy resources, and distributes power in highly efficient ways. Smart grid uses distributed energy resources and advanced communication and control technologies to deliver electricity more effectively with low green house gas emission and active involvement of Consumers as well.

This new technology consists of many components that play major role in making grid Smarter for e.g. Smarter Generation, Transmission and Distribution systems, Smarter substations, Smart loads and appliances, smart measurement systems, integration of renewable energy resources, etc. Out of all these

components of Smart grid, Smart meters though forms a tiny component, it is going to play a significant role in smart grid management and control. [2][3]

For efficient and stable operation of grid, electric supply and demand must remain in balance in real time. Therefore as an electrical engineer, it is essential to search out for a novel way to cope up with increasing need of energy, and to reduce the gap between demand and supply which include additional generational capacity in terms of renewable energy resources, improving system efficiency and stability, supply as well as demand side management.

To achieve this, it is essential to workout with real time information, integrating distributed intelligence using sensors with demand response programmes with providing new choices to the consumers. [2][3]

Automated Generation Control (AGC) can achieve the generation enhancement, where as load control can be effectively done through demand side management. In Smart grid, Load forecasting in demand side management, allows consumers to know and control their own electricity usage, while load scheduling offers them a right path to obtain efficient energy management without losing the comfort of using electricity. [4] Up till now, lot many strategies are introduced in the area of demand side management, but the work behind this paper is focused at demand side management based on load shifting, based on power and time optimization technique. However, practically the optimization technique may change according to the behavior of electrical appliances. For e.g. for the appliances which has to work according to its own power requirement, could be enumerate for power optimization, but the same appliance could operate under the time optimization effectively and vice versa.

In this paper we are suggesting a hybrid technique for demand side management through power and time optimization considering both, satisfaction of consumers and utilities; as well as making the existing grid as “Green Grid.” With this optimization technique, we are able to flatten the load curve, by shifting he peak demands to off peak hours. For implementing this optimization, Residential load network area is considered primarily, however it can further be employed to Industrial and commercial load areas also.[5][6]

Considering users’ own load plan, flattening of load curve is achieved during this study. We are aiming at not only to shift the peak demands to off peak hours but also to reduce the peak demands; along with the satisfaction of consumer and utility both. Using demand side management techniques, we can design a new load schedule and available load- reduction capabilities of the system for each time duration set, and accordingly utilities can offer various time and cost incentives in the market. This will ultimately encourage consumer to adopt demand side management.

There are number of Demand side management techniques suggested in the literature. Some of these techniques are system based or strategy based or strategy based or based on variety of devices to be taken under demand side management and also based on number of devices to be handled. However it seems that consumers do not have much control over their energy consumption with these strategies; hence a demand side management strategy need to handle large number of power devices along with consumer satisfaction and freedom of electricity usage. From electricity consumers’ perspective, there should be a freedom of selecting economic and efficient electricity usage; and from utility perspective there should be a flattened generation curve. To achieve these perspectives, a significant part of generation is now followed by the use of Renewable energy resources. In spite of unreliable and unpredictable nature of renewable energy sources, they can be effectively used with storage techniques to minimize the peak durations along with the conventional energy resources. [9][10]

In this paper, a demand side management technique is proposed for smart grid, which will automatically switch the Shiftable loads and achieve the peak load shifting of several numbers of groups of devices. A heuristic optimization technique is used for selecting the suitable device to operate at suitable time period, and using Linear Integrated Programming technique, automatic shifting of selected lode is done from peak hour to off peak hour, also from rated power consumption of loads to reduced power consumption for the power shift able loads.

A load curve after and before Demand side management is obtained, by designing a prototype which is controlled by a program, for automatic load shifting for variety of loads. Also during this study, a practical load data from substations of different locations is analyze mathematically and some equations along with an evolutionary algorithm is developed, which can easily implement demand side management technique effectively.

The paper is organized further more as follows. Load analysis and proposed automated demand side management is described in section II. Automated prototype is briefly explained in section III. Algorithm and programming results are given in section IV and in section V the whole study is concluded.

II. Flattening of Load Curve

A. Load Analysis

Smart meters are the key components of the Smart grid. It collect all the information regarding to the consumer's own power consumption plan, and accordingly suggest the scheduling information to the utilities as well as to the consumer.

These meters collects the information showing power consumption of each device connected to the grid, and then globally optimize the hourly consumption of all the devices and accordingly schedule them to achieve demand side management. Based on collected data of power consumption before any optimization technique applied, a maximum allowable value for power consumption is set, say Threshold Value. Then the optimization is applied. During this optimization, all the connected devices are categorized into two brief categories of Shiftable and Non-shift able loads based on their time of operation and power consumption. Optimization will ensure the continuous power supply for the devices requiring fixed power supply at fixed operating time. But for Shiftable devices, the automatic switching of these devices will carried out, if the power consumption for particular time period is increased beyond predetermined Threshold value. Due to such shifting of devices, there could be the reduction in peak demands, and peak hours, which will smooth the Load Curve. [13]-[21]

Along with Shifting the peak load demands on the system, demand side management aims at valley filling technique in order to flatten the load curve. This valley filling can be achieved by using renewable energy resources. During preferable environmental conditions, energy generated from renewable energy resources is stored and can be utilize to full fill the load demand to flatten the load curve.

II. PROPOSED DEMAND SIDE MANAGEMENT WITH HEURISTIC AND LINEAR PROGRAMMING OPTIMIZATION

The consumption Scheduling mechanism can be mathematically expressed using linear optimization in order to minimize the peak load, during peak hour as below:

$$P(SSE) = \sum_{t=1}^{N} [P(Load\ (t)) - P(Objective\ (t))]^2 \qquad (1)$$

Where, SSE is Sum of Square Error and it must follow,

$$P(SSE) \leq P(Threshold) \qquad (2)$$

$P(Load\ (t))$ Is the actual power consumption at time (t),

$P(Objective\ (t))$ Is the value of objective curve at time (t)

Now, $P(Load\ (t))$ can be calculated as,

$$(P(Load\ (t))) = P(Forecast\ (t)) + P(Connect\ (t)) - P(Disconnect\ (t)) \qquad (3)$$

Where,

$P(Forecast\ (t))$ Is forecasted power consumption at time (t)

$P(Connect(t))$ Is total connected load at time (t),

$P(Disconnect(t))$ Is total disconnected load at time (t).

Now let,

$$P(Forecast(t)) = 0.2 \times P(Connect(t)) \quad (4)$$

$$\therefore P(Forecat(t)) = 1.2 \times P(Connect(t)) - P(Disconnect(t)) \quad (5)$$

Now, for any time duration say t = (i) to (t-1);

Power consumed by connected load can be determine by

$$P(Connect(t)) = [\text{No. of devices connected}] \times [\text{Power consumed by each device}]_{t=i}^{t=(t-1)} \quad (6)$$

Similarly,

$$P(Disconnect(t)) = [[\text{No. of devices Disconnected}] \times [\text{Power consumed by each Disconnected device}]]_{t=i}^{t=(t-1)} \quad (7)$$

Now, considering P [objective (t)] = [R]

I.e. Variable [R] is representing predetermined objective power Consumption of the system.

Also let, Maximum power consumed by the load is recorded as [L] during time (t) from [i] to [t-1]; Then,

$$P(Threshold(t)) = (L \times 0.8) \quad (8)$$

Now by analyzing all equations, the desired condition of,

$$P(SSE) \leq P(Threshold)$$

Can be obtained and Demand Side Management can be achieved.

During this optimization, Demand Side Management formulation have assumed as the connection time of Shiftable devices can only be delayed and not brought forward. Also, the number of devices to be shifted should not be a negative value. The proposed optimization aims at to minimize the $P(SSE(t))$ as possible, so as to achieve desired demand side management strategy.

III. AUTOMATED PROTOTYPE

As shown in Fig. 1, complete system can be divided into two units. First unit consists of microcontroller Arduino Uno along with LCD, current transformer, loads, and triac, relay and power supply.

Loads are interfaced with microcontroller through relay and triac. Output of current transformer is monitored using ADC channel of microcontroller.

Particular wattage is displayed on 16X2 LCD. PWM channel is used to control power used by a load which drives triac. Serial module is interfaced to UART 1 port of microcontroller which transfers power values serially out to PC.

Second unit consists of a PC along with MATLAB. This unit is required to get the data from microcontroller and display it on screen. Using MATLAB we have designed Graphical User Interface (GUI). GUI enables the connection of PC with serial module through serial port. Also it displays power data in watts on time axis.

In this case study, on a typical day a set of Residential appliances and their power requirements as listed in Table 1. This study can be further extended for the commercial and Industrial survey as well in the same way as for the Residential load.

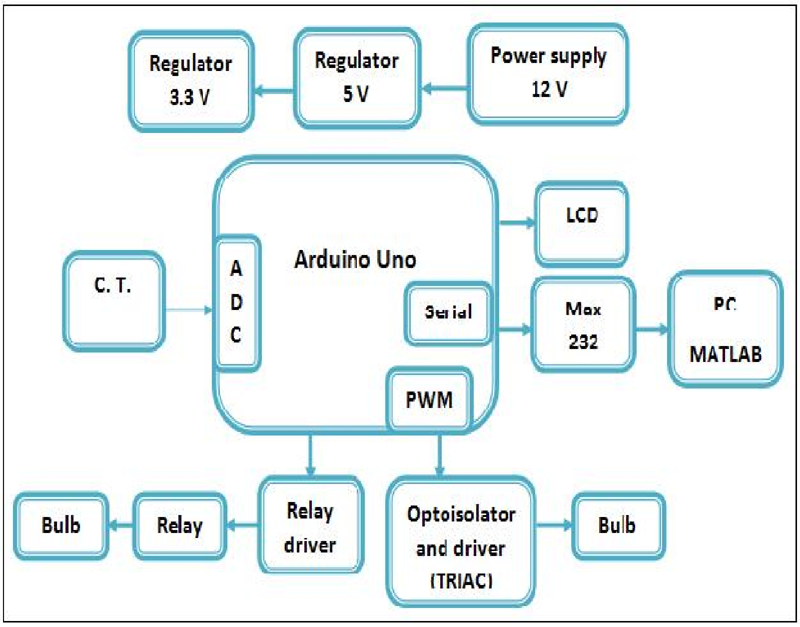

Fig.1 Block Diagram

It is observe that the same optimization technique if find effective with considerable power and cost saving in electricity bills. Usually more the number of devices available for the control, more effective results will be there for demand side management. But during this study, it is observe that, power ratings for the Industrial equipments is much higher than that of Commercial and Residential equipments, and Commercial equipments consume more power than Residential loads. This is because, even though the number of devices available for control in Industry are less, and also they are working for the less time period of the day as compare to Residential and Commercial equipments, Power scheduling of these Industrial devices will give highest Power saving. Similarly in Residential area, number of equipments available for control is more, but the percentage reduction in Power consumption and cost is lowest.

This can be concluded in the fact that, Load shifting of high power rating equipments gives huge power saving.

No.	Name	Type	User Preference and Power requirement per day.
01	Water Heater	Non-Shiftable	5am-7am, 10pm-11pm Hourly consumption:1kWh.
02	Refrigerator	Non-Shiftable	Operating 24hrs Hourly consumption: 0.12kWh
03	Water pump	Shiftable	6am-7am, 6pm-7pm Hourly consumption: 0.4kWh
04	Washing Machine	Time Shiftable	Operating two hours per day Hourly consumption: 0.5kWh
05	Laptop charger	Time Shiftable	Operating one hour per day Hourly consumption: 0.1kW
06	Lighting system	Non-Shiftable	6am-7am, 7pm-11pm Hourly consumption: 0.180kWh
07	Microwave Oven	Non Shiftable	9am-11am, 7pm-9pm Hourly consumption: 1kWh

Table 1: Appliances and Power Consumption Pattern for Residential load

IV PROPOSED ALGORITHM AND RESULT

Each type of load is having different consumption characteristics and can have several heuristics; hence the designed algorithm must possess ability to handle all the devices to achieve effective Demand side management. We have proposed such evolutionary algorithm for automatic scheduling of the load and to achieve effective automated Demand side management.

Algorithm for Linear programming:

1. Initialize serial port at baud rate 9600.
2. Initialize PWM at 50Hz and 100% duty cycle.
3. Initialize ADC1.
4. Read the ADC pin and save data at adc_data variable.
5. Display saved data on LCD
6. Also send ADC reading to PC end
7. Check if ADC data is greater than 90
8. If ADC data is greater than 90, set PWM duty cycle to 75%
9. Check again if ADC data is greater than 90
10. If ADC data is still greater than 90, set PWM duty cycle to 50%
11. Send ADC reading to PC end through UART.
12. Check again if ADC data is greater than 90
13. Clear the relay pin
14. Send ADC reading to PC end through UART0
15. If ADC data is still greater than 90, set PWM duty cycle to 1%
16. Check if ADC data is less than 90
17. If ADC data is less than 90, set the relay pin ON
18. Set PWM duty cycle to 100%
19. End.

The result obtained by implementing the proposed technique to the residential area is as shown in Fig. 2.

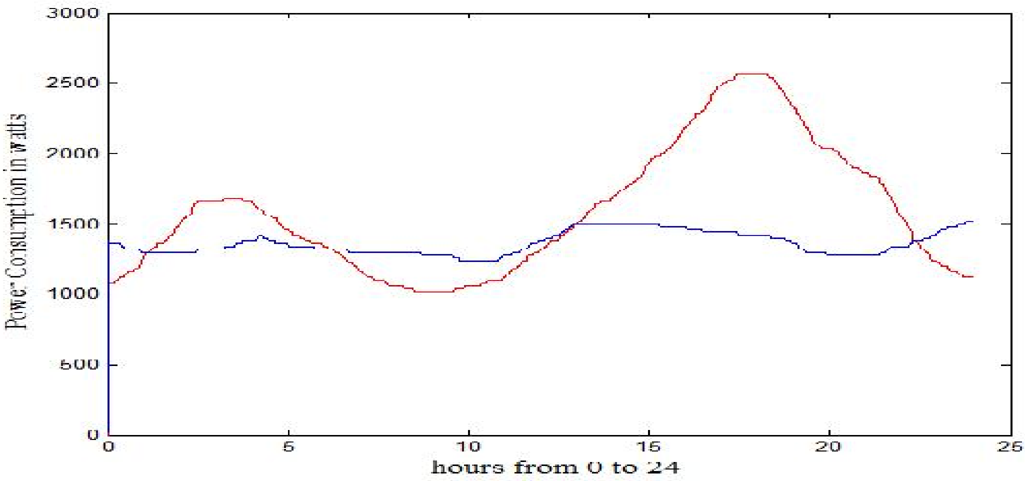

Fig. 2 Load curve for Residential load, Red is without load scheduling, Blue is with Load Scheduling.

Fig. 2 shows load curve obtain before and after load scheduling to achieve demand side management. Load curve with Red colour is showing the power consumption before load scheduling, and the one with Blue colour is showing the power consumption after load scheduling. It is seen from this result that the peak hour demands are get reduced from 2500 W. to 1500W. i.e. proposed technique has achieved the goal of flattening the load curve through load scheduling and demand side management has achieved.

It is observed that the proposed optimization is able to reduce the maximum load on the system and improve the performance and reliability of power grid by reducing Peak demand and peak hour to the average load demand.

CONCLUSION

We have proposed an integer linear programming and Heuristic based optimization technique which can be found beneficial to develop a reliable, efficient, stable and Green smart grid. We have designed an automated demand side management technique by setting a threshold power value based on maximum power consumption of the system. This will make this optimization beneficial for both consumer as well as utility. Using this optimization technique, we are able to flatten the load curve with satisfaction of both consumer and utility.

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