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Design of an Optimized Model for Residential Load Control using Electric Price Variability for Future Grids

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Abstract: In recent times, research is focused on optimal techniques for efficient and effective distribution and utilization of energy in future grids. Aim of the researchers is to plan such a system which can timely manage and meet the power demand requirements effectively. Domestic appliances consume the massive part of the total electricity. Household energy consumption is considered the most inelastic and uncontrollable as compared with the consumption of any other end user. Demand side management in smart grids is an optimized approach in future smart grids in which consumers are well aware of their energy consumption and they can make decision accordingly. This can evenly distribute loads throughout the day and reduce system tension and outages. This research paper presents household EMS (EMS) in which controllable or non-critical loads are controlled systematically and shifts the peak hours loads to the off-peak hours and distribute the total energy evenly throughout the day. Previously different models have been designed to distribute the loads flatly throughout the day while this EMS technique distribute the loads evenly as well as reduces the electricity costs effectively. Previous works lack flexibility for additional loads; EMS model described here is flexible and adjusts for "On Demand" loads.

Keywords: Demand side response, Smart Grids, Household Loads Models, EMS, AC, and Pricing.

1. INTRODUCTION

Peak demand of power in current infrastructure is increasing the risks of distribution and transmission failures. These failures increase outages which have affected the stability and reliability of the power system in past decades. Reducing peak power demands can ultimately increase the reliability of the system as well as reduces the chances of outages. Demand response (DR) is the only solution to deal with the peak loads and to make the network flexible by shifting loads. By reducing peak demand via DR, a significant cost saving could be achieved, as DR would eliminate the operation of high cost generating units (Hubert and Grijalva, 2012). For industries and commercial usage many demand responses have been established during past decades. Demand responses are either attained directly or indirectly load control. Demand Response systems in smart grids are only limited to the commercial usage and not implemented widely i.e. for residential usage because of numerous reasons. Demand response systems that are implemented lack automation system and are normally based on manual response approaches. Automation response approaches are also becoming prominent slowly and gradually in commercial sectors. While in residential sector very little number of demand response systems is functional as these systems accounts for substantial sum of the total energy demand. In residential sector, peak demands are mostly managed by utility by using Direct Load Control (DLC). In this mechanism customers shift their loads to off peak hours and are paid per their usage in DLC programs. But in these programs, residential customers are supposed to compromise upon their comforts so most of them are not willing to join DLC programs. Real Time Pricing (RTP), Critical Peak Pricing (CPP) and Time of Use (TOU) are direct load controlled based i.e. incentive based. These DR systems are mostly used in commercial sectors. These PR systems need active participation of the consumers for managing and setting up the energy utilization on hourly basis. Due to lack of automation mechanism consumers are supposed to adjust their utilities on hourly basis to manage real time prices. In real time pricing adjustments, consumers should make active decisions about their consuming loads. Participation of all consumers in DR programs is necessary to be assured in both commercial and residential sectors. As DR programs, do not tolerate interruptions in the system and if consumers do not participate properly, the system will experience services interruptions. Consumers' participation is satisfactory in DR programs of smart grids when we talk about industrial sector (Chen and Wu, 2013). In Residential sector consumers, cannot participate properly, hence not satisfactory. Therefore, automation system in residential sector needs to be improved for which work has been carried out in this paper. This work emphasizes on peak load mgt. in residential sector and architecture for efficient DR program.

An EMS has been proposed that can shift the load of consumers during peak hours, automatically without compromising on consumers' comfort. Here, consumers

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will be aware of their power usage and status of the appliances (Nguyen and Le, 2014). Proposed EMS system is designed in such a way that total energy consumption will be efficient and cost friendly; i.e. system will automatically shift the load in such a way that will minimize the overall burden and will lower the cost of energy usage.

2. RESIDENTIAL LOAD DISTRIBUTION

Domestic Electricity is utilized in various ways. Some usages like electricity used by lightning, freezer or refrigerator is on daily basis while some variates with the weather. Space cooling/heating depends upon the weather. Some of the usages depend upon the individual's need. In household energy usage space cooling and heating accounts for the major consumption. Refrigerator/Freezer and water geyser also play main role in electricity consumption. (Siano, 2014) Third main electricity consumer is the lightning system of the house which uses the largest part of the total household energy. Other appliances are the kitchen utilities i.e. oven, juicer/grinders, electronic appliances, iron, electric motor, chargers, clothes dryer, washing machines, entertainment devices, laptops, televisions that use remaining electricity.

Loads considered here in critical load segments are lightning and cooking, loads that are listed in non-critical segment are Refrigerator, Deep Freezer, and Air-Conditioner, Water Heater and UPS system. Electric Iron and Clothes Dryer are placed in "on demand" segment (Saad, *et al.,* 2012). Operating times of non-critical load as well as on demand loads will be managed by the proposed EMS for which the load priority will be specified by the consumer. EMS will manage to keep the loads bellow the demand limit. In this work, MATLAB based simulations are made to develop an algorithm to control the operating times of non-critical loads. These loads can easily be controlled and can bring about significant change in the total domestic load demand. By monitoring and managing these loads total peak loads can be reduced during peak hours.

Power consumption models must be modeled for developing household load controlling algorithms.

3. CRITICAL LOAD MODELS

3.1. Water Geyser Load Model: Here Water Geyser (WG) model has been developed to find power consumption and temperature of the hot water of the tank. Power consumption and the temperature of the water would be found out in each of the time slot *i(minutes)* (Maharjan, *et al.,* 2013). **(Fig. 1)** shows WG model.

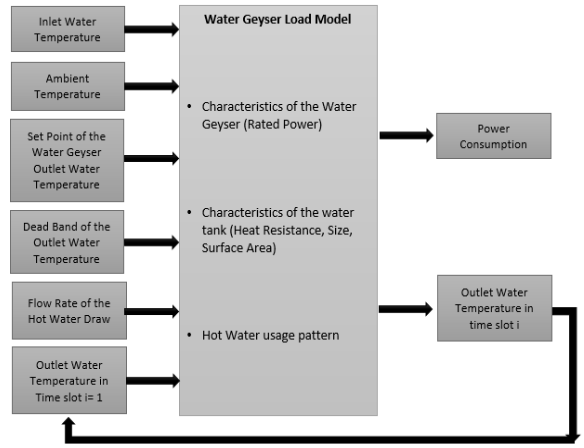

Fig. 1: Water Geyser Load Model

In this model, two limits of water temperature have been defined i.e. higher limit and the lower limits respectively. These temperature limits are the desired limits of the temperature range of the WG model (Shao, *et al.,* 2014). When the water temperature drops below the lower limit then the coils that are meant for heating in geyser are turned on and when the temperature of the water rises the desired limit then the coils of the geyser are turned off. When the temperature of the water is within the required range then these heating coils' statuses are let as it is.

3.2. Air Condition Load Model: Load model of an Air Conditioner (AC) is designed to find the power consumption by the AC in each time slot ***i*** in accordance with the change in room temperature. To find the power consumption by the AC and the room temperature in certain time slot there would be some parameters needed for the model, some parameters of which are the built-in functions of the AC unit. (Chai, *et at., 2014*) **(Fig. 2)** shows the load model of the AC unit with all the required parameters, input and output values.

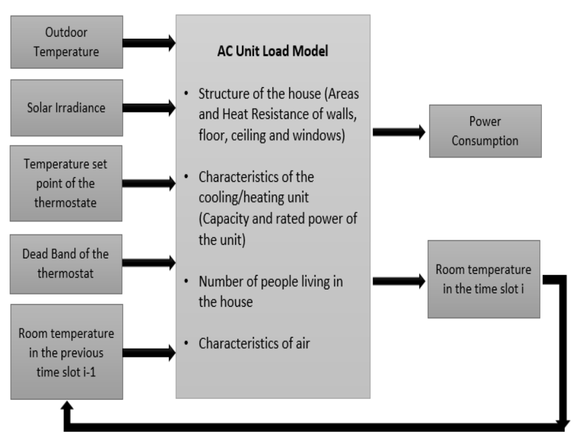

Fig. 2: AC Load Model

Temperature of the space i.e. room/hall is kept within the predefined range of temperatures by the thermostat of an AC unit. Thermostat maintains the temperature in preferred range by controlling in and out heat flow in AC unit. It senses the room temperature and matches the temperature with the defined limits in the AC unit and in accordance with the variation it turns on or off the heating or cooling coils and in such a way temperature of the room is regulated desirably. On either side of the set points range thermostat could turns on and off. Band of set points and the differences in allowable temperature ranges i.e. higher and lower limits combined is called differential/deviation temperature or the dead band.

3.3. Clothes dryer Model: Cloth dryer is considered as on demand appliance but its priority is not kept that much high. In peak hours if the cloth dryer is turned ON it will automatically have switched OFF otherwise if the load is within normal range it will work as it is. **(Fig. 3)** illustrates working of cloth dryer, in which built in functions and inputs/outputs of the cloth dryer are considered

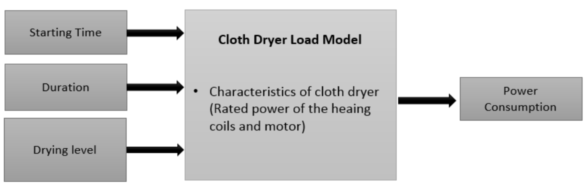

Fig. 3: Clothes Dryer Model

User enters the needed time as in input to the clothes dryer. Required time is stored as an input time and cloth dryer operates till that required time is achieved, i.e. during the operation accumulated time will be less than the required time.

3.4. Model of UPS Batteries Load: With the model of UPS load model, status of the batteries in UPS during charging and discharging can be found. Power consumption details can be retrieved for charging of batteries of UPS for each time slot *i*. **(Fig. 4)** shows the status of batteries, built in parameters of the UPS and energy inputs and outputs consumption details.

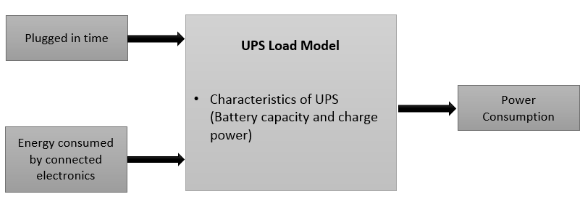

Fig. 4: UPS Load Model

4. HOUSEHOLD EMS

The main purpose of this algorithm is to reduce the peak power demand limits and to distribute the loads evenly throughout the day. For demand response system, the power incentive of non-critical load models is modified. This modified power incentives of non-critical load models are verified through MATLAB simulations.

The main purpose of this research is to design an algorithm that is cost efficient and that keeps all the household power consumption below certain level and to distribute the loads evenly throughout the day. When loads are shifted from the peak hours to off peak hours the total power consumption in any time slot will be reduced and thus will reduce outages and overloading of the system. As earlier discussed manual system of load shifting can cause discomfort so this shifting and monitoring would be done by EMS with reduction in power failures and outages overall cost would also be reduced.

4.1. Load Models for which Demand Response is enabled: During the demand response situation, EMS system will set the signal for the non-critical depending upon value of the priority set by the utility. These priority levels are compared and signal is transmitted accordingly. This signal is called demand response signal. Controllable non-critical loads' power consumption also depends upon demand response signal. This demand response signal by EMS is also considered in each time slot while finding the power demand of the non-critical loads that are controllable.

- Model of Water Geyser that is enabled for demand response or the modified version of the water geyser model that is already discussed is as follows (Tasdighi, *et al.*, 2014);

$$P_{WG,i} = P_{WG} \times W_{WG,i} \times \eta_{WG} \times D_{WG,i}$$

Here,

$P_{WG,i}$ is the water geyser power consumption in time slot *i*

P_{WG} is the water geyser rated power (*kW*)

$W_{WG,i}$ is the water geyser's status in any time slot *i*

η_{WG} is the measure of efficiency

$D_{WG,i}$ is the water geyser's control signal in any time slot *i* received from EMS

$$D_{WG,i} = \begin{Bmatrix} 1 & \textit{when EMS turns on water geyser} \\ 0 & \textit{When EMS turns off water geyser} \end{Bmatrix}$$

- AC unit model that is modified for demand response, can be shown as follows;

$$P_{AC,i} = P_{AC} \times W_{AC,i} \times D_{AC,i}$$

Here,

$P_{AC,i}$ is the AC unit power consumption (*kW*) in any time slot *i*

P_{AC} is the AC unit rated power (*kW*)

$W_{AC,i}$ is the AC unit status in any time slot *i*

$D_{AC,i}$ is the AC's control signal in any time slot *i* received from EMS

$$D_{AC,i} = \begin{Bmatrix} 1 & \textit{when EMS turns on the air conditioner} \\ 0 & \textit{When EMS turns off the air conditioner} \end{Bmatrix}$$

- Modified model of clothes dryer that is demand response enabled is shown below:

$$P_{CD,i} = k \times P_{hc} \times W_{CD,i} \times D_{CD,i} + W_{CD,i} \times P_m$$

Here,
$P_{CD,i}$ is the clothes dryer power consumption (*kW*) in any time slot *i*
P_{CD} is the clothes dryer rated power (*kW*)
$W_{CD,i}$ is the clothes dryer status in any time slot *i*
P_m is the power consumption
$D_{CD,i}$ is the clothes dryer's control signal in any time slot *i* received from EMS
k is the dryer level.

$$D_{CD,i} = \begin{cases} 1 & \text{when EMS turns on the Clothes Dryer} \\ 0 & \text{When EMS turns off the Clothes Dryer} \end{cases}$$

- Demand response enabled UPS load model is presented. EMS will control the charging of the UPS batteries in accordance with the predefined priority level. EMS working mechanisms will be the same as described in other demand response enabled appliances (Oh, *et al.*, 2011). This power consumption by UPS batteries is shown below;

$$\boldsymbol{P_{UPS,i} = P_{UPS} \times D_{UPS,i} \times W_{UPS,i}}$$

Where,
$\boldsymbol{P_{UPS,i}}$ is the UPS batteries power consumption (kW) in any time slot i
$\boldsymbol{P_{UPS}}$ is the UPS batteries rated power (kW)
$\boldsymbol{D_{UPS,i}}$ is the control signal from the EMS to UPS in any time slot i
$\boldsymbol{W_{UPS,i}}$ is the status of the UPS batteries in any time slot *i*

$$D_{UPS,i} = \begin{cases} 1 & \text{When EMS turns on the UPS} \\ 0 & \text{When EMS turns off the UPS} \end{cases}$$

EMS controls to turn on or off by checking demand limit first. EMS send turn on command to the non-critical load when the demand limit is below the acceptable level. And when there is a condition where demand limit exceeds the acceptable level then EMS send the control signal of turn off the load.

5. ALGORITHM FOR HOUSEHOLD EMS

In household EMS, first step is to check the status of the domestic appliances. In checking the status household appliances actually send data to the EMS. EMS interns monitors and control the appliances. In monitoring EMS first checks whether there's demand limit imposed by the utility or not (Lakshminarayana, *et al.*, 2014), (Silveira, 2005). If there's no demand limit, then EMS does not turn off any of the non-critical load. But if there is a demand limit imposed by the utility then it starts turning off the non-critical loads per their priority level. If the power consumption becomes lowered than the demand limit, then EMS decides running on the critical loads and vice versa.

In model development, priorities are set for the non-critical loads. Priorities that are considered for the proposed EMS are shown in **(Table 1).**

Table 1. Priorities of EMS System for Non-Critical Loads

Non-critical Loads	Defined Priorities
Air Conditioner Unit	1
Water Geyser	2
UPS	3
Clothes Dryer	4

In proposed EMS a program based on MATLAB simulations has been developed in which operations of the controllable or controllable loads have been considered. Priorities as shown in table are considered in the simulation program. Time periods of 24 hours for each season are also taken into consideration. Reference time for each period is chose to be starting at 6am (Beck and Martinot, 2004), (Chang, *et al.*, 2003). Working of controllable or non-critical loads is observed in accordance with the total power demand of the household. Priorities, demand limit and the control strategy of EMS has been observed. Results of these simulations are discussed in coming section. Efficient and effective results have been observed.

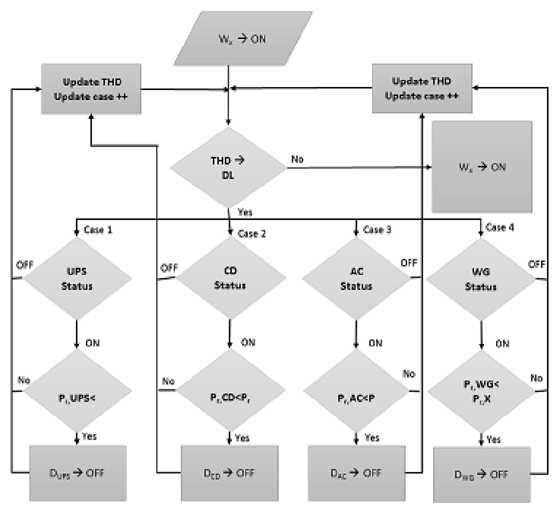

Fig. 5: EMS algorithm's flow chart in accordance with loads priorities level

In **(Fig. 5)**, CD is the clothes dryer, AC is the Air Conditioning Unit, DL is the demand Limit, WG is the Water Geyser, TDH is the load of total household, W_x is the signal to request change in non-critical load, *x*, $P_{r,x}$ is the defined priority of the non-critical load, *x*. D_x is the signal of EMS that control non-critical load, *x*.

This EMS developed for the household loads is very cost efficient. That is why will be popular among domestic consumers. Different load models that were controllable have been associated with the EMS system and this is observed that 12% to 26% cost efficiency has been achieved. This variation from 12% to 26% is due to variation in weather changes and other conditions that are when on demand loads are turned on.

6. SIMULATION RESULTS AND DISCUSSION

Simulations are done in MATLAB in which all the load models and the real world scenarios are considered. Several simulations have been made for each of the load model and then their collectively effect has been analyzed. Demand limit has been set for a signal house. Total household power with and without EMS are found and compared.

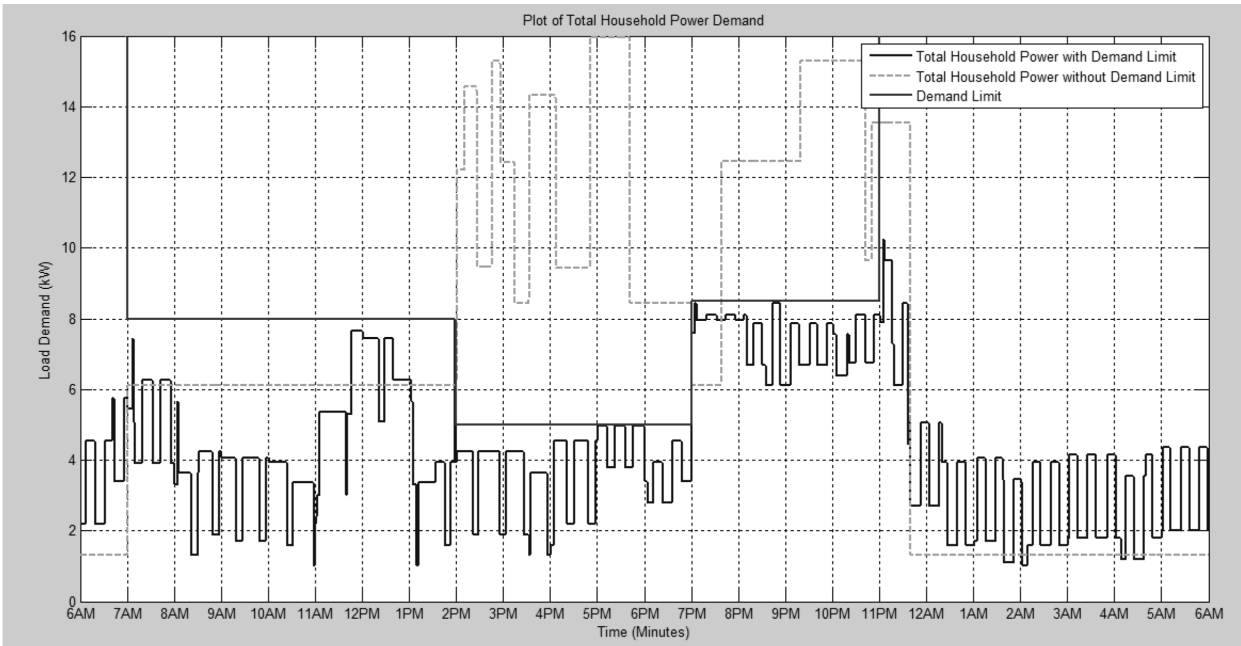

Fig. 6. Total House Hold Power Demand

(Fig. 6) shows the total Power demand of the household for the whole of the day. We can observe that without EMS, i.e. the graph in green shows that the House Power demand was shooting the demand limit peaks and system seemed to be overburdened. This overburdened system ultimately increase chances of outages and blackouts. Power demand of household increases exponentially without EMS. This collectively with other houses loads create tension in overall system. In **(Fig. 6)** with the installation of the EMS we can observe that the blue line i.e. total household power remains within the demand limit. And is not crossing the peak this is how the EMS efficiently manages the demand and works. With EMS installation, total load can be distributed evenly along the day. This greatly reduces the chances of outages and black outs. As household users are considered as the major electricity contributors in all end users with organization of EMS, overall load of the electricity can be effectively divided and can minimize the overall shortage of electricity. With the installation cost can also be reduced as appliances will be monitored constantly without the intervention of any individual and appliances would be turned off during spare times. EMS is very effective in load and minimizes cost efficiency subsequently.

7. CONCLUSION

In this paper optimal technique “EMS” is presented which can timely manage and meet the power demand requirements effectively. Domestic appliances that are non-critical are controlled in real timing total electricity is consumed effectively. Results reveal that Household energy consumption with EMS is really moderate and can control the overall outages by just managing household loads on smaller scale. Without EMS it could be clearly seen that the peak demand is achieved exponentially, which shows that without EMS household loads are inelastic and can cause maximum damage to the overall system. While with EMS customers are well aware of their energy consumption and they can make decision accordingly. Results show that the loads are distributed evenly throughout the day and have reduced system tension. This research also shows that the electricity consumption is less and hence reduced cost efficiently to minimum level. Algorithm is simple but has yield best results without compromising the comforts of the end users. Previous work lacks flexibility for additional loads. EMS model described here is flexible and adjusts for “On Demand” loads This research paper of household EMS (EMS) can be extended in future by addition of the renewable energy sources in which these sources will contribute further in overall electricity system and hence chances of outages and blackouts will be completely eliminated.

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