Development of DSM based HEMS Model for Energy Management in Smart Grid

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***Abstract*— DSM is a series of measures established to reduce energy consumption. It can be a long term solution of our current energy problems. The benefits of DSM can be fully tapped after its integration with Smart Grid. In this paper, We present a habit based Demand Side Management (DSM) model. To monitor the usage on energy, a Home Energy Management System (HEMS) is introduced. HEMS monitors the consumption of energy within a household and shares it with consumer. Several methods of DSM are reviewed and their mathematical modeling is discussed. A new HEMS technique is implemented at hardware. It is thoroughly investigated after integrating it with appliances. Monitoring and controlling hardware has been developed and functioning is controlled with help of software. An optimized scheduled has been employed to control the appliances operation. This is attributed to the independence of appliances that can be connected and its flexibility in managing the energy supplied to these appliances.**

Index Terms*— Demand Side Management, Smart Grid, Home Energy Management System, Sensors, Battery, Energy Management.

I. Introduction

With the passage of time, our electricity demand is increasing at a significant rate. This is attributed to a number of reasons. Our current power plants are decreasing in productivity and the appliances in households are increasing in number, introduction of Electric Vehicles (EVs) and faults in our distribution networks are exhausting the power stations. As a result, the distribution companies have introduced load shedding to manage the power supplied to consumers.

Demand Side Management (DSM) refers to the methods used to influence the energy consumptions of end users. With the implementation of measures highlighted by the DSM, a major reduction of demand of electricity can be easily possible. DSM is mainly practiced at the consumer end as well as production end. DSM focuses on habits of users as demand of electricity varies from person to person. Use of energy storage devices would be soothing for power stations especially during peak load hours.

Smart Grid is an updated form of traditional grid. Supplying and distributing electricity is still its main objective but there are some more advantages. The consumption of electricity and its pattern is monitored by consumers and suppliers. It helps the distributors to know the total consumption of an area as well as monitoring for any thefts and faults. Addition of renewable energy sources helps existing power plants in electricity production.

In this paper, Home Energy Management System (HEMS) is implemented in households to monitor and control the usage of electricity. It brings into use sensors, connection devices and various software. HEMS makes the user aware of its consumption rate and may alert it in case of excessive use. The appliances can be connected to it by user's choice and comfort.

In section II, DSM, Smart Grid and HEMS are investigated in detail. Their advantages are weighted against their drawbacks. Section III deals with mathematical implementation of various DSM techniques. In section IV, a method is proposed which successfully integrates DSM and HEMS, keeping in view the habits of a user. At the end, conclusions are drawn in section V.

II. DSM and Smart Grid

DSM refers to all the actions taken by a user in order to lower his energy usage and expenses. This does not necessarily mean that a user is forced or compelled to turn off certain appliances. DSM manages to change the consumption pattern of the user so that his energy expenses are decreased. This can be done by changing the course by which routine work is done, by using energy efficient appliances, by installing an energy storage unit in house or any other means. In short, a balance of consumption is made between the workload and the expenses during on peak and off peak hours. DSM can be achieved by numerous approaches. These all are similar and different from each other in a number of ways. These include user involvement, expenses, software used, efficiency and as such. Use of energy efficient appliances, Time of Use procedure, smart meters and habit monitoring are some of the more common ways of practicing DSM.

This procedure is helpful in a number of ways. Firstly, the total consumption of electricity is reduced which collectively decreases the shortfall of electricity. Secondly, when the load on power plants and the distribution system is reduced, the number of faults and breakdowns occurring is also reduced. This means that the expense on maintenance and repairs is ultimately reduced. Renewable energy sources like solar panel or wind panel can be installed in homes. This factor reduces the dependence on the grid for electricity. Progression in practicing DSM at domestic level can open doors to a new field in research, development and industrial sectors.

Smart grid is lot more than the traditional grid. Along with supplying electricity, it has the capability of monitoring the usage. It is a collection of electricity distribution network, monitoring equipment, monitoring centers, storage units and small renewable energy units. In many ways, a smart grid is different and better than a traditional grid. There is no energy monitoring mechanism in traditional grid whereas in smart grid, energy flow and usage is monitored. In a smart grid, distributed generation of electricity takes place. Energy can be stored in specially designed units within a smart grid but a traditional grid does not have this feature. Excessive electricity usage due to theft or fault can be easily detected and countered in a smart grid. As a result of these features, the electricity expenditure of consumers is reduced.

Gradually, the world is trying to replace the traditional grids with smart grids. This is attributed to a number of reasons. Energy storage capability of smart grid allows the usage of its energy during peak hours and blackouts. Addition of renewable energy means that the electricity generation charges from fossil fuels are decreased and the surrounding environment is kept cleaner. Monitoring equipment can be used to look for faults in the distribution system. Maintenance staff is able to pinpoint them quickly and solve them. However, implementing smart grids is not an easy task. The application of smart grid in an area requires a lot of cost and it is the main factor why most governments and distributors are reluctant to apply them. Its deployment, monitoring and maintenance requires highly skilled and educated staff. On the other hand, application of smart grid can put a lot of people out of work. Still, when the advantages of smart grid are compared to its drawbacks, the benefits prevail over them.

Home Energy Management System is an integration of different hardware and software used to monitor and control the energy consumption in a house. When appliances are operational, their readings are collected by a server or device and then this data is used to control and examine the flow of electricity. HEMS takes into account the number and type of appliances connected, electricity and its ongoing tariff and activities of users. An important principle of HEMS is use of different kinds of sensors along with optimization and updating algorithms.

HEMS is a whole process and it is more than just monitoring or controlling of appliances. Normally, a sensor or a controller is connected to an appliance. Its operation may be controlled and the electricity consumption is monitored. The information is fed to a server or controlling device. It alerts and updates the user about the energy usage. Algorithms can be used to optimize the intake of electricity so the consumption rate and cost can be reduced. HEMS is able to reduce the energy costs of a household as well as allows the connected appliances to function properly. Use of controllers allows easy operation of appliances and their control can be guaranteed being far from home. It can also include a renewable energy source for better functioning and decreased reliance on grid for electricity supply. HEMS comes with some drawbacks also. The whole system is costly and there is a dire need to develop cheap HEMS applications. Use of a large number of sensors can cause connectivity and communication complications. This is an application which guarantees benefits of DSM and smart grid. Above that, deployment of HEMS is critical if the distributors want to curb the current and future energy crisis.

In [1], authors have implemented DSM based on priorities assigned to the appliances. This is a sound approach as the user has independence of assignment of appliances. Appliances are handled automatically and their operation can be controlled through mobile phone application via Global Positioning System (GPS). This technique is especially efficient for appliances which consume high energy, reducing 11.2% of total power consumed. On the other side, too much load could lead to damaged appliances.

As compared, In [2], a controlling unit has been used which itself records the consumption of electricity and this information is shared with the rest of community. Furthermore, [2] has divided appliances into shift able and non-shift able devices. Electricity controlling unit is integrated with the smart meters. Use of electricity can be adjusted during the on-peak and off-peak hours. Energy consumption is reduced to 24%. This is an efficient DSM approach with significant reduction in energy consumption.

Authors in [3] have used a combination of [1] and [2] by using metering devices and energy efficient appliances. Metering devices are used to monitor the usage of electricity whereas energy efficient appliances consume less electricity as compared to the normal appliances. Such appliances also have a longer life and nowadays they are widely available also but sometimes such appliances maybe expensive. [3] has also proposed other changes in habits which can decrease electricity consumption. In [4] and [5], a sensor based method has been proposed to monitor activity of user. [4] has used multiple types of Markov chains to achieve its results. Markov chains monitor the activity of users and make future predictions of energy usage based on the readings measured. [5] has specifically used Zigbee Sensor to sense and update the electricity usage. According to [5], users have the ability to control number and type of devices connected to DSM system. Furthermore, an alarm system is also present to alert the user in case of any fault.

In [6] and [7], authors have used the sequence algorithms in combination with Markov models to provide energy to user in near future. However, the results achieved by [6] are not very encouraging as its prediction accuracy is only 40-60%. [7] uses sensors to monitor the activity within household and a battery to provide energy backup in case of increased load. Battery also decreases the dependence on grid as the source of electricity.

In contrast, reference [8] shifts the load of appliances during on peak and off peak hours. It is pointed out that electricity demand remains variable throughout the 24 hour period. During the night, the load is high and at that time DSM could be employed to decrease electricity utilization. Figure 1 shows renewable energy and storage based DSM.

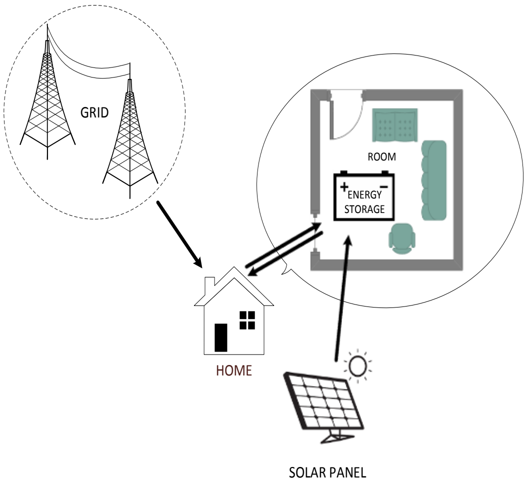

Figure 1: Schematic Diagram of Renewable Energy and Storage based DSM

In [9], Demand Response (DR) is used which is a type of DSM to manage the devices. Comparison is made between incentive based and price based demand response. Moreover, author has pointed out that changes in price of electricity during the day could affect the activities of user. In response, the demand of electricity also changes. Price based DR is about development of variable electricity charging mechanism according to the demand of electricity and its production by the power plants. On the other hand, incentive based DR is about the ways in which load can be reduced on consumer side e.g. efficient appliances, timed operation of appliances, temperature controlling activities and others.

Authours in [10] have considered a smart home which uses DSM and sensors. Smart home has allowed maintaining a balance between the appliances usage and the human activities. Sensors, with help of DSM, perform a number of tasks which include checking occupation of the user in the room, monitoring its activity while being in the room and predicting future electricity usage based on current activities. Prediction of future electricity usage is not perfect but it is a good estimation. In [11],the approach of [9] has been taken for further work by integrating demand response with retail pricing to manage devices, using Simulink (Matlab). Moreover, authors have also pointed out that Climate of a certain place greatly influences the electricity usage in terms of controlling temperature of surroundings. Therefore, it has reached an optimum temperature for switching between heating and cooling episodes. This way, electricity consumption has been reduced.

Demand response gives user the response on its demand of electricity. It is one of the main factors which increases grid efficiency and reduces peak load by knowing user's priority and habits. Furthermore, the concept of metering devices gives user its electricity consumption pattern so that end-user can manage its devices easily according to the retailing prices. Both retailing prices and metering devices are dependent on each other for functioning. Retailing prices give electricity rates of different time slots i.e rates of peak and off peak hours in an efficient manner. It reduces the electricity cost based on user's habit Sensors continuously sense and update the electricity data and send information about electricity consumption units to the user. With the date acquired from these sensors the on and off operation of devices can be controlled by using specific controllers.. Sensors can also monitor the resident's activity.

III. Mathematical Modeling of HBDSM

In [2], mathematical modeling based on multiple users connected to a single power station has been formulated. Appliances are charged using Time of Use (ToU) pricing. 10 appliances are considered per user. A timing interval is considered and following cost function is used:

$$C_h(E_h) = \begin{cases} \sum_{a=1}^{A}\sum_{h=1}^{h_o} E_{n,a}^{h} U_{h_o} & if\ off\ peak\ hrs \\ \sum_{a=1}^{A}\sum_{h=18}^{h_o} E_{n,a}^{h} U_{h_p} & if\ peak\ hrs \end{cases}$$

Where U_{h0} is electricity pricing during off peak hours and U_{hp} is electricity pricing during on peak hours. $E_{n,a}^{h}$ is the energy consumption of an appliance 'a'. [4] has used a segmentation algorithm to utilize the readings of sensor. It also uses the timing interval of readings.

Prediction algorithms for user actions were introduced in [6]. Author explained 4 basic sequence prediction algorithms. Most of them used fundamental concept of Markov's chain rule.

A user action is characterized by a symbol. This user action is the input sequence. A superset containing all the possible input is $\sum$. Suppose A = $a_1 \ldots a_n$ (having a record of all the actions whether performed already or not) with $a_j \in \sum$ be a sequence of input symbols. From ($a_1 \ldots a_i$) are the actions which are already being performed. A Sequence Prediction Algorithm decides whether it is able to make a prediction and if yes then it returns the probability for each symbol $x \in \sum$.

One of the first algorithms to be used is IPAM. It is based on Markov model, i.e. it predicts last seen symbol of the input sequence. In this algorithm two lists are made. One contains all the conditional probabilities $P_{ipam}(x|y)$, x, y $\in \sum$ and other contains list of unconditional probabilities $P_{ipam}(x)$, $x \in \sum$. New probabilities defining unexpected actions $P'_{ipam}(x|y)$ are computed for all $x \in \sum$. According to following equation:

$$P'_{ipam}(x|a_i) = \begin{cases} \alpha P_{ipam}(x|a_i) + (1-\alpha) & if\ x = a_{i+1} \\ \alpha P_{ipam}(x|a_i) & otherwise \end{cases}$$

Authours in [7] have made a game model of DSM, assuming electricity prices and behavior of user. An objective function is made:

$$\max \sum_i (p_i - \overline{p_i})(\sum_{t \in i} Q(t,p)\,\Delta t)$$

Where Q(t,p) is consumption profile and p is random price. By this function, different pricing periods are made and prices assigned to them.

In [9], days are divided into N slots i.e n Ɛ {1,2,3,…..,N} ,also Sn denoted the rooms at which user stays Sn={1,2,3…..M} where M is the total no of rooms. At time n let the user be in room i so the probability of use moving to room j is given as:

$$Pn_{ij} = (sn+1 = j|sn = i)$$

So, now according to Markov's chain rule we have P matrix at time n is:

$$P_n = \begin{pmatrix} P_{11}^n & P_{12}^n & \cdots & P_{1M}^n \\ P_{21}^n & P_{22}^n & \cdots & P_{2M}^n \\ \vdots & \vdots & \ddots & \vdots \\ P_{M1}^n & P_{M1}^n & \dots & P_{MM}^n \end{pmatrix}$$

Where P represents all the matrices:

$$P=\{P_1,P_2,P_3\dots P_N\}$$

Energy consumption is directly related to time and user location. If the user is outside energy consumption is zero(0) while when it stays home energy consumption is sometimes high or sometimes low. So, here another matrix E records the data of power consumption.

$$E = \begin{pmatrix} e_{11} & e_{12} & \cdots & e_{1N} \\ e_{21} & e_{22} & \cdots & e_{2N} \\ \vdots & \vdots & \ddots & \vdots \\ e_{M1} & e_{M2} & \dots & e_{MN} \end{pmatrix}$$

Where $e_{i,n}$ represents the average power consumption of room i at time slot n.

On the basis of P and E matrix we predict the future values of user habit and its energy consumption pattern.

In contrast, [12] has used Matlab to develop a dynamic demand response controller. This author considers a single home which has a HVAC system for controlling home thermostat. Following heating and cooling functions of HVAC have been created:

$$E_{cool}= -199163.34\Delta T+46530.67 \text{ [J/15min]}$$

$$_{heat}= 196204.81\Delta T +13010.29 \text{ [J/15min]}$$

Where E_{cool} is electricity consumption of HVAC for cooling and E_{heat} is electricity consumption for HVAC for heating. ΔT is the temperature difference. Cooling is set at 23^0C and heating is set at 22^0C. it should be noted that these are initial temperatures respectively. After this, HVAC electricity consumption is made into a function of ΔT. These functions change into following forms:

$$HVAC_{cool}= -0.055\Delta T + 0.013 \text{ [kWh/15min]}$$

$$HVAC_{heat}= 0.055\Delta T + 0.004 \text{ [kWh/15min]}$$

From the equations, it is evident that the $HVAC_{cool}$ is a function of cooling temperature and $HVAC_{heat}$ is a function of heating temperature. Then, the initial set point temperature for heating and cooling are set as following equations:

$$T_{sp,cool}[C^o] = \begin{cases} 23 + \Delta T_{cool,} & for\ P > P_{th} \\ 23 & for\ P < P_{th} \end{cases}$$

$$T_{sp,heatl}[C^o] = \begin{cases} 22 - \Delta T_{heat,} & for\ P > P_{th} \\ 22 & for\ P < P_{th} \end{cases}$$

The initial temperatures are the same as those mentioned earlier (23^0C for cooling and 22^0C for heating). After further processing, it is concluded by [12] that electricity consumption of HVAC system is reduced by nearly 20% in the same house.

The management systems, their implementation constraints and other relevant details have been tabulated in Table 1. These details are from all the papers discussed in the mathematical modeling section and the contributions made by their respective authors.

TABLE I: Comparison of Various DSM Techniques

S. No	Management system	Simulation Software	Pricing Schemes	Communication Module	Energy sources	Algorithm
1	Demand side management	N/A	Load shedding	Smart switch	Grid	N/A
2	Demand side management	N/A	Load scheduling, Time of use	Energy consumption controlling unit, smart meters	Grid	N/A
3	Feedback induced energy saving	N/A	N/A	N/A	Grid	N/A
4	Activity recognition	N/A	N/A	Passive sensors	N/A	DBSCAN clustering algorithm, mining algorithm, Apriori algorithm
5	Energy management	N/A	N/A	Zigbee sensors, hall effect based sensor	N/A	N/A
6	Proactive user interface	N/A	N/A	N/A	N/A	Markov models
7	Model predictive control	Matlab	Load shaving	N/A	Grid, large battery	Markov process, rolling optimization
8	Demand side management	N/A	Forward price, final price	N/A	N/A	Stackelberg game model
9	Demand response	N/A	Price and incentive based	N/A	Grid	N/A

S. No	Management system	Simulation Software	Pricing Schemes	Communication Module	Energy sources	Algorithm
			programs			
10	Home energy management system	Sweet home 3D, DIALux	Load shifting	Occupancy sensor	Grid	Rolling optimization
11	Home energy management system	Matlab, EnergyPlus, OpenStudio	Demand response	Dynamic demand response controller	N/A	N/A
12	Demand side management	N/A	N/A	Load profiles	Grid	N/A
13	Demand side management	N/A	Time of use	Smart meters	Grid	N/A
14	Demand side management	GoldSIM	Time of Use, Energy efficiency, Demand Response, Spinning Reserve	Zigbee smart energy profile	Grid, Virtual power stations	Monte Carlo method
15	Demand side management	Matlab (Simulink)	Load Scheduling	N/A	Grid	N/A

IV. Proposed Scheme and Hardware Implementation

Home energy management is important to make the energy usage efficient. This is possible only after knowing the consumption pattern of the appliances. Sensors are important in sensing the voltage and current consumption of the connected appliances. However, their operation is not possible independently. Software and monitoring algorithms are also needed to work along with sensors. A hardware based model has been developed which consist of following two parts:

(I) Switching circuit

(II) Energy monitoring and controlling circuit

Energy supply is done from the grid and solar panel. A switching circuit is made for selecting an appropriate electricity source as shown in Figure 2. The choice is made between the solar power and grid power. Preference is assigned to the solar power and during its availability; electricity from grid is not consumed. In the absence of sunlight, connection is made to the grid section. This operation has two advantages. Expenses of consumer are reduced by usage of renewable energy and electricity supply to the storage unit connected to it remains continuous.

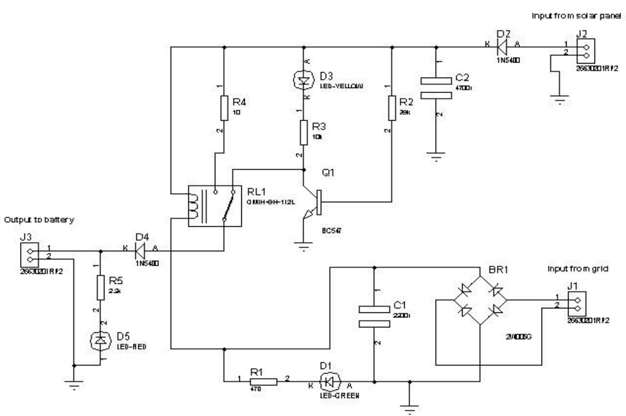

Figure 2: Schematic Diagram of Switching Circuit

Then, an energy monitoring and controlling circuit is developed to note the current and voltage values of all the appliances connected to it. In Home energy management system, different tools can be integrated together in order to optimize energy consumption. The whole scenario is based on microcontroller and sensors that collect data from the appliances and then this data is communicated with microcontroller. In the proposed model, a pair of ZigBee modules is used which are interfaced with Arduino Mega 2560 microcontrollers. ZigBee forms mesh network and its range is comparatively longer than other modules, making it an ideal choice for domestic use. Working as a pair, one module is connected to the appliances and the other is connected to an operating device, e.g. a laptop. Lastly, a software based program is prepared to display the values to the user as well as operating the appliances. This operation is also done in two ways. Normal switching of appliances can be carried out and timed operation of appliances is also possible. HEMS model with its basic components is shown in Figure 3. Figure 4 shows the schematic diagram the complete circuit of the model in which four loads are used.

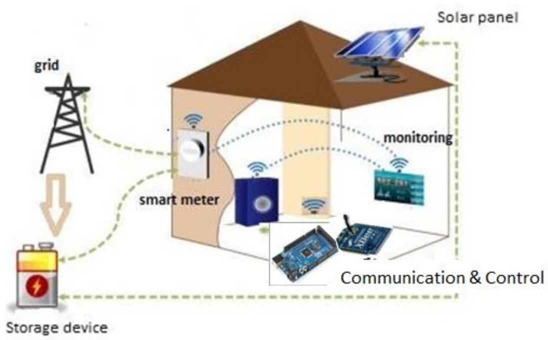

Figure 3: A model of HEMS with all the basic components

V. Conclusions

Monitoring of power consumption for home appliances is important and necessary in reducing their energy usage. In this paper, we have implemented a new HEMS scheme for energy management. We have successfully employed a switching circuit to shuffle the supply between solar panel and grid. Addition of solar PV panel has decreased the reliance on electricity from grid. In addition, the switching circuit has made the transition from one source of electricity to another easy and secure. The components used are cheaper and easily available. Integration of storage battery decreases the load placed on power supplies, especially during peak hours. The battery is safe in terms of usage and the storage capability can be further enhanced by using higher rated units. Voltage and current sensing is instrumental in making user aware of his energy consumption pattern. The developed hardware is not complex, neither expensive for domestic users. It can be easily connected to the appliances. Optimized pre-defined schedule for appliances operation has been implemented in order to conserve the electricity usage and peak demand management.

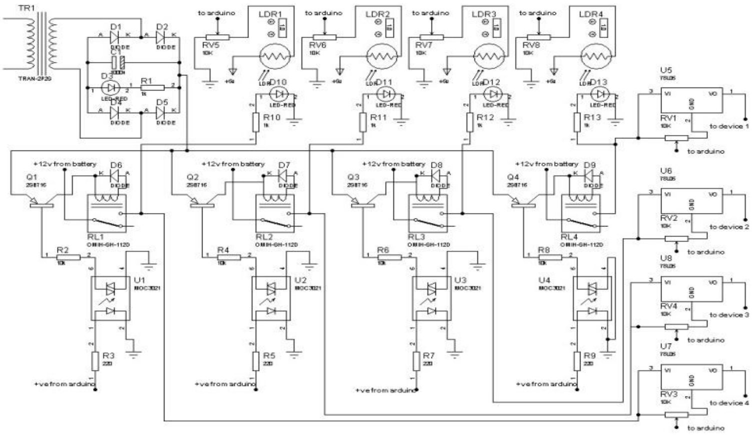

Figure 4: Schematic Diagram of Four Loads Control and Monitoring

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