A Review on Up Gradation of Conventional Grid to Smart Grid for Optimal Residential Power Scheduling

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Abstract*—Residential and commercial sector share up to 40% demand of power grid. For optimal power scheduling of appliances in this sector, power grid must be intelligent enough so that using Information and Communication Technology (ICT), peak demand and Peak to Average Ratio (PAR) can be decreased. Such upgraded grid is called as Smart Grid. In Smart Grid consumers can get benefit by applying different types of demand response (DR) programmes. Using Real Time Pricing (RTP) Tariff, consumers can reduce cost of daily consumption and PAR of the grid.. For this purpose, devices like Home Energy Controllers (HEC) should be used. If the domestic appliances are smartly scheduled, the line losses of the grid can also be reduced.

Keywords*— Information and Communication Technology, Peak to Average Ratio, Smart Grid, Real Time Pricing Tariff, Home Energy Controller

I. Introduction

Power and energy supply are facing many challenges in present era so power transmission and distribution technology must be advanced. In coming years use of low carbon energy must be increased due to limited stock of fossil fuels [1]. The development of such smart grid will be proved the best solution for the integration of renewable energy sources with conventional energy sources to reduce bad effect on environment. A Smart Grid is one that uses information and communications technology into every aspect of electricity generation, distribution and consumption in order to minimize environmental impact, enhance markets, improve reliability and service, and reduce costs and improve efficiency [2].

Using Information and Communication Technology in conjunction with traditional power plant and distributed renewable energy sources such as solar, wind etc. we can reduce the consumption of carbon fuel and emission of green house gases. The consumers can minimize their expenses on energy by scheduling the operation of intelligent domestic appliances. Home Energy Controllers (HEC) schedule appliances at domestic and commercial consumer’s premises to save energy, reduce cost, increase reliability, efficiency and transparency.

The transmission and distribution infrastructure of the Smart Grid is a web-like network of interconnected nodes. Consumers and utility are tied together with new grid components, such as energy storage units and intermittent renewable supplies. Like a living organism or cells, the grid controls energy flow to dynamically balance changes in supply and demand. IT and automation systems act as the central nervous system by collecting and processing the large amounts of data coming from sensors in from the extremities and control system elements.

Traditional power system depends on large scale power plant supplied multiple customers. It consist power plants supplying energy, transmission channels, distribution system and various consumers. The scope of future smart grid extends over all the interconnected electric power systems, from centralized bulk generation to distributed generation (DG), from high-voltage transmission systems to low-voltage distribution systems, from utility control centres to end-user home area networks [3]. A smart grid is expected to be a modernization of the age old electricity network. It provides data collecting, protecting and optimizing automatically to operation of the interconnected elements [4].

Fig.1 illustrates the architecture for smart grid communication infrastructure. Demand response services can be enable with help of Information and Communication Technology (ICT) that can respond to real time pricing signal and different types of grid condition signal through smart grid enabled energy management, results in financial savings for both consumers and electric utilities [4]. Though renewable sources are still not economical compared to conventional generation but they will be economical in future due to increasing fossil fuel prices. They will be economical in future due to research and development in renewable technologies as well as economy of scale resulting from large scale production of renewable resources [5]. Even with current technology we can produce about 12 MW/sq. km and 25 MW/sq. km by wind and solar resources respectively [5]. Countries like India have sufficient land to produce the electrical power through renewable energy sources to fulfil the present demand. Governments of developing countries also take different steps to use renewable energy sources. In order to achieve next generation energy efficient, sustainable and novel Smart Grid, ICT architecture as shown in Fig. 1 is needed [6].

With the help of smart grid technology, traditional investments can be diverted or minimized by applying demand-side management. The participants will try to minimize their electricity usage or offer flexibility to the operator of the demand-side management system to decrease their costs of energy or to gain personal benefit through maximizing the use of sustainable energy [7].

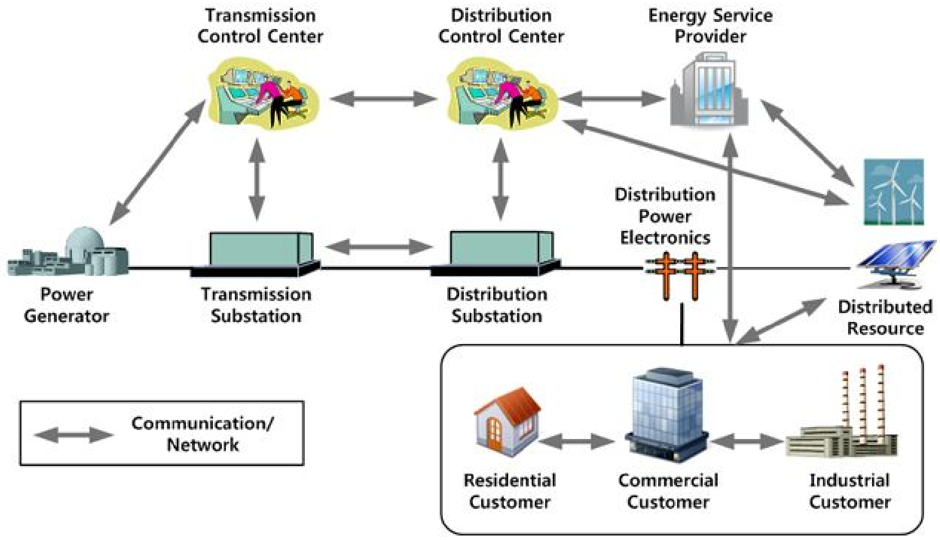

Fig. 1 Smart grid Communication Infrastructure

Demand response (DR) is a key feature of a smart grid that allows power utilities to manage the demand on the electricity grid and empowers consumers to manage their energy use. It allows consumers to schedule their consumption patterns in response to changes in the price of electricity over time allowing load to be shed from the network during times of peak demand. This is achieved through smart appliances which operate in conjunction with a smart meter and Home Energy Controller to adjust their operation based on a signal received from utility. Such appliances may also allow the utility to remotely control their operation to balance network load.

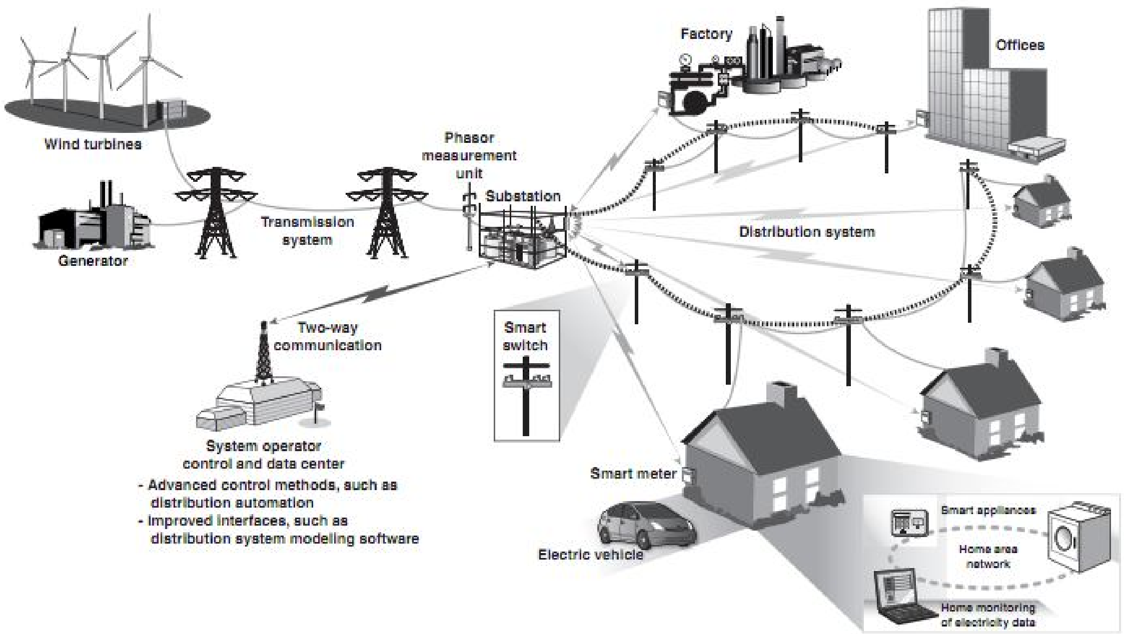

Fig. 2 System Model

Using smart grid we not only reduce the peak demand, but operate appliances when the price is low. Domestic appliances can be divided in two categories. The first category is a set of schedulable appliances that must turn “on” immediately (like fan, tube lights, air-conditioner etc.). The second are schedulable appliances (like washing machine, dish washer, Electric Vehicle (EV) etc.) that can be started with delay. One of the approaches being used to reduce the peak demand and improve the system reliability is demand response (DR), in which the end users modify their electricity consumption patterns in response to variable prices of energy or incentives provided by the utility [8]. DR is an alternative solution to reduce peak loads and adjust the demand in peak times to delay the investment in new generation capacity. Moreover, in regions with high penetration of renewable energy sources, DR can be used for the change of demand to follow the change of supply [9].

DR architecture centred on HEC which interconnects the Home Area Network (HAN) and Advanced Metering Infrastructure (AMI) domains, as seen in Fig. 2. Real time pricing (RTP) and DR signals are sent to the smart meter via the neighbourhood area network (NAN) of electric utilities with the neighbourhood transformer serving as the aggregation point for all the smart meters in that region. The HEC monitors the operation of all the attached smart appliances in the Home Area Network.

Plug in electrical vehicle can be designed smarter schedulable appliance as most vehicles can reasonably be expected to be plugged in for 10–12 hours a day (more for vehicles that are regularly plugged in both at home and at work). Smart charging is more than just charging at off-peak times. It involves fine-grained control of the charging of each vehicle to meet both the needs of the vehicle owner (charging the vehicle by a certain time) and the needs of the grid (matching supply and demand, providing frequency regulation, and perhaps also avoiding overload in distribution networks from many vehicles being charged at the same time) [10].

Recently, some home electronics companies such as General Electric have already started to produce smart appliances with IP based remote control signal receiver [11]. To evaluate the DR impacts on consumer daily life, comfort indices are needed to measure consumer comfort levels. The consumer convenience indices are defined based on the severity, scale, and duration of convenience violations for each controllable appliance [11].

II. REDUCTION IN DISTRIBUTION LINE LOSSES USING POWER SCHEDULING

Power scheduling of the appliances not only reduces the peak demand but reduces the line loses also as shown in following example. Another idea is that when there is lack of power, some apparatus should stop consuming energy or reduce the consumption. For example, PHEV can stop working for a while for the hot plug-in apparatus. In addition, many apparatus should reduce their power when energy crisis occurs. This can reduce the need for electrical storage or standby generators. For this reason, hybrid vehicles are perfect choice. If a load control device can be applied to shift one peak from the other, not only does it reduce the total peak demand but it also improves the PAR, reduces the line losses in the feeder and improves the feeder voltage [4]. Assume two coincident peak loads with the same time duration δt are carried by a line which has resistance of R Ω. The load currents are I_1 and I_2.

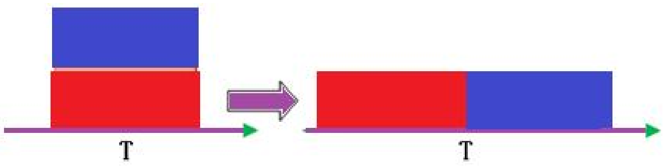

Fig. 3 Line losses in two different cases during power scheduling

The total loss in the circuit for the duration of the coincident peak is

$$(I_1 + I_2)^2 * R * \delta t$$
$$= (I^2{}_1 + 2* I_1 * I_2 + I^2{}_2) * R * \delta t$$

If the peak loads are controlled with help of HEC no coincidences are allowed as shown in Fig.3 and the losses becomes:

$$= (I^2{}_1 + I^2{}_2) * R * \delta t$$

If we take the case such that the both load currents are equal, the total loss in first case becomes:

$$= 4 * I^2 * R * \delta t \quad (I_1 = I_2 = I)$$

In second case the total loss becomes

$$= 2 * I^2 * R * \delta t$$

The difference in the losses in two different cases is 100%. So power scheduling not only reduces the losses but improves the PAR of each feeder.

III.SCHEME FOR REDUCTION IN PEAK DEMAND AND COST OF ENERGY

It is assumed here that the Real Time Prices are received by HEC to calculate a maximum allowable power for the consumer during a particular time slot, t. On the availability of renewable energy in the grid and weather there is peak load on the power station and according to that utility sends Real Time Pricing (RTP) signal to HEC. Communication with utility server and HEC of HAN can coordinate usage and calculate maximum allowable peak by running an algorithm [12].

Block Diagram of Home Area Network

Fig. 4 shows the block diagram of Home Area Network considered in our case. Here all the appliances are either smart appliances or receive power through smart plugs that senses the signal sent by HEC. The consumption of each device is shown in each block. Utility may sends the Real Time Pricing signal via Wimax, Power Line Carrier (PLC) or GSM network.

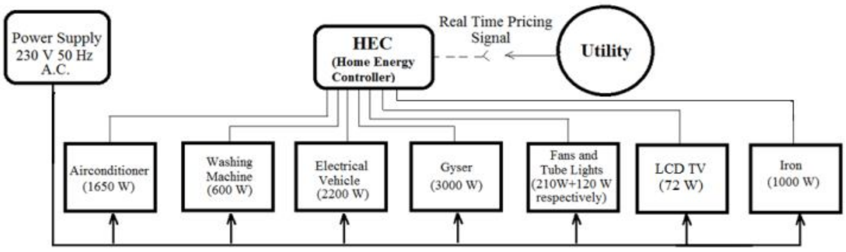

Fig. 4 Block diagram of Home Area Network

The appliances may connect with HEC via Wi-Fi, Zigbee or wired connection. Non-schedulable appliances can switch "on" any time. If any schedulable appliance wishes to join the active set of appliances, it first send power request to the HEC. If the total consumption is less than target level P_{max},t at that time, the incoming appliance can switch "on" at that time. If at the time of request of such schedulable appliances (like PHEV) the total consumption is close to the P_{max},t, the HEC will not permit it and that appliance has to wait until the total consumption becomes lower. By this manner peak demand reduces. HEC tries to allow the schedulable appliances during the time of lower energy cost. By this manner the overall cost of energy consumed is minimized.

TABLE I

Typical use of appliances without HEC

Sr. No.	Appliance Name	No.s	Consumption Watt	Duration hours
1	Split A/C	1	1650	13:00 to 17:00 22:00 to 7:00
2	Washing Machine	1	600	9:00 to 10:00
3	E.V.	1	2200	7:00 to 8:00 21:00 to 23:00
4	Gyser	1	3000	7:00 to 8:00
5	Fan	3	210	9:00 to 11:00 18:00 to 22:00
6	Tube-Light	3	120	18:00 to 22:00
7	LCD TV	1	72	18:00 to 22:00
8	Iron	1	1000	8:00 to 9:00

TABLE II

Typical use of appliances controlled by HEC

Sr. No.	Appliance Name	No.s	Consumption Watt	Duration hours
1	Split A/C	1	1650	13:00 to 17:00 22:00 to 7:00
2	Washing Machine	1	600	9:00 to 10:00
3	E.V.	1	2200	7:00 to 8:00 20:00 to 22:00
4	Gyser	1	3000	8:00 to 9:00
5	Fan	3	210	9:00 to 11:00 18:00 to 22:00
6	Tube-Light	3	120	18:00 to 22:00
7	LCD TV	1	72	18:00 to 22:00
8	Iron	1	1000	10:00 to 11:00

In the scheme described here, different types of typical appliances are connected in HAN. The consumption and the time of use is shown in the Table-I. In this case the care is not taken to reduce the peak demand so peak demand in this case becomes 5.2 kW. In second case as shown in Table-II the appliances are controlled by HEC so the peak demand remains at 3 kW. The time of use of the appliances will be clear with help of wave-forms presented in the following section.

IV. SIMULATION RESULTS

Simulation is done with help of MATLAB R2011a software. Fig. 5 shows the simulink model of HAN.

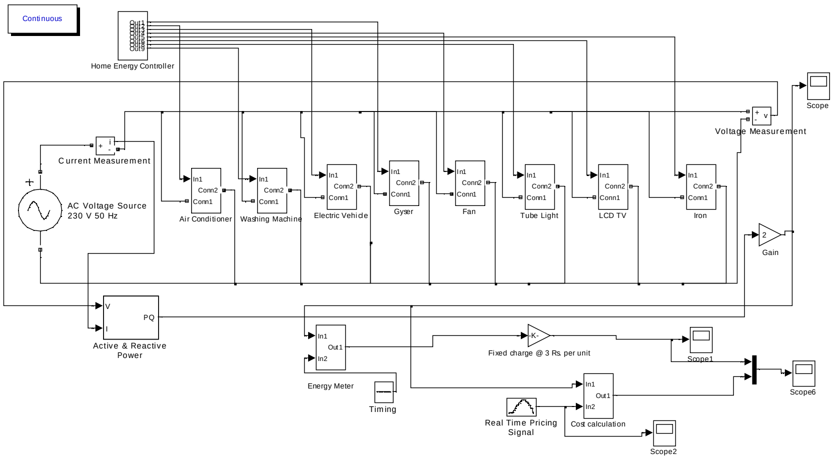

Fig. 5 Simulink Model of Home Area Network.

Fig. 6 shows the load curve for the time of use shown in Table-I. Here the appliances are operated without control of HEC so the peak demand becomes 5.2 kW.

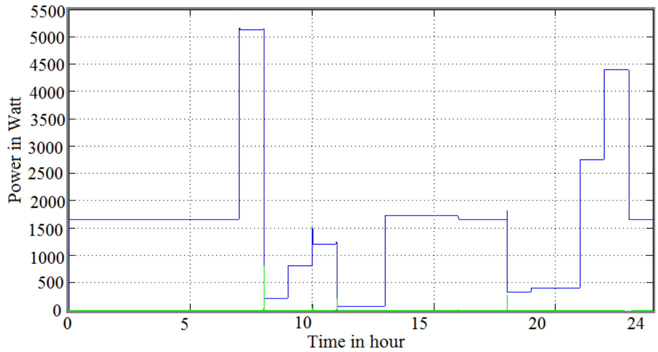

Fig. 6 Load curve without power scheduling

Fig. 7 shows the load curve for the time of use of appliances as tabulated the data in Table-II. Here the appliances are operated through HEC. So peak demand reduces to 3 kW.

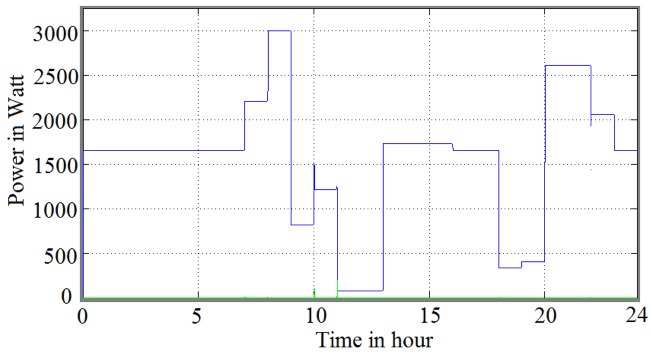

Fig. 7 Load curve with power scheduling

Fig.8 shows the typical RTP signal sent by utility. During peak time the price of energy is kept higher to reduce the peak demand. Incentive based and price based DR programs can be used for reduction in peak demand. Incentive based DR program offers customers some monetary bonus to reduce the load upon operator's request. Price-based programs allow customers to voluntarily adjust their demand based on electricity prices [7]. In such price-based programs the RTP signal shown in Fig.8 is used.

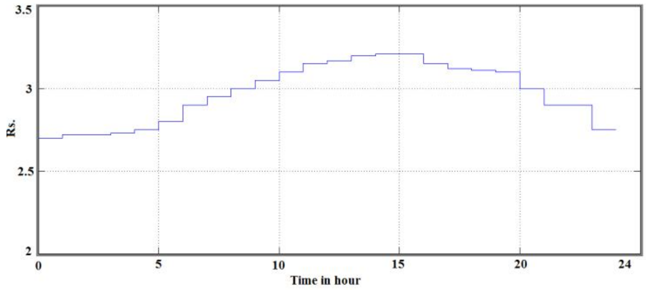

Fig. 8 Real Time Pricing signal

In countries like India still such price-based programs are not used. Normally constant value per unit is applied during the whole day. To calculate and compare the cost of energy consumed, both cases are considered in this simulation. In first case the total cost of energy consumed during the day is calculated using the rate Rs. 3 per unit. In second case the price-based incentive scheme is used to calculate the total cost of energy used. For this RTP signal is generated in the simulink model shown in Fig. 5.

The total cost of power consumption with and without power scheduling is shown in Fig. 9. The cost of energy consumed at the end of the day without power scheduling is Rs.112 and the cost of energy consumed at the end of the day with power scheduling (keeping load below P_{max} =3kW) is Rs. 98. However the cost of energy consumed without considering the limit $P_{max,}t$ is Rs. 94. According to RTP signal shown in Fig. 8, the charge of energy is lower during period 00:00 to 06:00. So if we shift the charging of EV during period 00:00 to 03:00 and use of washing machine during the Period 22:00 to 23:00, as shown in Fig. 11, the cost of energy reduces.

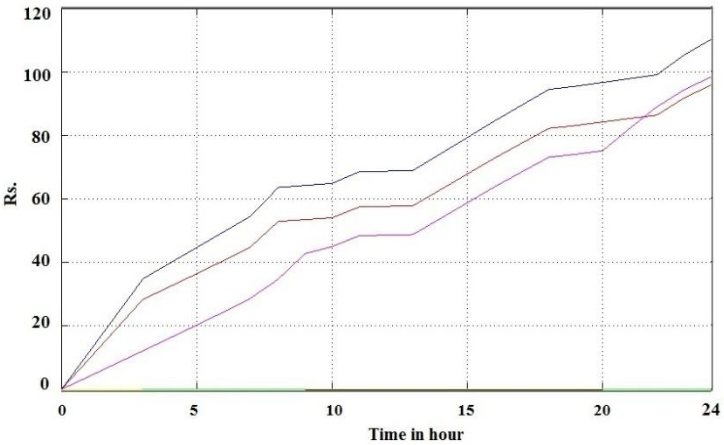

Fig. 9 Cumulative cost of energy consumed. Upper trace: Cost without power scheduling. Middle trace: cost with power scheduling, Lower trace: cost with power scheduling and maintaining load below P_{max}.

If consumer uses solar energy by installing 200W solar panel on roof, the cost of energy consumed can be further reduced. Consumer participates by this manner in reduction of green house gases. Due to use of solar energy in day time, the cost of daily energy consumed reduced to Rs. 91. As shown in Fig. 12, the total energy cost of the day remains same without power scheduling (i.e. Rs. 112). With shifting of load of EV and washing machine during lower energy charge period, the total energy cost of the day is Rs. 94. So Rs. 4 (or 4.1%) is saved per day by shifting of load during lower energy charge period. However reducing the cost of energy by this manner, the peak load increases to 3850 W (instead of 3000W). If we consider the saving in energy cost using solar panel, the daily cost reduces to Rs. 91 as shown in fig. 12. So consumer can save 7.1% using this strategy.

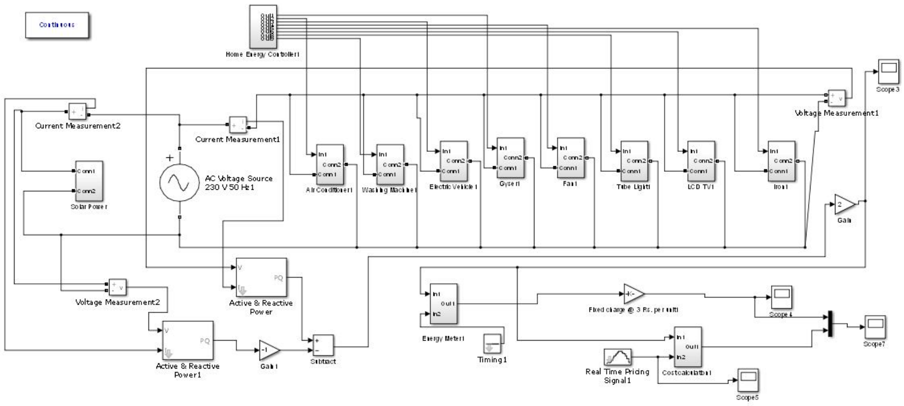

Fig. 10 Simulink model with solar panel

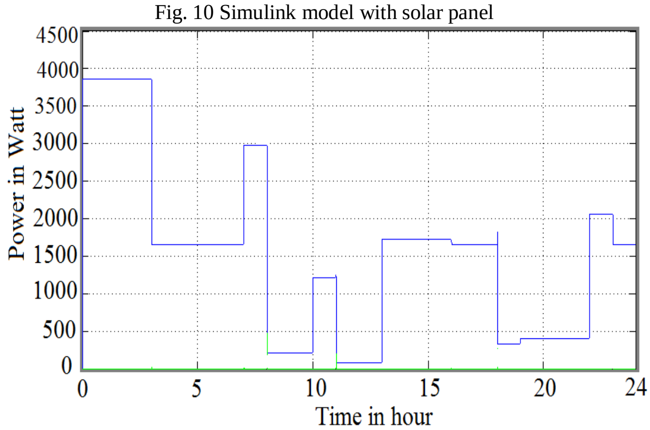

Figure 11. Load curve with shifting of load of EV and Washing Machine

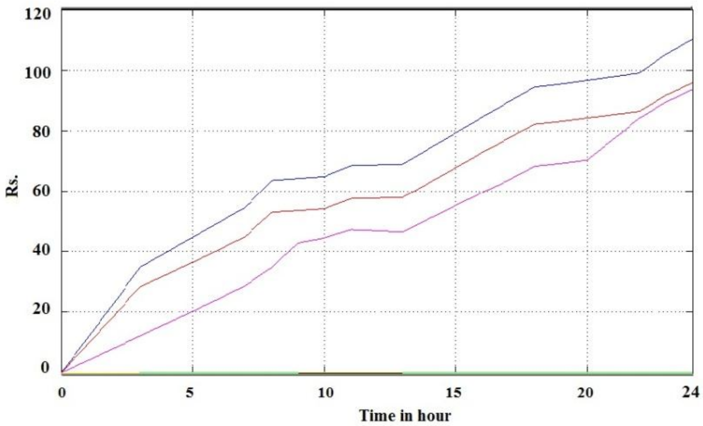

Fig. 12 Cumulative cost of energy consumed. Upper trace: Cost without power scheduling. Middle trace: cost with power scheduling, Lower trace: cost with power scheduling and maintaining load below $P_{max,}$ t. (Power used from 200W solar panel during day hours in third case)

V. CONCLUSIONS

This paper represents the concept of residential power scheduling. It is shown in the simulation that with help of HEC the total power demand can be kept below P_{max} , t. Using this technique, consumers can respond dynamically to variation in energy prices with help of RTP signal. By shifting the load during the low price duration (off peak period) we can save energy cost by 4.1% (keeping the daily consumption equal). By this manner customers can be encouraged to use the energy during the availability of renewable energy and they can reduce the emission of green house gases. If consumer uses solar energy from 200W solar panel, he further saves 7.1% in daily consumption. However if the number of schedulable appliances (like EVs and Plug In Hybrid Vehicles) under given demand limit are more, it may difficult to keep the load of feeder below target limit, so either the peak demand increases in that duration or the consumer's comfort level decreases. Another big challenge in DR program is cyber security. To manage DR program successfully in future, the communication infrastructure of smart grid must be secured.

REFERENCES

[1] Pathirikkat Gopakumar, M. Jaya Bharata Reddy, and Dusmanta Kumar Mohanta, “Letter to the Editor: Stability Concerns in Smart Grid with Emerging Renewable Energy Technologies”, Electric Power Components and Systems, taylor and Francis, 42(3–4):418–425, 2014.

[2] Mohamed E. El-hawary, “The Smart Grid—State-of-the-art and Future Trends, Electric Power Components and Systems, taylor and Francis, 42(3–4):239-250, 2014.

[3] Ye Yan, Yi Quin, Hamid Sharif and David Tipper, “A Survey on Smart Grid Communication Infrastructures: Motivations, Requirements and Challenges” Communications Surveys and Tutorials, IEEE. Issue 99, p.p. 1-16., Feb 2012.

[4] Hengsong wang, Qi Huang, “A Novel Structure For Smart Grid Oriented To Low-Carbon Energy” Innovative Smart Grid Technologies (ISGT) 2011, IEEE PES, p.p. 1-8, 17-19 Jan 2011.

[5] Wang, J.; Biviji, M.; Wang, W.M. “ Case Studies Of Smart Grid Demand Response Programs In North America” Innovative Smart Grid Technologies (ISGT) 2011, IEEE PES, pp 1-5, 17-19 Jan 2011.

[6] Koen KOK, Stamatis KARNOUSKOS, Jan RINGELSTEIN, Aris DIMEAS, Anke WEIDLICH, Cor WARMER, Stefan DRENKARD, Nokos HATZIARGYRIOU, Valy LIOLIOU, “ Field Testing Smart Houses For A Smart Grid”, 21st International Conference on Electricity Distribution, p.p. 1-4, Frankfurt, 6-9 June 2011.

[7] J. Kohlmann, M.C.H. van der Vossen, J.D. Knigge, C.B.A. Kobus, and J.G. Slootweg, “Integrated Design of a demand-side management system- A smart grid lighthouse project in Breda, the Netherlands”, Innovative Smart Grid Conference (ISGT Europe), p.p. 1-8, 5-7 Dec-
2011.

[8] Abiodun Iwayemi, Peizhong Yi, Xihua Dong, and Chi Zhou, Illinois Institute of Technology “Knowing When to Act:An Optimal Stopping Method for Smart Grid Demand Response”, p.p.44-48 IEEE Network. September-October 2011

[9] Abraham. Zhi Zhou, Fei Zhao and Jianhui Wang, “Agent-Based Electricity Market Simulation With Demand Response From Commercial Buildings” IEEE TRANSACTIONS ON SMART GRID, VOL. 2, NO. 4, p.p. 580-588,DECEMBER- 2011

[10] Alec Brooks, Ed Lu, Dan Reicher, Charles Spirakis, and Bill Weihl, “Demand Dispatch- Using Real-Time Control of Demand to Help Balance Generation and Load” IEEE Power An Energy Magazine p.p. 20-29, May-June 2011

[11] Shengnan Shao, Manisa Pipattanasomporn, and Saifur Rahman, “Grid Integration of Electric Vehicles and Demand Response With Customer Choice”, IEEE TRANSACTIONS ON SMART GRID, VOL. 3, NO. 1,p.p. 543-550, March 2012

[12] Gang Xiong, Chen Chen, Shalinee Kishore and Aylin Yener, Alec Brooks, Ed Lu, Dan Reicher, Charles Spirakis, and Bill Weihl, “Smart (In-home) Power Scheduling for Demand Response on the Smart Grid” Innovative Smart Grid Technologies (ISGT) 2011, IEEE, p.p. 1-7, Jan 2011.

