REAL TIME PRICING BASED POWER SCHEDULING FOR DOMESTIC LOAD IN SMART GRID

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Abstract- The concept of shaping domestic and commercial loads can be an effective way of controlling the load profile of a distribution company. Flat energy rates don't provide incentives to customers to use power as would be optimal from a utility point of view. Price of energy should be fluctuating according to peak or off peak load condition. Smart meters can offer solution to this by allowing sophisticated measurement of consumption and using real time pricing (RTP) signals sent by utility. The consumer can minimize their expenses on energy by adjusting their intelligent appliances operation. Home Energy Controllers (HEC) control appliances at domestic and commercial consumer's premises to save energy, reduce cost, increase reliability, efficiency and transparency. In this paper different automated meter reading (AMR) technologies and architecture of smart meter are discussed. Appliance scheduling approach is realized here with help of MATLAB simulation to keep the peak power demand for the homes below target value and reduce the cost of energy

Keywords- *Real Time Pricing, Home Energy Controller, Automated Meter Reading.*

I. INTRODUCTION

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 centers to end-user home-area networks, from bulk power markets to demand response service providers, and from traditional energy resources to distributed and renewable generation and storage [1]. A smart grid is expected to be a modernization of the legacy electricity network. It provides monitoring, protecting and optimizing automatically to operation of the interconnected elements [2].

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 pricing signal and grid condition signal encouraging consumers to use energy efficiency and reduce peak load through smart grid enabled energy management, results in financial savings for both consumers and electric utilities. [2].

Though renewable sources are still not economical compared to conventional generation, they will be economical in future due to upward pressure in fossil fuel prices, progress in renewable technologies as well as economy of scale resulting from large scale production of renewable resources [3]. Even with current technology we can produce about 12 MW/sq. km and 25 MW/sq. km by wind and solar resources respectively [3]. Our country has enough land to produce the electric power to fulfill the pres ent demand.

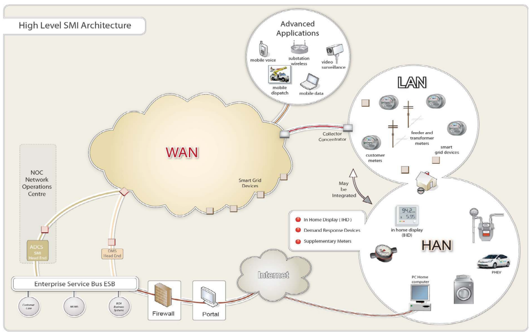

Figure 1. Smart grid Communication Infrastructure

The residential and commercial building sector together is responsible for over 50% of electricity consumption. The current electricity system doesn't include the active collaboration of parties such as homes and buildings. This limits the effectiveness of energy management efforts. In order to achieve next generation energy efficiency and sustainability, novel smart grid ICT architecture enables the Smart Grids is needed [4]. This architecture enables the aggregation of houses as intelligent networked collaborations, instead of seeing them as isolated passive units in the energy grid.

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 [5].

To help consumers shift their loads during off peak period, appliances that can act autonomously are required. These appliances are called smart appliances. A smart appliance is fitted with additional IT components connecting it to the smart grid.

II. POWER SCHEDULING OF APPLIANCES AND DEMAND RESPONSE IN SMART GRID

Using smart grid we not only reduce the peak demand, but operate appliances when the price is low. Two types of appliances are used in home. The first are real time 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.

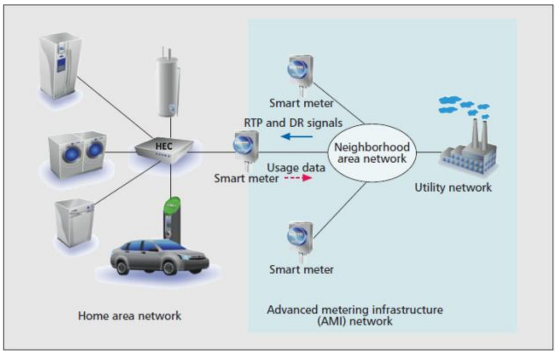

Figure 2. System Model

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 price variations or incentives provided by the utility [6]. DR is an alternative solution to reduce peak loads and adjust the demand in peak times to postpone the investment in new generation capacity. Moreover, in regions with high penetration of renewable energy sources, DR can trigger the change of demand to follow the change of supply [7]. DR architecture centered on an 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 electric utilities neighborhood area network (NAN) with the neighborhood 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. It then uses current electricity prices to determine:

• The operation mode of each device

• The load scheduling strategy required to balance occupant comfort and electricity usage.

Plug in electrical vehicle can be designed smarter schedulable appliance as most vehicles can reasonably be expected to be plugged in for 10–15 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 generation and load, providing frequency regulation, and perhaps also avoiding overload in distribution networks from many vehicles being charged at the same time) [8].

The smart appliances will have two-way communication with the HAN control center. Each smart appliance has an IC built in to report the status and to receive the control signal. Recently, some home electronics companies such as General Electric have already started to produce smart appliances with IP based remote control signal receiver [9]. 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 [9].

III. REDUCTION IN LINE LOSSES USING POWER SCHEDULING

Power scheduling of the appliances not only reduces the peak demand but reduces the circuit 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, refrigerators 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 load factor, reduces the line losses in the feeder and improves the feeder voltage [2]. 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.

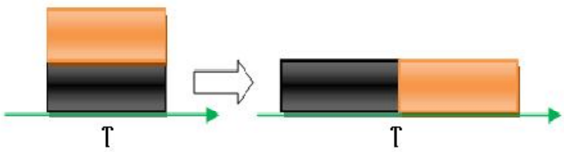

Figure 3. Line losses in two different cases during power scheduling

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 load factor of each feeder. This type of power scheduling is shown in fig.3.

IV. AMR CURRENT TECHNOLOGIES

The term Automatic Meter Reading (AMR) refers to the technology that helps to collect the meter measurements automatically and send commands to the meters [10]. A key element in an AMR system is communication between networks and utility servers.

For data collection the meter can read through a serial port (e.g., RS232), Infra Red or Radio Frequency. Smart meters enjoy high hardware/software capabilities that enable them to run TCP/IP suite and have the ability to run applications on top of TCP. Smart meters are equipped with processing capability ranging from SOC (system on a chip) microcontrollers to 32-bit processors. The operating system, supporting an extensive library of routines and applications, has a task scheduler that rotates between a number of tasks such as communication, measurement and database management. Such architecture is sown in fig. 4.

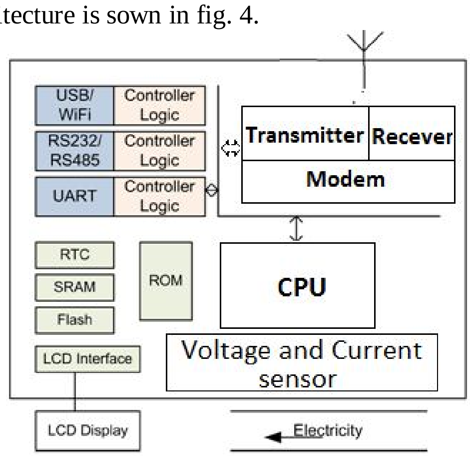

Fig.4 Smart Meter Architecture.

There are various benefits of AMR. With help of Real Time Pricing signal customers are charged tariffs that vary over short periods of time. It helps customer to control their consumptions and cost of energy they use. The metering data is sent to power company premises and power consumption reports are generated fully automated. For any time span this report can be generated in Excel or PDF format. Another salient feature of AMR is that utility can enable or disable energy to certain customer if required.

What AMR can offer is not limited to what has been mentioned above. Generally speaking, having a two way communication facility in place definitely it enables many sophisticated services.

Some manufacturers use PLC (Power Line Carrier), GSM (Global System for Mobile) network, telephone lines and Short Range Radio Frequency. However these technologies are not satisfactory. To support more services, AMR demands investigation into more sophisticated technologies with higher bandwidth. Third generation (3G) wireless technologies are getting more and more attention today for their flexibility, easiness and high speed of deployment, cost-effectiveness, scalability, and business needs. Various 3G wireless technologies have been introduced to the community, some of which had actual implementations. Long Term Evolution (LTE), High Speed Packet Access (HSPA) and IEEE 802.16 (known as Worldwide Interoperability for Microwave Access or WiMAX) comply with International Mobile Telecommunication (IMT-2000).

There are various challenges that must be considered while designing the Smart Meter. The data constitutes small packets transmitted from hundreds of thousands of small devices (meters) very frequently and control data sent down to the meters. Electricity is at the front today, but the challenges apply to all metering data. The AMR application is particularly different in its management of various types of traffic, its tolerance and reaction to failure, its tolerance to delay, and its security needs. One of the important challenges is the security.

AMR security must be end-to-end to prevent unauthorized access to the metering equipment or any of the AMR intermediate devices and to prevent tampering with data. Adding security cryptosystems however incurs extra load on the device processing and impacts the energy consumption and bandwidth [10]. Thus, selecting the right cryptographic tool is critical. For example, confidentiality of the AMR data is not as critical an issue as is data integrity. Therefore, a strong message authentication protocol is preferred while encryption cryptography can be kept simple.

V. POWER SCHEDUALING MODEL IN HOME AREA NETWORK

A. Scheme For Reducing Peak Demand and Cost of Eergy

We assume here that real-time prices are used to calculate, P_{max},t, a target power consumption level for the home at time t. For example, this target value can be obtained by incorporating current electricity prices with the customer's budgetary preference (e.g., no more than Rs.x to be spent on electricity bills this month) and their usage pattern (e.g., total cost incurred thus far this month and expected usage for the remainder). Or it could be a power level set by the utility, e.g., as a part of a (Direct Load Control) DLC program.

We here further assume that on the availability of renewable energy in the grid and weather there is peak load on the power station or not, the utility sends Real Time Pricing (RTP) signal to HEC. Our joint media access and appliance scheduling approach gives an access method for the common control channel of the HAN so that appliances can coordinate usage and meet the target P_{max},t [11]. Two types of appliances are accommodated. First are "real-time" which are granted immediate access to the active set (i.e., those that must be turned on immediately); the second are "schedulable" which can be turned on at a later time. Results show that for an appropriate P_{max},t, this scheme leads to a reduced peak demand for the home and reduces the cost also.

The goal of the scheme presented here is to exploit the "schedulability" of smart appliances to bring peak usage at or below the threshold power level. We note, however, that certain usage patterns will not permit total usage below P_{max},t; in such cases, our scheme will attempt to reduce overall usage close to P_{max},t with the understanding that the customer will have to pay more for the higher demand.

Some loads like storage heaters and electric cars can operate at night when electricity is cheap. These loads could be scheduled for night time to take advantage of lower fixed tariffs. An example is the cheap night time "Economy 7" tariff in UK [12].

B. Block Diagram of Home Area Network

Fig. 5 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 or Power Line Carrier (PLC).

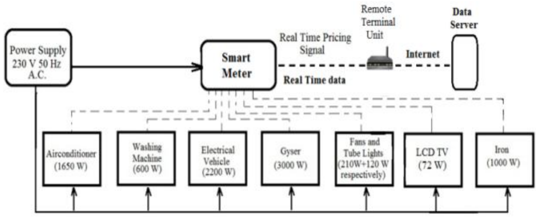

Figure 5. Block diagram of Home Area Network

The appliances may connect with HEC via Wi-Fi, Zigbee or wired connection. In this case the connection is done (for exchanging signals) with control cables. Here two types of appliances are used, active and schedulable. Active 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 central HEC [11]. 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 battery charger of EV) 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.

The real time architecture provides numerous benefits to the suppliers and customers. The power companies can exercise control over the demand which increases the reliability of grid operations, helps in obtaining power at lower costs from other distribution companies because of the increased accuracy of demand forecasting. Suppliers can also use real time information of existing demand and supply to efficiently trade excess power with other distribution companies or for re-generating purposes like pumping the water back to the reservoirs or charging the batteries. Short term demand forecasting can be significantly improved by analyzing the information present in the smart control panel (HAN) settings. By deducing the upper and lower bounds of demand of the customers based on historical data the suppliers can achieve significant reliability in terms of power distribution as well reduce the maintenance costs and capital expenditure costs like conductors, insulators and transformers. The capacity margin observed over a period of time can help investors and supplier make informed decisions about capacity expansion.

If utility sends RTP signals regularly, the 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.

In this scheme different type 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.

TABLE I. Typical use of appliances without HEC

Sr. No.	Appliance Name	Nos	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	Nos	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

The time of use of the appliances will be clear with help of wave-forms in the following section.

VI. SIMULATION RESULTS

Simulation is done with help of MATLAB R2011a software. Fig. 6 shows the simulink model of HAN. Here different domestic appliances having typical load are used. The equivalent model of such load is taken in simulation. The control signal sent to different appliances through wire in this simulation. In actual case if we may control only schedulable appliances with help of Home Energy Controller to minimize complexity of the Home Area network. In first case of simulation , to calculate the cost of energy, flat rate tariff is used. In second case, to calculate the cost of energy consumed Real Time Pricing Signal is used.

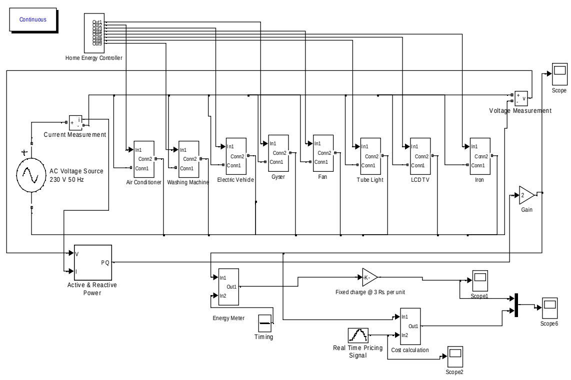

Figure 6 Simulink Model of Home Area Network.

Fig. 7 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.

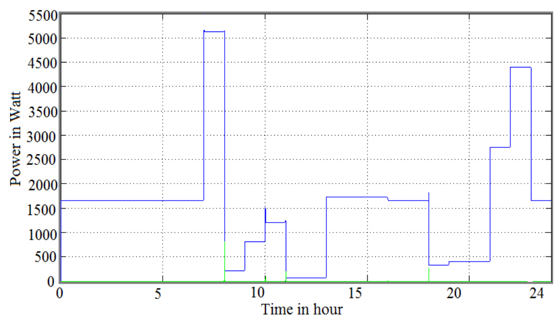

Figure 7. Load curve without power scheduling

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. 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 [8]. In such price-based programs the RTP signal shown Fig.8 is used.

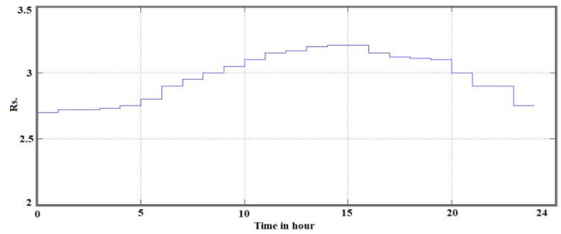

Figure 8. Real Time Pricing signal

In countries like India still such price-based programs are not used. Normally constant value per unit is applied during the whole day. So to calculate the cost of energy consumed, both the 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. 8.

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. 9, the cost of energy reduces. As shown in Fig. 10, 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. 18 (or 16%) 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).

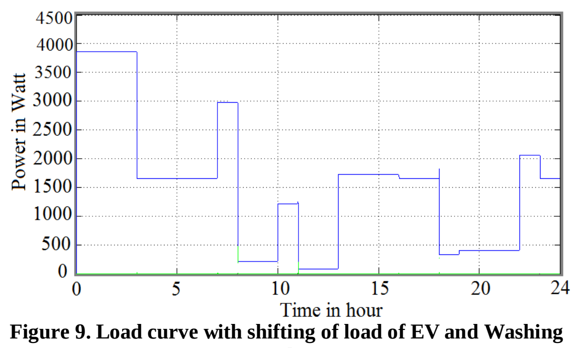

Figure 9. Load curve with shifting of load of EV and Washing Machine

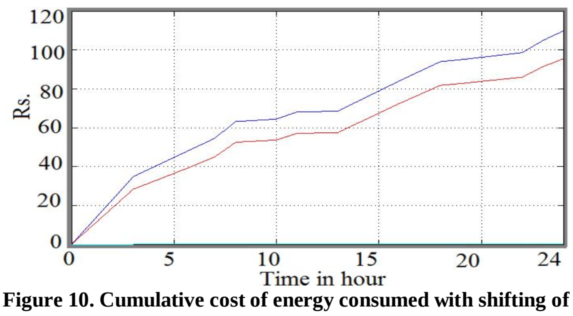

Figure 10. Cumulative cost of energy consumed with shifting of load when energy charge is lower. Upper trace: Cost without power scheduling. Lower trace: cost with power scheduling.

VII. CONCLUSION

The architecture and operation of smart energy meter are outlined here. The smart meter sends data of various electrical quantities at every minute to the server. Customer can generate the report of any time duration with help of web portal. If customer's load demand exceeds the value of contract demand, an alert message is sent to the customer through e-mail and SMS. The concept of power scheduling of appliances as a part of DR strategy is presented here. It is shown in the simulation that with help of HEC the total power demand is kept below P_{max}, t. Consumers can respond dynamically to increment in prices with help of RTP signal.

In the simulation it is shown that by shifting the load during the low price duration (off peak period) we can save energy cost by 16%. By this manner customers can be encouraged to use the energy during the availability of renewable energy and they can reduce the carbon footprint and reduce the emission of green house gases also. 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 this duration or the consumer's comfort level decreases.

To solve such problem smart charging of EVs should be adopted. In which the group of EVs of particular area are get charged intermittently to avoid sudden rise in peak load during night and EVs are get charged before the targeted time. Another big challenge in DR program is cyber security. Hackers may gain access to control software and alter the load condition. To manage DR program successfully in future, the communication infrastructure of smart grid must be secured.

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