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A Study of Pricing Policy for Demand Response of Home Appliances in Smart Grid Based on M2M

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***Abstract*—Demand Response (DR) is one of the core components of smart grid. Demand response is the management of electricity consumption of customer in response to supply conditions of smart grids, for example, during the peak hours or in response to electricity price the customers reduce their electricity consumption. In Demand response mechanisms, the shut off request is explicitly made, whereas the demand devices passively shut off when the grid observes the stress. Demand response curtail the power used and it can also start on-site power generation which may or may not be connected in parallel the smart grid. DR is different from the energy efficiency which means using less power to perform the same tasks or perform the same task on a continuous basis. At the same time, demand response is a component of smart energy demand, which also includes energy efficiency, home and building energy management, distributed renewable resources, and electric vehicle charging. In this paper, we propose a pricing policy mechanism based on the provider's prices announcement and control of the appliances remotely during peak hours of the day.**

***Index Terms*—Smart grid, demand response, pricing, home appliance control, utilities**

I. INTRODUCTION

Demand Response (DR) is the changes in electricity usage by end-use customers from their normal consumption patterns in response to changes in the price of electricity over time. Furthermore, DR can be also defined as the incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized [1]. DR includes all intentional electricity consumption pattern modifications by end-use customers that are intended to alter the timing, level of instantaneous demand, or total electricity consumption [2].

The DR can be categorized to two categories; the priced based DR and incentive-based DR [3]. Price-based DR programs include the use of time-based rates to encourage retail customers to reduce demands when prices are relatively high. These demand-response programs may also include the use of automated responses. Customers may or may not have the option of overriding the automatic response to the high prices. Incentive-based DR programs pay participating customers to reduce their loads at times requested by the program sponsor, triggered either by a grid reliability problem or high electricity prices. There are various types of DR discussed in [4].

Smart grid is an intelligent electricity network that combines the activities of all users connected to it. It also makes use of advanced information, control, and communication technologies to save energy, reduce consumption cost and increase efficiency, reliability and transparency. In future smart grid applications, the interaction between energy provider and end users enabled by advanced communication infrastructure (e.g., wireless sensor networks and power line communications) and protocols will greatly enhance demand response capabilities of the whole smart grid system. Recent overview of challenges and issues of enabling communication technologies in this regard can be found in [5]. It has been shown in [6] that demand response can deliver significant benefits for consumers, utilities, and society at large. According to the experiments in [6], there exist huge DR opportunities in residential homes where the operation of many home appliances (e.g., freezer, dishwashers, dryers) can be shifted to off-peak times. Moving one million smart appliances from on peak to off peak will save billions of dollars in coal power plant construction cost. Further, with the wide adoption of PHEVs (plug-in hybrid electric vehicles) in the future, there is a clear need for more active and enhanced demand response mechanisms such as proposed in [7]. In [8], user preferences are taken into account with the concept of discomfort level and an optimization problem is formulated to balance the load and minimize the user inconvenience caused by demand scheduling. Several ideas from the distributed computing area such as make-span have been introduced to energy consumption optimization. An energy consumption scheduling problem was established to minimize the overall energy cost [9]. They applied similar approaches to those used in wireless network resource allocation to solve the optimization problem. In both works, the user demands are known beforehand and the optimization problem was solved in numerical iterations.

The implementation of DR programs may reduce energy costs and increase reliability. To fully harness such benefits, existing load controllers and appliances need around-the clock price information [10]. Advances in the development of Advanced Meter Infrastructures (AMIs), and various dedicated embedded control systems provide the capability to effectively address this requirement.

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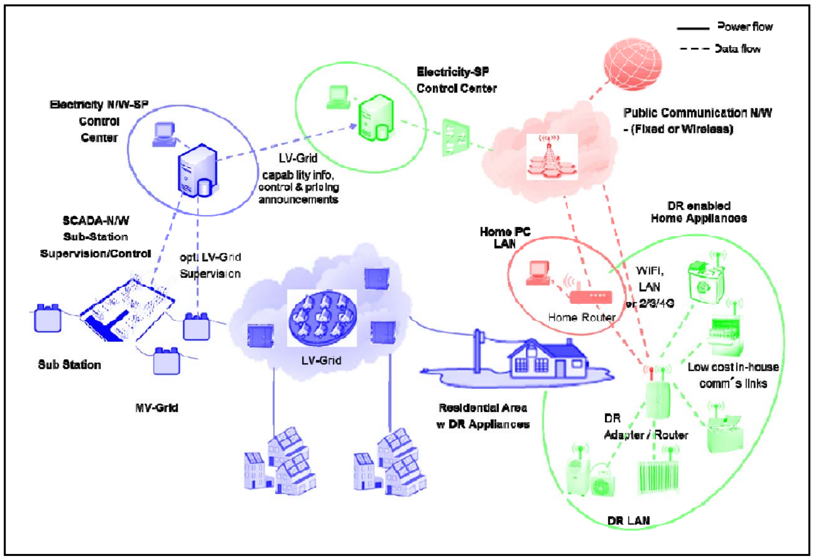

Figure 1. Smart grid appliances demand response services [11].

In this paper, we present and develop pricing policy in smart grid based on M2M for demand response of home appliances, where the only information available to the end users is the current price which is dependent on the overall system demand and energy production. Based on this information, the users try to adapt their demands so as to minimize their utility Bills. There is no central control entity. Inspired by the well-established work on congestion pricing in IP networks, we propose a simple adaptation strategy based on price feedbacks and show that it is very effective in achieving demand response.

II. Demand Response Architecture For Home Appliances

Until now Home DR applications are not completely standardized in its real essence and it follows a different kind of standardization than the one originally used in energy-sector. The most common driving force is the IEC which is coming from the electricity-N/W field. In Fig. 1, Home-DR applications are defined through White and Red Ware equipment's, which the user sets up them. These devices are connected to an outlet called router. The router can be located anywhere in the home where it can be suitable for Home-DR applications. The aim is to save energy at the peak hours of the day, during the lifetime of the devices, will overcome the additional cost of enabling this functionality. We know that due to the lack of energy resources, the energy prices increases day by day, so we need a cost effective implementation of this strategy, this is known from consumer electronics and home networking.

Operation of such devices must also be consider and should be flexible enough to guaranty customer's requirements and satisfaction. For example washing machines which are capable enough delay watching the clothes and shifted to a off-peak hours of the day where the energy prices offer by the energy providers company (electricity-N/W SP) is low.

In case of watching machine, watching clothes can be delayed and shifted from peak hours to off peak hours when the sun is shining at its best and PV generates high power or when wind speed is strong and high wind energy is generated. Further examples are air-conditions, tumble dryers and dish washers, where the customer may agree on a proposed scheduled runtime or movable heating/cooling devices to simply reduce high priced time of day operation.

This proposal is forward looking, since the Low Volt Distribution Network (LV-Distribution-N/W) needs to be prepared for flexible tariff accounting. Therefore it is required that the Local Electricity N/W-SP did install a Smart Meter infrastructure before in his Low Volt-Grid (LV-Grid).

As stated above and for privacy control reasons as well as implementation point of view, it is proposed to keep the smart metering communication´s N/W separate from the Home-DR communication´s-N/W. Another advantage of this approach is to fulfill the legal requirement to be able to choose a suitable local Electricity-SP separately. It is anticipated that the Electricity-SP is interested to offer Home-DR services to differentiate them from the competition. The Electricity-SP control center receives LV-Grid capability, control and pricing information from the Local Electricity-N/W-SP. This information is then coordinated by the Local Electricity-N/W-SP with the smart meter tariff, accounted in the consumers´ residential home. Through the Communication-N/W (including the consumer's Home-N/W, when operating through Fixed Network) the Electricity-SP announces this pricing information to the gateway supplied by the company, this router is named as DR-Adapter/Router. This is a new device class in the residential home, at best logically comparable with a set-top box (for e-Energy management purposes, instead for multimedia). The DR Adapter/Router receives and stores the control and pricing information.

On demand, the subsequently connected devices ask for currently available options, when the consumer communicates with "programs" them or as in case of the washing machine, upon internal demand planning by the device's controller. This requires a simple low profile object model for each device to be connected and controlled, which shall be supplied by the White or Red Ware manufacturer and adapted to the DR-Adaptor/Router by the Electricity-SP, on a forward-looking basis and downloaded to it on a regular update basis. End-to-End communication protocol security and privacy between the Electricity-SP and the DR Adapter/Router (including the communication N/W path) shall meet at least high consumer requirements (if not national law requirements as in the Smart Meter communication case), which is comparable to home–banking application standards, due to the financial analogy. This advises strong data encryption and privacy, which should be administered and guaranteed by the Electricity-SP.

III. Proposed Pricing Policy For Demand Response Home Appliances

A. *Pricing Information*

In most electric power systems, some or all consumers pay a fixed price per unit of electricity independent of the cost of production at the time of consumption. The consumer price may be established by the government or a regulator, and typically represents an average cost per unit of production over a given timeframe (for example, a year). Consumption therefore is not sensitive to the cost of production in the short term (e.g. on an hourly basis). In economic terms, consumers' usage of electricity is inelastic in short time frames since the consumers do not face the actual price of production; if consumers were to face the short run costs of production they would generally increase and decrease their use of electricity in reaction to those cost-based price signals. In effect, consumers served under these fixed rate tariffs are endowed with real "call options" on electricity.

B. *Appliance Control and Peak Time Response*

In an electricity grid, electricity consumption and production must balance at all times. Any significant imbalance could cause grid instability or severe voltage fluctuations, and cause failures within the grid. Total generation capacity is therefore sized to correspond to total peak demand with some margin of error and allowance for contingencies (such as plants being off-line during peak demand periods). Operators will generally plan to use the least expensive generating capacity (in terms of marginal cost) at any given period, and use additional capacity from more expensive plants as demand increases. Demand response in most cases is targeted at reducing peak demand to reduce the risk of potential disturbances, avoid additional capital cost requirements for additional plant, and avoid use of more expensive and/or less efficient operating plant. Consumers of electricity will also pay lower prices if generation capacity that would have been used is from a higher-cost source of power generation. Demand response may also be used to increase demand during periods of high supply and/or low demand. User will select the devices to be ON during the peak hours as given below:

$$\forall\, n \in N, T_{off}(n) \quad when\, P_u > \theta \tag{1}$$
$$\forall\, m \in N, T_{on}(m) \quad when\, P_u > \theta \tag{2}$$

$$\forall\, n, m \in N, T_{on}(N) \quad when\, P_u \leq \theta \tag{3}$$

Where *n* is the list of appliances of the users that should remain OFF, *N* is the total number of appliances and P_u is the price per unit of electricity. Equation (1) shows the list of appliances that should remain OFF during the peak hour or when the price per unit is higher than the threshold, θ. Equation (2) shows the list of appliances that should remain ON even if the price is high. Equation (3) shows that supply of electricity to all the appliances should remain ON when the price per unit is less than threshold, θ. Some types of generating plant must be run at close to full capacity (such as nuclear), while other types may produce at negligible marginal cost (such as wind and solar). Since there is usually limited capacity to store energy, demand response may attempt to increase load during these periods to maintain grid stability. For example, there may be a short period of time when electricity prices are negative for certain users. Energy storage such as Pumped-storage hydroelectricity is a way to increase load during periods of low demand for use during later periods. Use of demand response to increase load is less common, but may be necessary or efficient in systems where there are large amounts of generating capacity that cannot be easily cycled down.

C. *Algorithm*

The steps of the application's program are:

1. Servers start listening of client programs.
2. Initially server announced pricing of the energy.
3. Users set their own preferable prices for the home appliances.
4. Server receives each client's set prices for the appliances.
5. Server then controls each home appliance with respect to the users set price.
6. Then different appliances are ON/OFF automatically with respect to the offer prices and user set prices.
7. Check for the energy sources availability.
8. Check for the outside environment temperature, sun shining and wind speed.

$$P_u = \frac{1}{Pr_e} \tag{4}$$

Where Pr_e is the Production of electricity.

9. Update step 2 periodically whenever there is enough changes in the step 7 and 8.
10. The algorithm will stop when there is no change in the price.

The server will continuously update their current prices with respect to the environment updates. The clients will update their current energy prices according to the server updates, and control of the appliances with respect to the user's settings.

IV. SIMULATIONS AND RESULTS

Microsoft Visual Studio 2010 is used to simulate the proposed idea. A client server mechanism is used to implement pricing policy for demand responses of home appliances. To do this, two basic services are implemented during the simulation process. PricePolicy and AppliancesControl services. PricePolicy() is a service that is implemented for the sole purpose of the price announcement to the customers. The price announcement updated periodically whenever there is a change in the price. The change in price occurs due to the shortage in available energy. For example when sun is shining and wind speed is also more than the normal wind speed, then at that time the unit price of the energy will be come down. Then this price is communicated with the customer on regular basis. GetUtilities() is a method which is implemented for the purpose of providing utilities information's to the customers. This method is basically works under the PricePolicy service. It contains information's like total energy consumed by a particular appliance, bill to date for each appliance, and etc. SetPeakPrice() and Set OffHourPrice are the other two methods implemented for the setting of prices during peak hour and off hour time of the day. ApplianceControl is a second service which is implemented to control the home appliances during peak hour or off hour price rates. GetListOfAppliance() is method which is implemented to know the list of appliances a customer have registered with the energy providers company. The method is works in conjunction with AppliancesControl servce.

Fig. 2 shows the flow chart of the demand response services of the energy to the customer's home appliances with respect to the pricing policy. Flow chart shows the way client server application provides the services to the customers. When the applications start all these services begins listening and some of them provide periodic updates to the customers, like price updates. Client contains the user request to the server for some specific queries. The server has control functionality to control the home appliances during power shortage or peak price time of the day. Fig. 3 shows the sequence diagram of the implemented client server application for the pricing policy and demand response of the home appliances. It consists of the user interface which provides user to communicate with the system. User interface consists of utilities interface, pricing interface and appliance control interface. The user communicates with the system through these interfaces and receives information's regarding pricing and utilities. The server also updates customer regarding updated prices through these interfaces. The server controls the user's appliances during various conditions of the environment and power availability through these interfaces. At the server side in the sequence diagram the pricing service provides pricing information's and control information's provides appliances control details

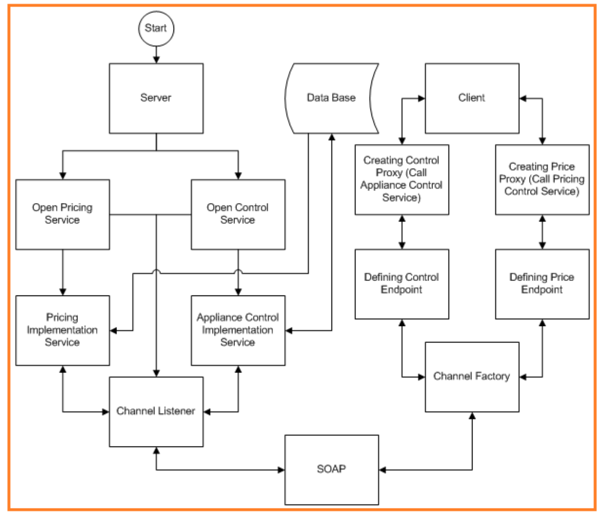

Figure 2. Flow chart of the home demand response services for pricing policy.

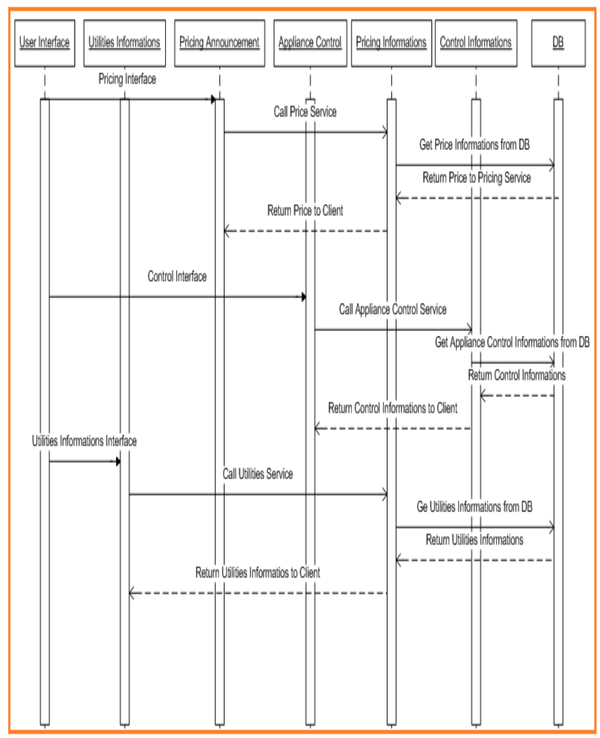

Figure 3. Sequence diagram of the client server application for the pricing policy and demand response of the home appliances.

Figure 4. Service providers interface of demand response services.

to the customers. The server gets the updated prices schedule from the database. The database is implemented in the Microsoft access.

Fig. 4 shows the server interface which provides starting and stopping of different services of the demand response application for the home appliances and pricing policy. Fig. 4, itself shows two services, pricing policy service/pricing service and device control service/appliance control. These services are starts/stop from this interface. When the services get started, the server application starts listening for the clients to connect with the application. For communication with clients SOAP message packaging is implemented.

Fig. 5 shows the user interface which communicates energy/power pricing information's with the customers that are currently offered by the energy providers company. This interface is a home display unit where user can see up-to-date pricing information's regarding energy and power. This information's are updated on regular basis when there is change in the environment. For example if the sun is shining most and PV generate more energy or if there is high speed wind and generate more wind energy then this information's will be updated. The update information's will be to reduce the prices due to the high generation of the energy. If this is not the case and sun is not shinning neither wind speed is high then the updated information's on the users home display unit will be to increase the price of the energy.

Fig. 6 shows the user interface which provides utilities information's about different home appliances, like current day energy consumption of a particular appliance, current

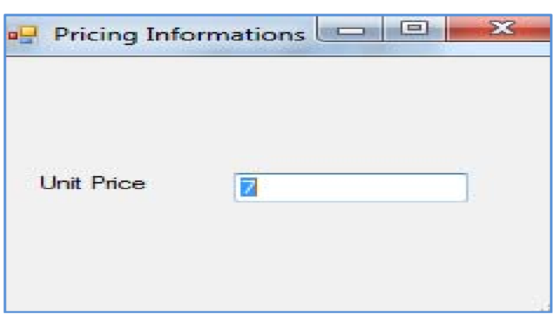

Figure 5. User interface of demand response services for pricing information's

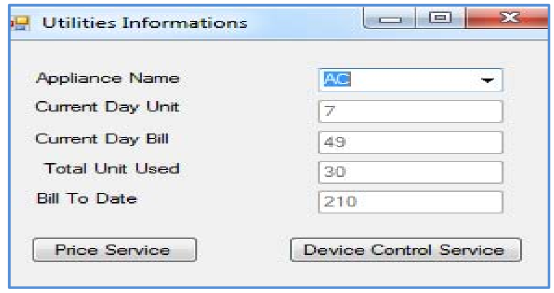

Figure 6. User interface of demand response services for utilities information's.

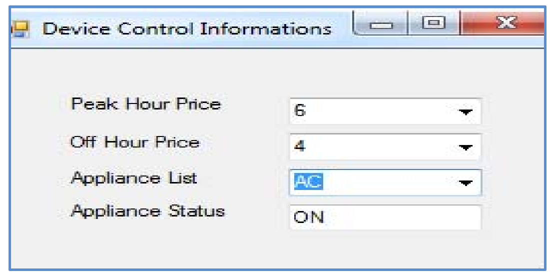

Figure 7. User interface of demand response services for Device Control.

day bill of a particular appliance, total unit used by a specific appliance and bill to data of a specific appliance. It also displays the name of the appliance about which the utilities information's are displayed. In fact utilities information's is just like an in-home display system where all the relevant information's about a specific home appliance can be displayed to the user.

Fig. 7 shows the user interface which provides control information's about different home appliances which are currently registered with the energy providers company. The appliances are controlled by the energy providers with respect to the price schedule set by each user. The appliances are ON and OFF according to the user preference prices. Using these interface users set their peak hours price and off peak hours price. On the basis of these settings the corresponding home appliance will be either in the running state or not running state. If the company's offer prices are high then the user set prices during peak hours, then some particular home appliances will not be running and energy will not be provided to it, while some home appliances may run during the peak hours because the user wants to run them in any case. For example in summer if the weather is hot then users wants to keep AC on without considering the price of the energy, while in case of washing machine the user can delay it to the off peak hours.

V. Conclusion

This study proposes a pricing policy framework for demand response in smart grid M2M networks. The focus of our paper is on the provider's prices announcements and control of the appliances remotely during peak hours of the day. More specifically, we have applied the concept of pricing in Internet traffic control to the DR problem and shown that it is possible that the burden of load leveling can be shifted from the grid (or supplier) to end users via pricing policy mechanism. Individual users adapt to the price signals to maximize their own benefits. User preference is modeled as a willingness to pay parameter which can be seen as an indicator of differential quality of service. The effectiveness of the proposed mechanism has been demonstrated by simulation results. This paper is just a first step towards our vision of pricing policy for fully demand response services. There are a number of directions for future research.

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