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Multiobjective optimization technique for demand side management with load balancing approach in smart grid

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ABSTRACT

Power companies are unable to withstand the consumer power requirement due to growing population, industries and buildings. The use of automated electrical appliances have increased exponentially in day to day activity. To maintain a possible balance between the supply and demand the power companies are introducing the demand side management approach. As a result, consumers are adopted for load shifting or scheduling their loads into off-peak hours to reduce the electricity bill. When all the consumers are trying to run the scheduled electrical appliances at the same time then the usage of energy in the off peak hour curve is marginally high. However, service providers are in need of a load balancing mechanism to avoid over or under utilization of the power grid. In the existing works, threshold limit is applied for a home to maintain the balanced load and if the consumer exceeds it then the additional charges are applied in the bill. To overcome the above mentioned drawbacks there is a need to increase the power usage with minimum cost and reducing the waiting time. For this purpose, in this paper we implement multi-objective evolutionary algorithm, which results in the cost reduction for energy usage and minimize the waiting time for appliance execution. The result reveals that if the consumer exceeds the threshold limit, the scheduled running electrical appliances temporarily stops to maintain the energy usage under threshold level for cost benefit and resumes the stopped appliances later. Further, the proposed technique minimizes the overall electricity bill and waiting time for the execution of electrical appliances.

1. Introduction

At present, brownout, blackout, fluctuations in the power and faults are the major issues faced by the customer. The most important activity of the utility company is to generate and supply the generated electrical energy to consumers actual demand with low operating cost [3,4]. One of the major challenging tasks for service provider is to satisfy the consumer energy demand for example, during the peak hours consumers energy demand is very high. Therefore, a proper mechanism is required to solve both the customer and service provider requirements. Due to various features of smart grid [5], such as consumer friendly, self-healing, bidirectional communication, reliable, sustainable and improvement in efficiency of operation, the outcome and interest on demand side management in smart grid has increased in the public domain [1,2,6,7]. Smart grid is a transformation of the existing power grid into future power system integrating the advanced information, networking and communication, computing and processing technologies [8,9]. It helps to transfer the electricity from bulk generation stations to distribution stations to deliver the power to consumers in an elegant and efficient way.

Consumer and service provider participation, both components are exceptionally playing an important role in the smart grid communication system [10]. In the past few years, the development of Internet of Things (IoT) has been posed a large communication medium for information exchange [11,12]. Presently, the smart grid information is exchanged using the Internet with the active consumer as well as service provider participation. Demand Side Management (DSM) is one of the interesting areas in the smart grid [13]. Thus, one of the main objectives of smart grid is to effectively use the available power by the consumer. At the same time, consumers energy usage cost is also reduced by operating the appliances during off-peak hours.

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Service providers are planning to design the power grid to satisfy the peak hour energy requirement instead of average demand. This system helps to maintain the reliability but it may end up with under utilization of the power grid [14]. The increase in population leads to increase in usage and smartness of electrical appliances. There is a necessity to get better utilization of power grid in both energy sources and consumers. The exponential growth of electrical appliances from (small electrical devices) charger to high energy consumption devices like PHEV doubles the consumers load at the distribution end. To solve these issues with the available energy sources demand side management plays a vital role in the smart grid environment [15].

One of the smart grid key features is the demand side management, which helps to convert the entire energy system into a more resourceful and minimize the operational cost successfully [16]. It is a software program or a method which also acts as a bridge between the consumer and utility for controlling the power load demand in peak hours by introducing the attractive incentive based tariffs to consumers for their energy usage cost [17]. Then the consumer energy usage activities may automatically reshaped from peak time usage into the rest of the time in a day to reduce the peak to average ratio [18]. As a result, the service provider can derive the consumer behavior in the power usage by shifting the usage from peak hour into the off-peak hour.

Load balancing and demand side management mechanism turn out to be extra complicated whenever the renewable energy sources are integrated with the power grid [19,20]. The energy generation patterns of renewable energy sources like wind and solar are not predictable and cannot give assurance for consistent generation. Due to climate change and moving clouds solar energy generation pattern can be varied from time to time. Similarly, wind energy source generation pattern may also vary from one season to another or time to time. The two way communication feature of smart grid supports to control the load directly and the load balancing mechanism for HVAC is discussed in [21].

Now a days time varying pricing models are introduced by the service provider and the same can be adopted by the consumer. The pricing models are critical peak pricing, Time of Use (ToU) pricing, etc., [5,22]. Scheduling helps the service provider as well as the consumer. By using the demand side management and scheduling, consumer can shift their load from peak hour into an off-peak hour. As a result, the high energy demand and the load balancing mechanism becomes necessity to reduce the energy bills for their energy consumption from a consumer point of view and the peak hour demand from the service providers view.

DSM also handles an essential responsibility in the energy trading. In [14], bidirectional energy trading has been done between the aggregator and customer by using the charging/discharging capabilities of EVs with scheduling option. It is implemented in two ways such as collaborative and non-collaborative. In collaborative, the social welfare of the energy system with the implementation of the distributed energy scheduling algorithm is discussed. In non-collaborative method, energy scheduling game has been implemented between the heavy and light customers.

Most of the existing work discussed about the evolutionary algorithm, handles either single objective optimization problem or combination of weights if the objective function is more than one [3,7,22,23,31,35]. In general, the real time problems in the smart grid environment have more than one objective so the evolutionary algorithm could be replaced with Multi-Objective Evolutionary Algorithm (MOEA). Smart meter pro-actively monitors the consumer energy usage to maintain a balanced load. The existing method increases the cost when a new appliance request enters to execution or consumer exceeds the threshold. The delay time of the scheduled appliances is also increased. In this paper, we implement MOEA which supports to obtain the minimized energy usage cost and delay time for home appliance execution in the home area network. The proposed approach gives an idea to maintain the load balancing mechanism, which helps to avoid the additional charges for consumers in the off-peak hours if threshold is applied for electrical appliance energy usage. The main contribution of this paper are summarized as follows:

- A communication architecture is developed for smart grid home area network with renewable energy sources.
- A Multiobjective Evolutionary Algorithm (MOEA) is employed to reduce the energy usage cost and delay.
- A novel residential home energy management algorithm for home appliances is proposed to maintain the load balancing mechanism.

The rest of the paper is organized as follows. In Section 2, the proposed architecture of smart grid communication network for consumer network is explained in detail. Section 3 provides a brief explanation about genetic algorithm with problem formulation and scheduling methodologies to reduce the energy cost and delay. Section 4 examines different results with different deferring techniques for load balancing. Conclusions are presented in Section 5.

2. Smart grid model architecture for consumer networks

There are various communication architectures available in the smart grid domain. Among these, selection of appropriate architecture is highly critical when it comes to public domain like Internet. It should satisfy the features of the smart grid and it must be easy to adapt in the real time environment with active consumer participation. The complete conceptual model of the smart grid system with home area network and renewable energy sources is shown in Fig. 1. It consists of conventional electrical system components (generation, transmission and distribution), the latest smart grid component (smart meter), active home appliances and renewable energy sources. Power grid, smart meter with home PC (personal computer), Internet, consumer and renewable energy sources are integrated with residential home.

The home computer runs the load balancing algorithm for electrical appliances to reduce the power usage cost and waiting time. Home PC acts as a centralized server which supports to communicate the consumer and service provider through Internet like a web server. In addition to that home PC is responsible for store and retrieval of the information. Also, supports for scheduling activity with the algorithm support. Information is exchanged between consumers and service providers by using the smart meter through Internet. The consumer can able to communicate the home network and its home appliances from any places through smart devices with the help of IoT and its technologies [12]. The consumer can communicate with service provider through Internet by using the home computer which also supports to communicate the home appliances. All the electrical appliances are equipped with sensors to monitor and transmit the data to centralized server [24]. It also supports the electrical appliances scheduling in home area network [25].

Service providers collect the data from smart meter to understand the user requirements like demand and setting up the pricing details for the ToU pricing models. Smart meter also helps to collect the electrical appliance usage details under different climate conditions, for example, an individual appliance energy usage for per hour, per day, per week and per month. Among these information service provider can identify the saturation level of consumers electrical appliances then these gathered information is interpreted by utility companies based on the automation