ABSTRACT

The ever-increasing demand for electricity, and environmental concerns in using traditional non renewable energy sources like coal insist the need for alternative Renewable Energy Sources (RESs). The traditional electric power grid system that has been serving the energy needs for nearly two decades, is rigid. The prominent inefficiencies with traditional power system are, lack of monitoring which leads to frequent failures, interoperability issues in adopting to latest Information and Communication Technologies (ICTs), absence of communication infrastructure and inflexibility in integrating renewable sources of power into the existing grid system. Smart grid is the key enabler for effectively generating, distributing and consuming electricity in a sustainable manner. The household energy demands contribute to the major part of electricity consumption around the globe. The optimal energy management strategies implemented at consumer level will have a greater impact on energy saving. The major challenges in implementing energy management methods at consumer level are; the dynamic nature of load demand, communication aspects between consumers and service providers and maintaining user comfort after scheduling. Smart grid provides an efficient Demand Side Management (DSM) framework for consumption analysis and this optimizes the energy usage pattern of the consumer. The methodologies, and the algorithms to achieve the DSM initiatives are called, Demand Response (DR) programs.

This thesis presents the studies that were done to implement efficient DR strategies that accounts for energy saving at consumer level and better grid stability at transmission side. The following ideas are discussed through this dissertation :i) the existing methodologies for implementing DR at consumer level and their inefficiencies in achieving efficient energy scheduling.

ii) The impact of implementing DR program on the grid operation iii) the challenges in integrating the static and dynamic energy sources into the grid for achieving DR optimization. iv) the feasibility of extending the proposed DR algorithms to the real time environment. In general, the thesis aims to provide an efficient group of algorithms for DR optimization at different stages.

The thesis contribution can be discussed in threefold scenario. Initially the impact of pricing schemes in implementing DR programs were studied. Based on the suitability a Real Time Pricing (RTP) model is adopted for implementing DR programs. In RTP model the electricity cost prices are dynamic in nature and varies for every hour of the day. A deterministic framework for household energy consumption incorporating cost and waiting time for appliance operation is formulated. The feasibility of different heuristic algorithms like Genetic Algorithm (GA), Grey Wolf Optimization (GWO), Binary Particle Swarm Optimization (BPSO) for solving scheduling optimization problems has also been studied. In particular DR objective functions have a minimum time frame for achieving an optimal schedule with a minimum computational complexity. This makes the heuristic algorithms inefficient for DR scenario since these algorithms are random and efficient in large population scenarios. Hence the first framework for single residential energy optimization is achieved using Interior Point Optimization (IPO) method.

Second, based on the previous framework more sophisticated modelling of DR optimization with multiple consumers and a single service provider is investigated. The behavior of individual consumers with near equal hourly demands are modelled. A stackelberg game theory approach is proposed for modelling consumer and service provider level optimization framework. There are two levels of game with service provider playing a leader level game and the consumers being the followers. In this regard every consumer attempts

to minimize their cost by shifting their demands to low price slots but this may overload the grid during off peak hours. Hence to maintain grid stability, and to improve the profit, the service provider sets an incentive factor to the consumers at these hours. The equilibrium of the proposed game is also been proved.

The rapid increase in electricity demand, mainly in the developing countries, insisted the need for efficient energy storage or additional sources of energy incorporation. Extending this to the DR scenario the idea of using an in home energy storage or integrating a small scale renewable units into household equipment has been studied in chapters 4 and 5. In chapter 4 a Battery Energy Storage System (BESS) is installed into the household scenario. An optimization model is developed as a weighted sum of BESS and household appliance usage. The charging and discharging periods of the battery are considered mutually exclusive and it is treated as a regular appliance while charging. There are two main objectives for the proposed optimization framework, initial is to minimize the consumption cost and the other is to find optimal time periods for battery charging and discharging. The formulated objective function is solved using Proximal Dual Descent Algorithm (PDDA).

In the BESS model discussed above there is an additional cost of charging the battery from the grid power which is continuous throughout the usage. Hence to avoid the charging costs, chapter 5 models a residential unit with a small scale RESs. The usage of RESs has a onetime installation cost which is very low compared to continuous battery charging cost. The framework incorporates two types of RESs solar and wind power. The energy generation of these RESs are greatly influenced by environmental conditions and they are intermittent in nature. This makes the proposed framework indeterministic in nature and hence it is solved using Stochastic Gradient Descent Algorithm (SGDA).

The efficiency of the proposed algorithms are studied under a simulation environment using three different metrics which are Peak to Average Ratio (PAR), consumption cost and computational complexity. All the proposed algorithms converges to the optimality conditions with minimum number of iterations, this overcomes the computational complexity that is very common in heuristic algorithms Meanwhile the proposed algorithms achieves an even distribution load without distorting the grid system and records an efficient PAR reduction and cost minimization.