Demand Side Management of Renewable Energy Integrated Smart Grid using Load Shifting Techniques

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*Abstract*— The Paris Agreement on Climate Change has led to introduction of new reforms for clean power plan such as decarbonization of power sector, planned decommissioning of thermal power plants and inclusion of renewable energy sources for power production. The integration of renewable energy resources to power system faces two technical challenges: variability and uncertainty. An effective energy management with help of smart grid engineering can be the key for its beneficial use. Demand Side Management (DSM) is a valuable function for energy management in smart grid. It supports numerous smart grid functionalities such as electricity market control, Load scheduling, management of decentralized distributed energy resources. Energy consumption patterns and electricity load profiles can be achieved through numerous DSM based programs. Load shifting based DSM is generally related with the behavior of consumers and how their electricity use is. Here, the applied demand side management techniques are based on load shifting to maximize the power efficiency, reliability, and resiliency of energy-driven from renewable sources. This paper reviews the various energy management strategies developed to minimize the impact of renewable energy intermittency using Load Shifting Demand Side Management.

*Index Terms*— Load Shifting Technique, Demand Side Management, Energy Management, Renewable Energy, Smart Grid.

# INTRODUCTION

T

he adoption of renewable energy resource-based power technologies is growing significantly as governments and policy makers are supporting pilot projects/ Power plants that integrates alternative energy resources. Renewable energy power generation resources include solar farms, wind turbines, hydropower plants, biomass, geothermal. The key drivers for incorporating theses renewable technologies owes to Paris Agreement, that aims to reduce carbon emission, dependence on fossil fuels and controlling environmental pollution. The presence of variability and uncertainty in solar radiation and in speed of wind is a challenge for grid operators. The term “variability” is related to continuous fluctuations in power generation due to intermittent nature of energy source such as solar and wind energy. Uncertainty comes from unpredictable nature of renewable energy sources in terms of magnitude and timing of power generation [1]. To build a renewable energy enabled smart grid the above concerns needs to be addressed. To sustain system balance of renewable energy integrated smart grid, the energy management system needs to harbor supplement resources to accommodate significant ramps when low or high. High amount of energy can be generated when demand is low and low amount of energy is generated when load demand is high. An example of it is timing of power generation through solar energy; surplus power is generated during day-time when the demand is low. Smart Grid offers multiple functionalities for instance: Dynamic energy markets, dynamic variation in tariff price, advanced control and management of power utilities, management of energy storage systems, control and management of energy resources. It also offers Demand Side Management (DSM) for time-based consumption-generation pattern. The DSM helps in reshaping the demand profiles, it maintains grid sustainability, helps in reducing energy wastage through in-time operation decisions and relocate demand to times of increased renewable energy production. It offers various DSM techniques out of which load shifting is most prominent one. This paper analyses various research works carried across using load shifting techniques in Demand Side Management. Further the presented brief literature study is used to predict the future direction of research. This paper is organized as follows: Section I shares brief introduction of smart grid and its role in renewable energy integration. Section II discuss load shifting based demand side management, Section III shares the strategies implied using load shifting based DSM for renewable energy integrated smart grid, Section IV holds the conclusion of the study carried and its future research scope.

# potentials of load shifting dsm

Historically, the balance between the generation and load demand was achieved mainly by varying the power generation output in order to match the load demand. For this the power plants management is planned to meet the maximum load by a reserve margin of 20%. This margin ensures the supply for peak demand load is supplied even at times when the generators are offline for repair works or maintenance. Renewable energy is intermittent in nature and many times non-dispatchable. For example: Solar PV system depends on solar irradiation so when weather is cloudy the generated power will not meet the demand profile. Similarly wind energy will generate electricity if its speed is between 12m/s to 16 m/s with optimal wind conditions. With these limitations, the traditional power system operation model could accommodate a very small percentage of renewable energy sources. The introduction of smart grids has enabled better integration of distributed energy resources for electrical power [2]. The smart grid provides information about generation and demand to both utility and consumers at any given moment thus enabling them to take actions accordingly [3]. This information can be used in Demand Side Management (DSM) of smart grids. The DSM can alter customer’s power consumption patterns which be used to make favorable changes in load shapes of power distribution systems. The DSM utilizes the consumer participation through incentives that can reduce their electricity cost, time of use (TOU) based electricity tariffs and government policies that promotes inclusion of renewable energy resources such as to mitigate peak load demand through energy management instead of expanding the generating capacity [3]. The DSM has six major techniques namely: Peak Clipping technique is used to reduce the coincident demand when the system is at its peak. Typically, it is implemented through direct load control (DLC) of the consumer’s appliance. Valley filling technique manages the electricity demand during off-peak hours which occurs on routine basis or in seasonal periods. Here to compensate the low periods of demand electric vehicles, battery energy storage , cooling or water heating/ cooling integrated with storage can be used during off- peak periods [4]. Strategic conservation technique it works to make the system more energy efficient by decreasing the total load demand. Strategic load growth technique aims to increase the total load demand that helps in increasing consumer’s productivity [5]. Flexible load shape technique enables an integrated grid by providing dynamic control and response to the consumer’s load and their use of distributed generation-storage. Here the control can be direct or through autonomous agent or by using controllable appliances or by planning based on energy management systems. Load shifting technique is used in peak- hours to shift the existing loads to off-peak peak hours. Its feature to reduce peak demand at specific periods reduces power plants installation for an emergency need thus reduces the operational costs of utilities. When utilities aims to increase uses of distributed energy resources. This can be achieved by using dynamic load shifting based DSM. Load shifting, in particular, involves shifts the load from peak to off-peak hours, without affecting the average load over time. It should be noted that by using Load shifting DSM the total energy consumed of the household does not overload the system as it shifts the demand pattern of the household. Figure 1 visualizes how the load peak hours are shifted to non-peak hours [6].

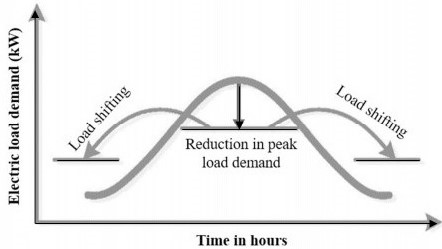


Fig.1: Load Shifting based DSM strategy [1]

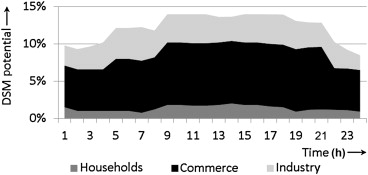


Fig. 2: Potential of load shifting [5]

Potential of load shifting in relation to total hourly load for different economic sector is depicted in Figure 2. Load Shifting DSM for renewable integration holds potential to use renewable energy as base load so that dependency on fossil fuels decreases. The next section discusses energy management strategies using load shifting demand side management technique.

# literature review

The study carried by S.B.Raha et.al [7] focused on economic aspect of a microgrid planning by using load shifting demand response management including advance controlled strategies. A residential microgrid consisting of sixty housing with power sources such as combines heat and power (CHP), renewable energy resources and energy storing devices. In this set up renewable energy power is supplied during off –peak hours to meet demands of peak hours CHP sources are used. This rises the electricity bills hence there is need of technology to reduce it. Therefore the author research focus was to maximize renewable energy resources utilization by using load shifting demand response energy management algorithm. For this the consumers were categorized in three groups: controlled, semi-controlled and un-controlled loads. A fuzzy controlled load shifting demand response management (FLDRM) algorithm is incorporated that helped to reduce consumers bill by 33.72 % compared to the billing done without using the controlled scheme. The proposed algorithm reduced the energy consumption, enhanced renewable energy integration without challenging consumers comfort.

The renewable energy is intermittent and variable in nature so is power produced through it. Taking in account of this issue the authors A. A. Almehizia et. al. [8] proposed a methodology that incorporates energy storage. Value storage of energy concept was introduced to replace the uses of large-scale battery energy storage system (BESS). The concept supports storage of excess of renewable energy as a product of industrial loads. A hybrid Photovoltaic-wind turbine generator with energy storage was proposed. The electrical load was divided by its ability to shift the demand and store. For this Load shifting technique demand side management was used. A size optimization using differential system cost was developed. It was solved with help of enhanced genetic algorithm technique. The results showed with proper planning: the load characteristics, choice for energy storage plays a significant role in lowering the system cost instead of using costlier BESS system.

The existing conventional energy management system employs system speciﬁc techniques only. In addition it can handle only a limited number of controllable loads which are of limited types. The power generating plants is constructed to meet maximum demand when needed. But to fulfill the gap between peak load and average load results in high per unit cost. As the Present grid is altering to smart grid it has two standpoints. First, integrating renewable energy resources: addressing its unpredictability in power dispatch through load control methodologies. Second, to establish two way information sharing. The proposed solution of this problem was given by T. Logenthiran et.al. [9] using day ahead Load shifting Demand Side Management technique. Their objective was to build an effective demand side management that beneﬁts the end users and utilities alike. For this they selected peak load management. As minimizing peak load demand improves grid sustainability, reduces cost as it restrains need for under-utilized electrical infrastructure to meet peak demands. The load was shifted to off peak hours which resulted in financial benefit to residential consumers. They developed a heuristic-based Evolutionary Algorithm (EA) that could adapt heuristics in the problem. The Simulations were carried on different load patterns in three areas: residential, commercial and industrial. The simulation results proved the strategy achieved substantial savings by reducing peak load demand of the smart grid.

D. P. Bertineti et. al. [10] proposed an algorithm for a multi-objective optimization DSM problem using day-ahead load-shifting strategy for scheduling. A discrete time varying model for the price of energy over a day was taken under consideration. A greedy search algorithm with limited complexity was used to achieve scheduling for controllable loads. Its aim was to reduce total energy daily cost and the Peak to Average Power Ratio (PAPR). The simulations proved the proposed algorithm to be adequate and suitable solution for scheduling as the results obtained gave low energy cost and low PAPR. Hence, by using load shifting controllable loads can be shifted to ﬁll the gap in day-time when renewable energy (such as Solar) is high and reduce the demand in peak hours.

A robust optimization was formulated by X.Ran et.al. [11] to reduce the energy cost and increase the robust level of system. For this enhanced Robust Index (RI) consisting of upper and lower limit was integrated to load scheduling as cost function along with constraints to find a reasonable energy dispatch strategy. A load shifting strategy was proposed using a quick sort algorithm to improve the robust level and reduce the energy cost of Home Energy Local Network (HELN) which arises due to uncertainty of customer behavior. HELN consists of energy storage system (ESS), electric vehicle (EV), a micro generator and renewable energy generation sharing energy from/to power grid. Numerous household appliances were divided as: essential loads, shiftable load, throttle able loads. Simulation results predicted that the scheduling algorithm increases the robust level and reduces the energy cost.

Traditionally the problem of demand and supply balance was dispatched at the generation side by adding capacity to consign load demand. With introduction of smart grids deregulated system has brought inclusion of diversified energy sources for electric power generation. Thus managing peak load demand can also be addressed from consumer side. K. P. Swain et.al [12] proposed an energy management technique load shifting based DSM technique for flexible loads. Three different procedures were used to predict which load should be selected first to shift. The methods were compared to decide most suitable one. The result demonstrated that descending order ranking is most suited process. As from the resulted graph, it was observed that when loads are sorted in descending order the optimized load curve was superior from other two methods.

Ilze Laicane et. al. [13] investigated the potential DSM to reduce peak load. Their objective was to study how the data obtained from smart metering can be used to provide end users energy-saving options, which is one of the basic principles of demand side management. Their analysis based on smart metering project “Promotion of energy efficiency in households using smart technologies”, that monitors household consumption with 5 minute interval time. The project aim is to fulfill climate and energy targets which can be achieved by improving energy efficiency at all stages of the energy system in this households covers 25 % of European energy consumption stake. A four-person household was selected for case study with aim to find user activities within the house based on use of appliances and time. For this, two appliances were chosen: a washing machine and a dishwasher to check potentials for load shifting. The derived results showed by using load shifting technique on washing machine and dishwasher the peak load of the residence was reduced by 24 % and 13.5 %. Proving appliance load shifting is a feasible way to reduce peak consumption.

The analysis done by the authors M. Ali et. al. [14] on Pakistan electricity sector highlighted two problems 1) generation capacity deficiency due to high demand factor and 2) high fuel cost. The reason for this issue as the power generating plants are designed maximum demand. But the peak load increases suddenly so there is a need to install large power generating plants to meet peak demand. It is not feasible for increases per unit cost and burdens countries with limited financial resources. They proposed a load shifting based DSM technique to shift the flexible load to off peak hours. This will reduce the energy cost of residential customers and encourage participation of renewable energy based power generation. “The Day Ahead Shifting” technique was proposed by the authors. Mathematical modeling and simulation conducted using MATLAB software. The findings suggested DSM approach attains significant energy cost savings.

Power operators have to coordinate between electric power demand and generation. In peak hours demand for generated power is high. Demand side management of smart grid can help power operators to cut peak load demand thereby reducing consumers electricity cost. This will help in operating the system sustainably and increase participation of all types of power generation. P. Balakumar et. al. [15] presented load shifting technique for demand side management of smart grids that could stem considerable amount of controllable devices. A DSM was modeled as an optimization problem using Evolutionary Algorithm (EA) its solution was achieved. The Simulations carried across the smart grid included consumers of residential areas with multiple controllable loads. The results obtained proved the proposed DSM could achieve considerable savings with reduced peak load demand.

A. Sinha et. al. [16] presented a load shifting DSM technique for residential consumers. It was achieved by shifting their loads at diverse time. For this an algorithm was developed that shifted the controllable load from peak hours to off peak hours. In this method the load shifting was done on the priority of loads and based on Time of Day (TOD) tanff. The experimental tests carried studied different households with variant load priority. It was concluded that the developed strategy to shift the consumer loads on pertinent times reduces the peak demand which eases utility power management.

M.Erkoc et. al. [17] studied a game-theoretic model for the load-shifting problem in the smart grid to understand managerial understanding that could help in adding incentives to consumers so that they actively participate in peak energy consumption reduction that will help in reducing demand fluctuations. They investigated the impact factors such as consumer types, market diversity, interactions between energy provider and customers. Their findings indicated that higher rebate is required when load-shifting discomfort levels for consumer is moderate and also when the consumer population is diverse in their discomfort types. They concluded that discounts are not effective in reducing Peak to Average (PAR) when the consumer population is little or too diverse.

An approach for the optimization and control of shifting loads in a power distribution grid was presented by W. Giral et.al. [18]. A mixed integer non-linear programming model along with variations in spot pricing was given. A semi deﬁnite relaxation was granted that allows getting boundaries of the problem. An integer solution was obtained using rounding algorithm. The paper made three contributions namely 1) use of group theory to design algorithms, 2) create a general model that includes stochastic behavior spot prices, 3) a semi deﬁnite relaxation which can be solved efficiently. Numerical simulation was carried using CVX/MATLAB indicated the advantages of the proposed methodology to minimize customer electricity bills as well as reduce peak power demand. By using this approach a residential customers could save 4.2% of their monthly bill and reduce their peak-power demand by13.45%.

An advance approach was proposed by M. Jamil et. al. in [19] for the demand side management based on shifting of load from peak to off-peak hours. Their aim was to reduce peak hour demand and utility bill of the consumers. For this, the proposed strategy was modeled as a minimized optimization problem. After which it was tested to find out the optimal solution. Two optimization algorithms, one with particle swarm optimization algorithm and second used grasshopper optimization algorithm were tested on three different loads patterns, i.e. residential, commercial and industrial. The simulation results showed a compelling reduction in peak hour demand and reduced utility bills.

R. N. E. idrissi et. al. [20] developed a load shifting DSM strategy. The strategy was based on an improved version of Differential Evolution (DE) called as Back Tracking Search Algorithm (BSA). The proposed strategy worked to minimize the peak load demand and utility overall cost. It considered three kinds of consumers: residential, commercial and industrial. The simulation results were compared with those procured by using Particle Swarm Optimization (PSO) algorithm. This testing between the two displayed the effectiveness of BSA to handle diverse amount of devices.

C. Li et. al. [21] introduced a distributed algorithm for sparse load shifting in DSM. Their aim was to address scheduling problem of residential smart appliances. They developed a bidirectional framework to solve the DSM problem in a distributed way to substantially improve the search efficiency. They used Newton method to spur the centralized coordination of DSM strategies. Additionally a dual fast gradient and convex relaxation was exercised to tackle the sub-problem to give the consumer best response that will help in reducing discomfort from load shifting DSM. Detailed results from illustrative case studies presented showed reduced costs of energy consumption and daily peak demand.

# Conclusion and Future Scope

The power generation based on renewable energy resources suffers from variability and uncertainty. An effective energy management can be the key for its beneficial use. For this Demand Side Management (DSM) can help in building an effective energy management system. During peak hours increment in load demand is at its peak thus it caters need for additional power generation support which is economically not feasible. Using load shifting DSM technique it is possible to schedule smart household appliances ranging between peak load hours and off-peak load hours. Load shifting DSM technique provides efficient energy management system by bringing harmony between demand and supply to the best possible way. For this, factors like interruptible loads, time of use and consumer willingness contributes to the peak load reduction play an important role. By increasing customer awareness and participation in demand side management, it is possible to spur demand side flexibility. The Future Scope of this review is to conduct economic analysis to identify load shifting potentials on end uses. The more end-uses be clustered, the more information will be available for load adjustments and shifting strategies. Another future scope is to investigate presence of energy storage devices and electric vehicles in energy management using load shifting DSM in renewable energy integrated smart grid.

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