Demand Side Management in Power Grid Using Particle Swarm Optimization

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Abstract— Demand side management (DSM) is an important function in a smart grid that allows customers to take decisions regarding their energy consumption which allows energy utilities to reduce peak load demand and reshape the load curve. This increases the reliability while reducing overall cost and carbon emission levels. This project implements a load shifting approach for demand side management to be implemented in the future smart grid which optimizes the energy consumption curves of household, commercial and industrial consumers. Particle Swarm Optimization has been modified and applied to minimize and fulfil the objective of load shifting for day ahead forecasted load. The simulation results show that the proposed demand side management strategy is successful in achieving considerable savings, while reducing the peak load demand.

Keywords: Power Grid, Particle Swarm Optimization

I. Introduction

In the era of load growth and increasing constraints on new and existing generation capacity, Demand Side Management (DSM) options are being considered all over the world as possible bridges between these two apparently conflicting requirements. The high variability of load from one day to another, and from one hour to the next, may provide significant opportunities for demand side management. DSM provides a workable solution to some of the major problems confronting the electric utility today.

There is a great deal of uncertainty in future demand, fuel prices, construction cost, availability and cost of power from other utilities, independent power producers, and the regulatory environment. This is leading electric utilities toward incorporating DSM concepts in their resource planning. Utility programs falling under the umbrella of DSM include load management, identification and promotion of new uses, strategic conservation, electrification, customer generation and adjustments in market share. The load shape objective can be realized in various ways. Six generic load shape objectives illustrate the range of possibilities: peak clipping, valley filling, load shifting, strategic conservation, strategic load growth, and flexible load shape. Once load shape objectives have been selected, an appropriate set of DSM programs needs to be identified. Load Duration Curve (LDC) is the vehicle through which DSM impacts are incorporated into power system planning and operation. Models of the LDC are one of the most important tools in the analysis of electric power systems. It has been utilized for various purposes, such as estimating the operating cost of a power system, predicting the amount of energy delivered by each unit, and calculating reliability measures. Due to the nature of electricity, and dependence of our society on its uninterrupted supply, reliability is one of the most important design criteria of an electric power system. Furthermore, reliability assessments are a necessary part of power system studies used to assist in managerial decisions regarding the adequacy and reliability of the system.

The approach used here to solve the continuous growth experienced in the demand of residential electric systems is to try to influence the customers to modify their load shape through Demand-Side Management (DSM policies) in order to obtain several objectives such as minimization of peak demand, improvement of load factor, improvement of system operation and planning, maximization of quality and reliability of service and customer participation in new market structure. The most common of all DSM policies is known as Direct Load Control (DLC), in which load portions such are heating, ventilation and air conditioning loads, water heaters and energy thermal storage systems are under the direct operational control of the utility taking into account several constraints fixed previously between customers and the Supply-Side. It is necessary to develop aggregate models for each load to have a way of anticipating DLC effects from two points of view-the system load curve modifications and the customer expectations-economy, quality of supply, comfort. The precision of this evaluation depends on several factors; among the most important are the elemental load model which has been used and the percentage of each end.

II. Demand Side Management Techniques

The load shapes which indicate the daily or seasonal electricity demand of the industrial, commercial or residential consumers between peak and off peak times can be altered by means of six broad methods: flexible load shape, strategic load growth, strategic conservation, load shifting, peak clipping and valley filling. Generally, these are the possible demand side management techniques that can be employed in the future smart grids.

These six demand side management techniques are illustrated in Fig. 1.

Peak clipping and valley filling focuses on reducing the difference between the peak and valley load levels to mitigate the burden of peak demand. This increases the security of smart grid. Peak clipping is a direct load control technique to make reduction of the peak loads, and valley filling constructs the off-peak demand applying direct load control.

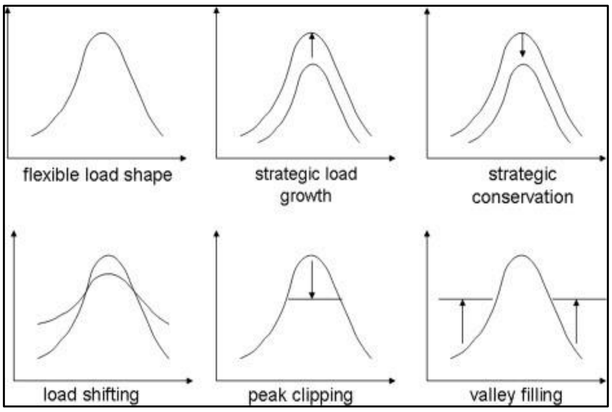

Fig. 1: Demand side management techniques

Load shifting is widely applied as the most effective load management technique in current distribution networks. Load shifting takes advantage of time independence of loads, and shifts loads from peak time to off-peak time. Strategic conservation aims to achieve load shape optimization through application of demand reduction methods directly at customer premises. The distribution management system has to consider this for longer term implications of demand reduction on network planning and operation. Strategic load growth optimizes the daily response in case of large demand introduction beyond the valley filling technique. It is based on increasing the market share of loads supported by energy conversion and storage systems or distributed energy resources. It is a planning and operations issue to balance the increasing demand with processes for constructing necessary infrastructure that accompanies load growth. The future smart grid has to provide the necessary infrastructure for strategic load growth. Flexible load shape is mainly related to reliability of smart grid. Smart grid management systems identify customers with flexible loads which are willing to be controlled during critical periods in exchange for various incentives. Studies have to be conducted to identify the anticipated load shape which includes demand side activities forecasted over the planning horizon.

III. PROPOSED STRATEGY

This project presents a generalized day-ahead demand side management (DSM) strategy for the future smart grid. It uses load shifting as the primary technique that can be utilized by the central controller of the smart grid. Objective of the demand side management could be maximizing the use of renewable energy resources, maximizing the economic benefit, minimizing the power imported from the main distribution grid, or reducing the peak load demand. Smart grid manager designs an objective load curve according to the objective of the demand side management.

Conventionally linear programming and dynamic programming are used to solve DSM problem. However, these methods take long time for achieving optimal solution and cannot handle more number of loads. On the other hand, the population based heuristic optimization techniques have the potential to solve conveniently such complex problems and also mostly provide global optimum solution. The proposed algorithm provides an efficient, cost effective and relatively simple method of solution of such complex scheduling problem. The proposed optimization algorithm aims to bring the final load curve as close to the objective load curve as possible such that the desired objective of the DSM strategy is achieved. Appliances are categorized on the basis of their power ratings. Different types of smart appliances are considered to be used and the corresponding price chart considered is shown later. The price chart is prepared in such a way that one has to pay more electricity price for on peak hours and less electricity price for off peak hours. Therefore, shifting of loads from peak hour operation to off peak hour operation would reduce electricity bill of customers. For solving this complex optimization problem, a particle swarm optimization algorithm is chosen where the solution is in form of 2D particle.

According to the proposed architecture, the demand side management system receives the objective load curve as an input, and calculates the required load control actions in order to fulfil the desired load consumption. It is carried out at the beginning of a predefined control period which is typically a day. Then, the control actions are executed in real-time based on the results.

IV. OBJECTIVE PROBLEM FORMULATION

A. *Minimization Function*

Let us assume that load i be the initial load curve or the forecasted load curve. This curve needs to be altered as per our objective curve. Let the modified load curve obtained be $load_f$, after the application of DSM. Then our objectives are as follows.

Minimize: $f_1: max(load_f)$ (1.1)

Minimize: $f_2: \sum_{h=1}^{H}\left(load_{fh}, P_h\right)$ (1.2)

Here, function f_1 denotes the maximum peak of the final load curve, which needs to be minimized along with function f_2 representing the total cost of electricity during H=24 hours of a day and P_h is price of electricity in hth hour. To solve the above minimization problems a function f is formed to obtain modified final load curve $load_f$

Minimize: f_h: $[|RLM_h|-|load_h|]$ (1.3)

subject to, for all h=1, 2… T. T is the number of time steps in hourly block. RLM is Reducible Load margin, which is simply calculated for each hour h as RLM_h where h∈H.

$RLM_h = forecast_h - obj_h$ (1.4)

The above equation determines the marginal load that completely or partially needs to be deducted from or added to the forecasted load curve at different hours, which brings it as close as possible to the objective curve.

$$RLM_h = \begin{cases} \geq 0 & forecast_h > obj_h \\ \leq 0 & forecast_h < obj_h \end{cases} \quad (1.5)$$

The RLM vector given above provides the information that whether $\Delta load_h$ calculated for a particular hour will be connected or disconnected. If for an hour h forecasted load is greater than the objective load means that hour becomes an instant for disconnection and wherever the forecasted load is lesser than the objective load that hour becomes an instant of connection. Thus, at each instant either connection or disconnection is done in order to obtain the modified load curve that is close to our objective curve.

The objective curve Obj_h is inversely proportional to the expected electricity prices. At times, electricity prices are high the value of objective curve is low and vice-versa. The equation for the formation of objective curve is given as:

$$\mathrm{Obj}_h = \left(\frac{p_{avg}}{p_{max}} \sum_{h=1}^{H=24} \mathrm{forecast}_h\right) \frac{1}{p_h} \qquad (1.6)$$

Where p_{avg}, is the average price during the period H and pmax is the maximum price throughout the day of H hours and ph is the price of electricity at hth hour and H is the total number of hours in a day i.e. 24.

V. Proposed Algorithm

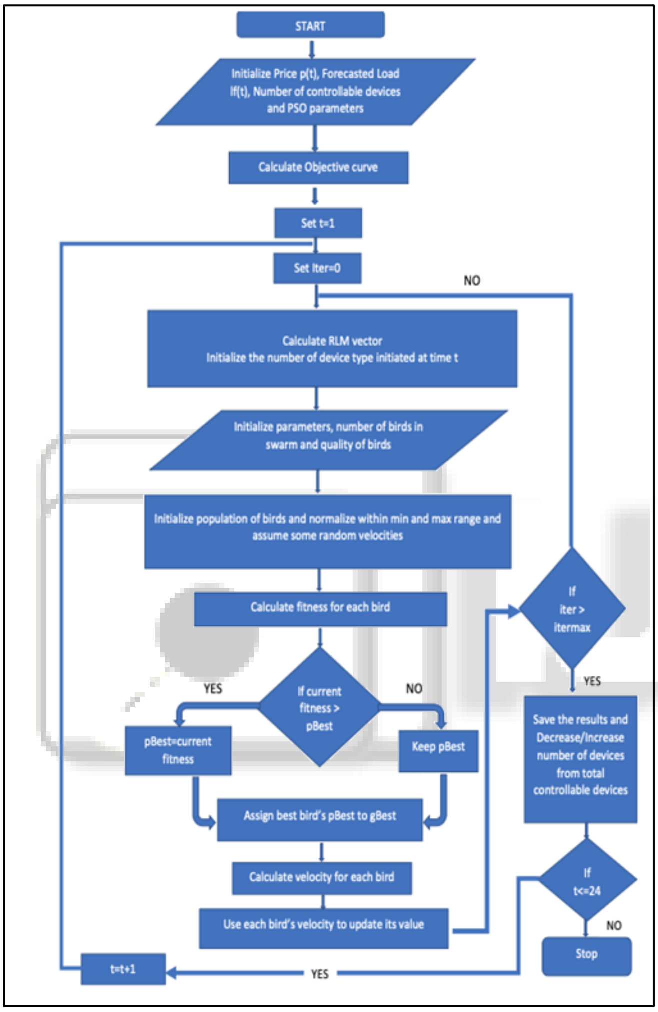

Fig. 2: Proposed Algorithm

VI. Result and Simulation

The proposed demand side management strategy using Particle Swarm Optimization has successfully managed to bring the final consumption close to the objective load curve in all the three cases. It has proved efficient in handling the large number of controllable loads of several types, and adopts all heuristics in the smart grid.

Simulation is carried out by using MATLAB software for residential, commercial and industrial areas having different types of appliances and different computation pattern of power rating. An affordable delay of 8 hours is taken which is applied to the data itself and fed as it is to the algorithm.

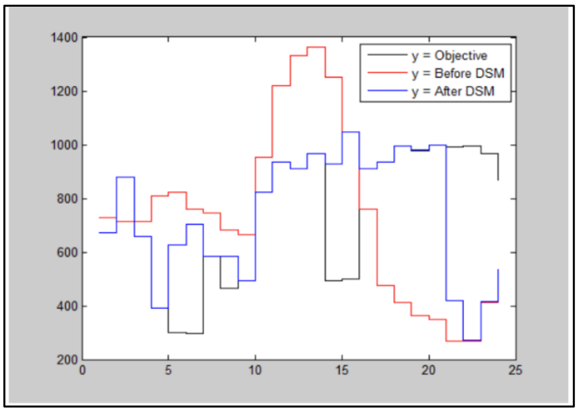

Fig. 3: Simulation results obtained from residential area

The simulation results obtained for the residential area are given in Fig 3.. The utility bill of the residential area for the day reduces from 230290 to 213620 rupees with demand side management strategy, resulting in about 7.2% reduction in the operating cost.

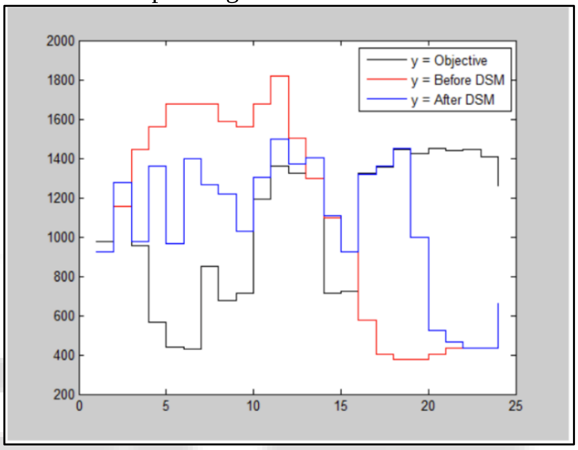

Fig.4: Simulation results obtained from commercial area

The results obtained for the commercial area are given in Fig 3. The utility bill of the commercial area for the day reduces from 362660 to 330650 rupees with demand side management strategy, which results in approximately 8.8% reduction in the operating cost.

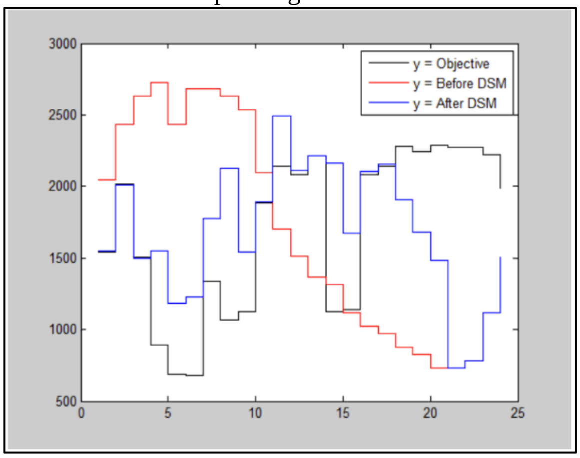

Fig.5: Simulation results obtained from industrial area

The results obtained for the industrial area are given in Fig. 9. The utility bill of the industrial area without demand side management strategy is 571200 for the day; whereas it is 496030 rupees with demand side management strategy, resulting in 13.2% reduction in the operating cost.

AREA	COST WITHOUT DSM	COST WITH DSM	PERCENTAGE REDUCTION (%)
Residential	230920	213620	7.2
Commercial	362660	330650	8.8
Industrial	571200	49030	13.2

Table 1: Reduction in Cost

AREA	PEAK LOAD WITHOUT DSM (Kw)	PEAK LOAD WITH DSM (Kw)	PERCENTAGE REDUCTION (%)
Residential	1363.6	1046.5	23.3
Commercial	1818.2	1498.5	17.6
Industrial	2727.3	2479.5	9.1

Table 2: Reduction in Peak Load

The approach has successfully managed to achieve the objective in all three areas, with considerable savings in the utility bills. Typically, demand side management results are better when the number of devices available for control increases. However, this may not be true in this case study because complexities of the devices under control pose restrictions. In this case study, even though the number of devices available for control is the least in the industrial area, the percentage reduction in the operating cost is the highest among all areas. On the other hand, the residential area has the highest number of devices available for control in terms of quantity and variety, but the percentage reduction in the operating cost is not much as expected. This can be attributed to the fact that high power consumption of devices in the industrial area compared to much lower consumption of devices in the residential area. Additionally, even small load shifting of high power devices results in huge savings for the customers.

AREA	TIME ELAPSED(SEC)
Residential	3.982326
Commercial	1.009190
Industrial	0.676769

Table 3: Time Taken For Optimization

The computation time for this approach increases with the type of devices involved. Residential load with 14 types of devices took 3.982326 seconds for calculating the appropriate load curve while commercial load with 7 variants in the types of devices took 1.009190 seconds. The optimization algorithm generated the final load curve in minimum time for industrial load with 5 types of devices. The time to evaluate the objective curve is independent of the production cost or the load demand.

VII. CONCLUSION

A novel intelligent demand side management scheme is proposed to control the ON and OFF timings of various categories of loads of each customer and uses demand side management strategy based on load shifting technique for a large number of different types of residential loads. The starting time of loads are scheduled by population based 2D particle swarm optimization technique. Hence this new scheme enables optimal utilization of renewable resources and helps to reduce electricity charges to be paid by the customers.

This algorithm is based on an analytic model of the load under control which gives it the advantage of allowing any type and any number of devices. The method can be used to minimize different objectives including peak load and production cost.

The extensive computer results indicate that suitable DSM strategies can lead to significant economical and technical benefits in urban distribution systems. DSM in its various forms is an important tool for enabling a more efficient use of the energy resources available to a country. As a conclusion, DSM strategies can achieve positive effects in peak power losses reductions, energy savings and economical savings, as well as their positive effects in the improvement of the quality of the electricity supply.

DSM applied to electricity systems can provide relief to the power grid and generation plants, defer investments in generation, transmission and distribution networks and contribute to lower environmental emissions. Similar benefits can be achieved from DSM when applied to the use of other types of energy. Thus DSM can offer significant economic and environmental benefits. Housekeeping and preventive maintenance are simple and cost-effective ways to reduce demand and have other benefits like process improvement. Opportunities may exist to take advantage of special tariff rates by changing load profiles or entering into contractual agreements with the utilities. It is therefore important to market DSM programmes to show potential customers their life cycle benefits and the techniques—often quite simple—for reducing demand.

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