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DEMAND SIDE MANAGEMENT FOR WIND INTEGRATED SYSTEMS USING GENETIC ALGORITHM

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Demand Side Management (DSM) is the most intelligent way to arrange loads for the future events. The main intention of DSM is reducing the peak load, improving the system load factor and efficiency. It is one of the key issues in present day power system operation. As wind power generation is variable and intermittent in nature, using wind power in demand side management is a critical task. This paper aims at maximum wind power utilization and improvement of system load factor. The paper presents demand side management incorporating wind generation into the system using a Genetic Algorithm (GA) approach. RTS (Reliability Test System) 24 bus and IEEE 14 bus systems are used to demonstrate day ahead demand side management with wind power integration. It uses load shifting Demand Side Management technique to improve load factor of the system.

Keywords: Demand Side Management (DSM); Wind power; Genetic algorithm; Load factor.

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1. Introduction

Integration of more renewable energy sources like wind power into the grid creates a balancing problem between supply and demand, because of uncertainty of these sources. Demand side management (DSM) plays a crucial role as more renewable energy sources are emerging into power system. It is introduced to make effective utilization and management of demand side resources. As per the regulation policies, DSM is the process of allocating loads properly, thereby improving energy efficiency and the effective resources allocation. DSM looks for low carbon economy and supports renewable energy access thereby protecting ecological environment.

In [1], 24 hours load shifting technique related to optimization problem has been discussed. Simulation studies have been conducted with heuristic techniques on a smart grid and proposed considerable savings. [2] Uses low voltage distribution network with two way communication system in case of distribution transformers for peak load reduction. [3] States smart pricing strategy in smart grid environment which is more efficient, thus creating truthfulness among consumers for demand side management. It also addresses payment related issues in social welfare maximization studies. DSM in combination with control systems are used in wide area monitoring applications for effective utilization of networks [4]. Rapidly growing distributed resources at particular location, need storage systems to meet DSM requirement and for reliability assessment [5]. The major conceptual

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difference between intelligent DSM and traditional DSM, advantages of intelligent DSM over traditional DSM in terms of social welfare maximization in smart grid strategy has been discussed in [6]. Advancement of communication technology makes DSM more efficient and reliable [7] during high wind penetration and system stability can also be improved with smart demand control technology. [8] Presented wind power generation with and without DSM on the IEEE 30 bus system. The benefits in terms of operational cost, have also been evaluated. In order to implement the smart grid concept in deregulated environment, demand side management together with renewable energy and storage systems are needed [9]. Evaluation of probabilistic reliability methodology considering DSM including wind generators have been discussed in [10] . [11] Presents system architecture for DSM with the control algorithm in the smart grid environment. In [12] an experimental platform SYSLAB has been used to identify possibility of load management with high wind penetration. Electricity price classification, forecasting and consumption studies in regulated electricity market have been included as a application to DSM in [13], [14]. Significance of energy storage systems for DSM studies as renewable energy is integrated to the grid is discussed in [15]. Renewable energy addition to the grid is creating a conflict between the availability and the demand. This can be avoided by energy storage systems which can also be useful at the time of peak load reduction [16]. In [23], a DSM technique is proposed which gives partial solution to the power issues in a specific location without accounting renewables. An efficient and reliable communication infrastructure which is an essential component for DSM is proposed in [24] based on game algorithm.

The proposed work is organised into the following sections. Section II describes various DSM techniques and their applications. Section III provides information of test systems used for DSM analysis. Section IV discusses proposed methodology for DSM study and its implementation. Section V presents results and their discussion and Section VI concludes the paper. This paper proposed an objective function formation that can accommodate maximum available wind power and meet the desired load factor. From the case study, power factor has been improved significantly for the RTS (Reliability Test System) 24 bus and IEEE 14 bus systems. For these two test systems, fixed load curve and controllable load curves are formed and based on genetic algorithm approach variable load is mixed with fixed load to meet the desired load factor.

2. Demand Side Management

Demand Side Management (DSM) is a set of interconnected and flexible processes which allow customers a greater role in shifting their own demand for electricity during peak time and thereby improving efficiency and load factor [17]. DSM focuses on utilizing power saving technologies, monetary incentives, power tariffs and policies to mitigate the maximum demand instead of expanding the generation capacity or reinforcing the transmission and distribution network. System instability can be handled by management of load, it could be reducing the load demand during peak time, and transfer these loads to appropriate time to reduce operational cost. In DSM possible techniques are load shifting, peak clipping, strategic load growth, strategic conservation and flexible load shape as is shown in figure1. In load shifting technique customer load shifts from high peak load to off peak load throughout the year or daily peak demand (during 24 hours period). Shifting daily demand flattens the load curve, more electricity can be provided at base load generation. Load shifting technique is the most popularly used technique as far as distribution networks are concerned [18], [19] and it is more suitable for time independent loads. Generally valley filling and peak clipping techniques are tried to equalize the difference in load demand between peaks and valleys. Strategic load growth improves the daily response where as huge demand exists beyond the valley filling technique. It is dependent on increased load share supported by storage systems and energy conversion systems. Flexible load shape is mainly connected to smart grid reliability [1]. DSM address the issues in the areas such as incentives, utility controls, access to information, education and marketing, rates and customer insight and verification. In this paper, load shifting DSM technique has been used for a day ahead load management (for 24 hours) using genetic algorithm, incorporating wind power.

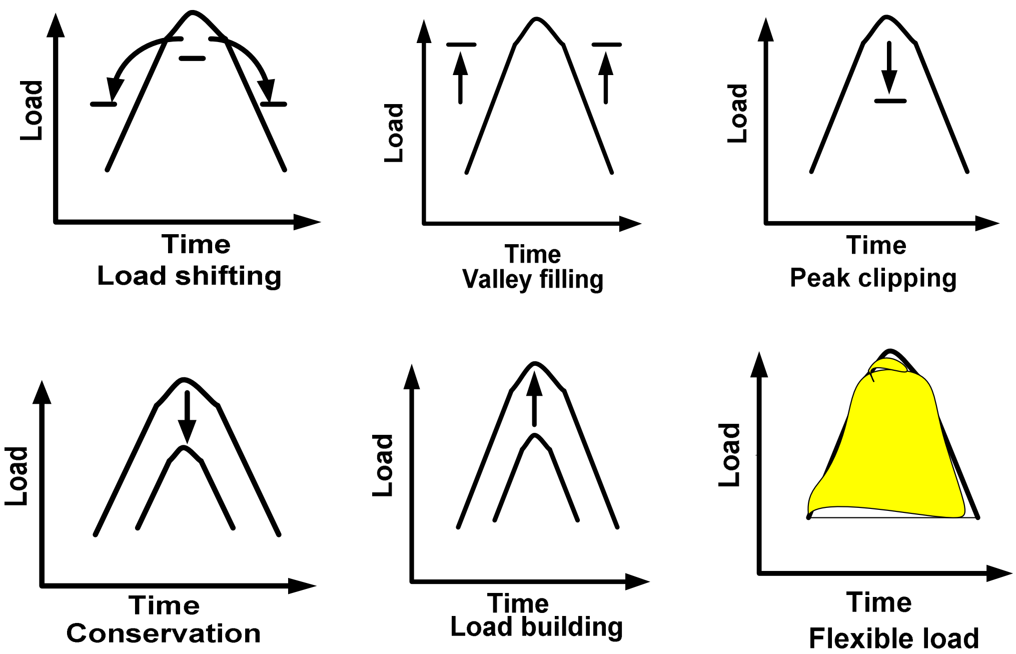

Fig1: Demand Side Management Techniques

3. Details of the Test system

RTS 24 bus reliability test system and IEEE 14 bus system are used for DSM analysis and they are shown in figure 2 and 3 respectively. RTS 24 bus system consists of 9 generators, 1 synchronous condenser, 38 lines and 5 transformers. The transmission lines are at two different levels of voltages such as 138 kV and 230 kV. The 230 kV is in the upper portion and 138 kV is in the lower portion connected by 230/138 kV transformers at bus numbers 11, 12 and 24.

IEEE 14bus system consists of 2 generators, 3 synchronous condensers, 20 lines and 4 transformers. The transmission lines are at two different voltage levels 69kV and 13.8kV. The 69kV is in the lower portion and 13.8kV is in the upper portion with transformers between bus numbers 6 - 5, 7 - 8, 7 – 4 and 9 - 4. In this work, 80% of total load is taken as fixed load and remaining 20% as variable load for IEEE 14 bus and RTS 24 bus systems.

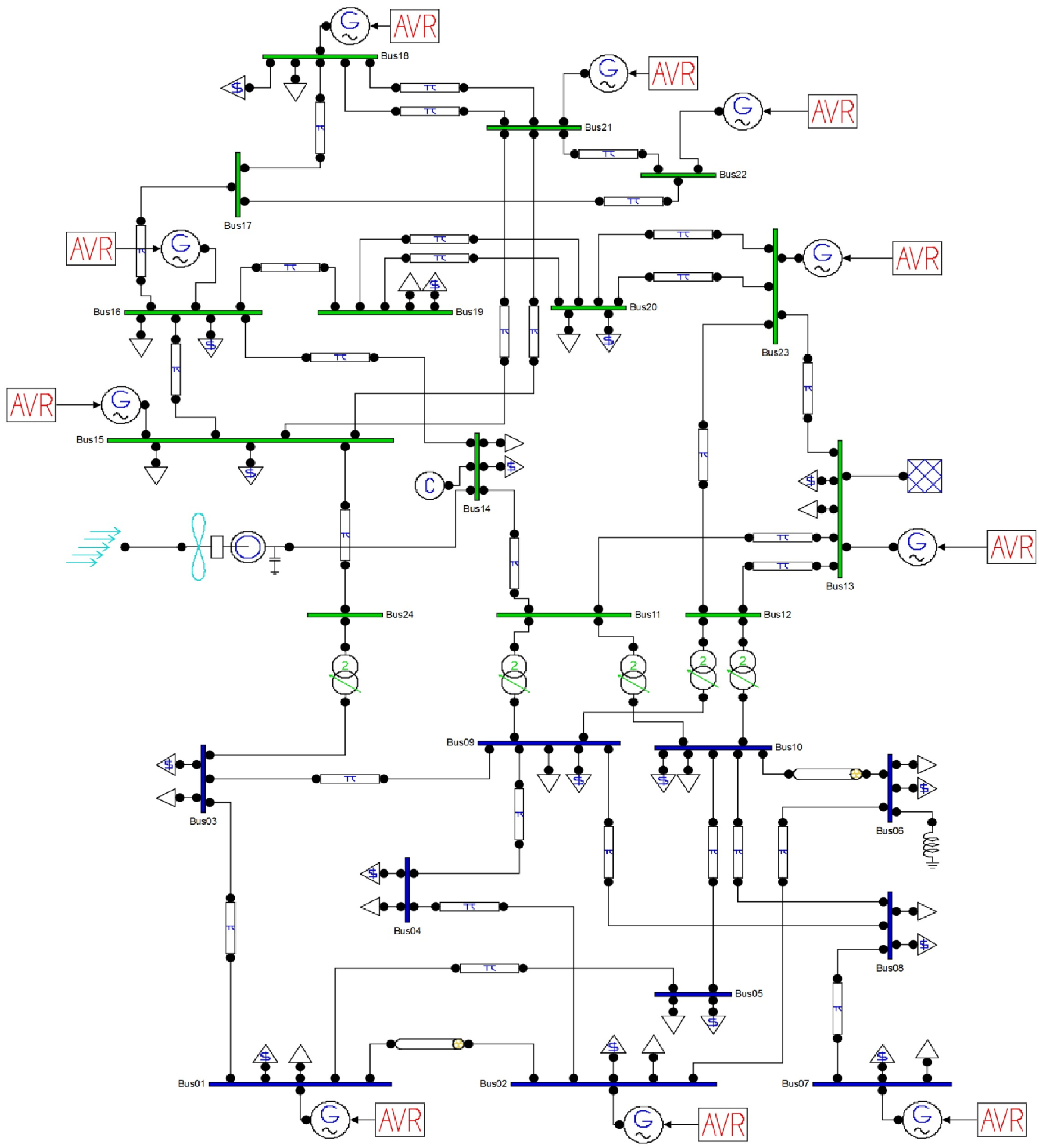

Fig2: RTS 24 Bus System

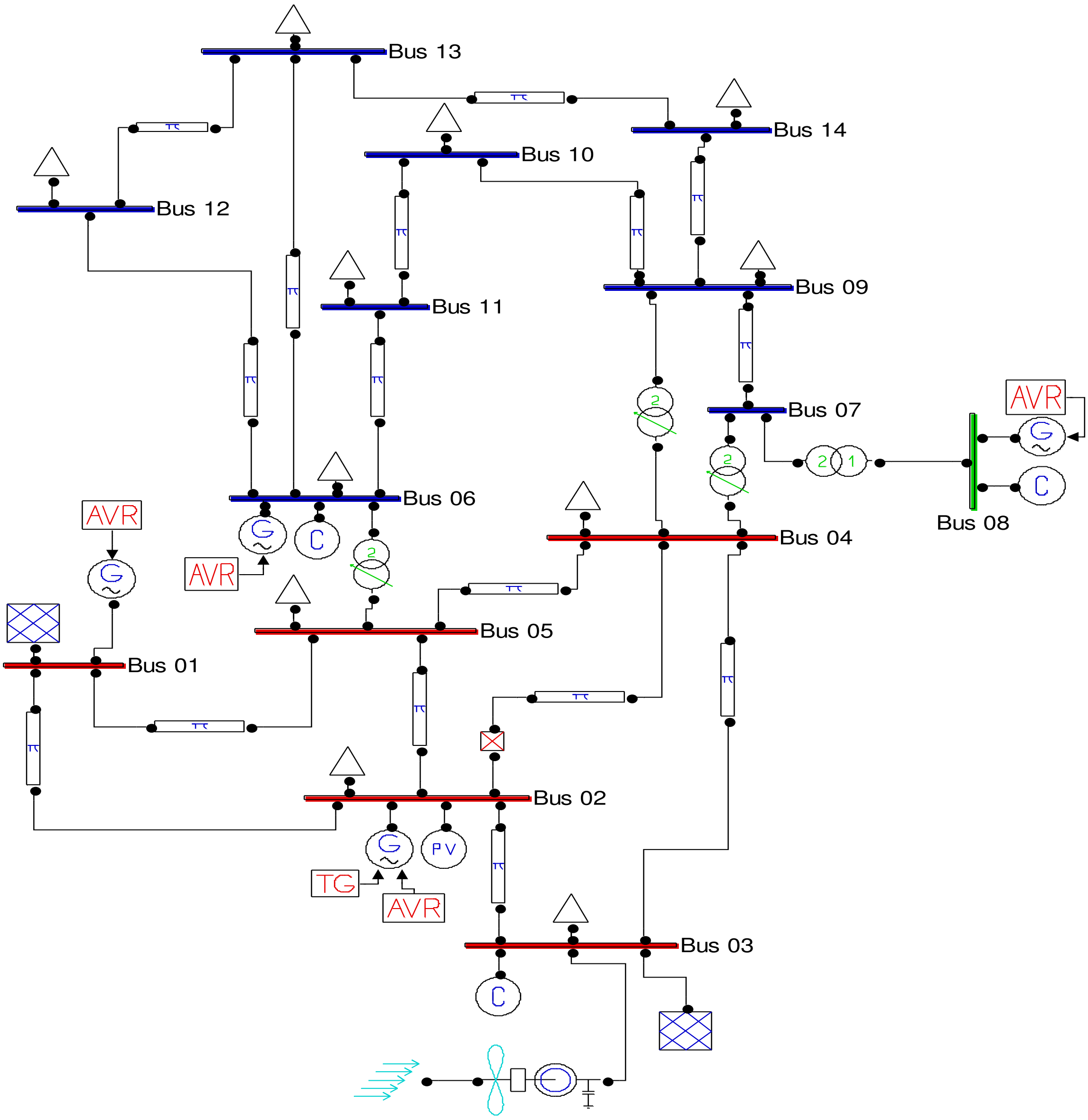

Fig3: IEEE 14 Bus System

4. Problem Formulation

4.1. Formation of Load Curve and wind power curve

For RTS 24 bus system a peak load (demand) of 2324MW and for IEEE 14 bus system peak load of 550MW have been considered from [20] and load curves are formed for 24 hours. The pattern of load curves for RTS 24 and IEEE 14 bus systems are shown in figure 4 and figure 5 respectively.

Wind power values can be calculated from wind speed using formula $P=0.5\rho AV^3$ and for calculation of density of wind (ρ) = 1.23kg/m^3, rotor swept area (A) = 7854m^2 have been considered [21]. Day ahead wind power curve has been estimated from forecasted wind speed data which is available in [22]. The wind generating system is assumed to have maximum of 120 wind turbines (each having capacity of 2MW wind power). Based on system configuration, integrated wind power can be changed *i.e.* number of wind turbines can be altered. Fig.6 shows day ahead forecasted wind power curve.

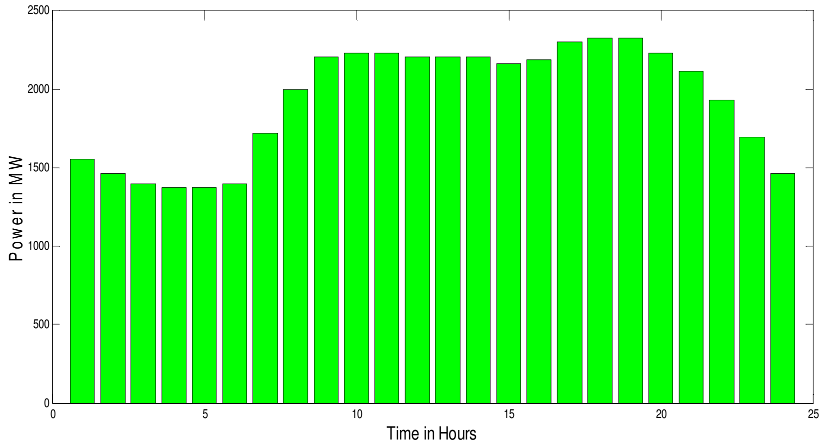

Fig4: Load data for RTS 24 Bus System

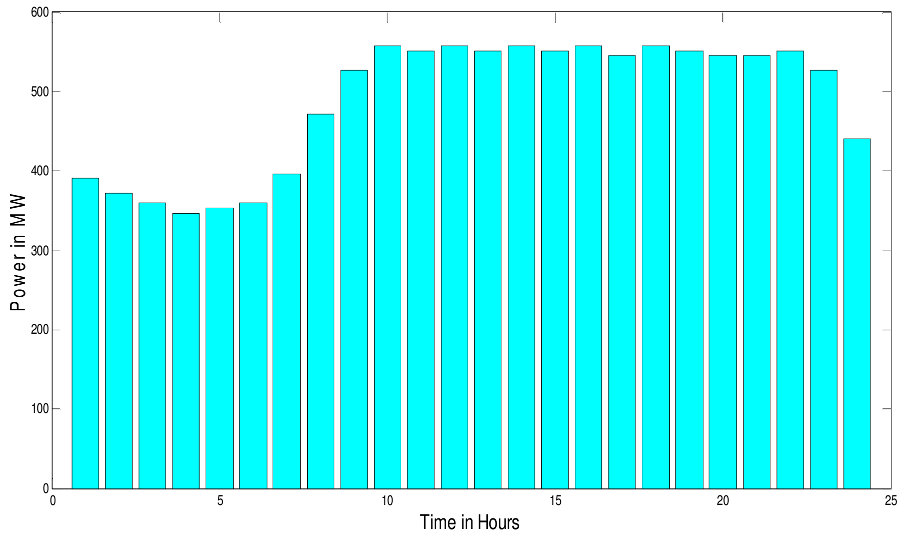

Fig5: Load data for IEEE 14 Bus System

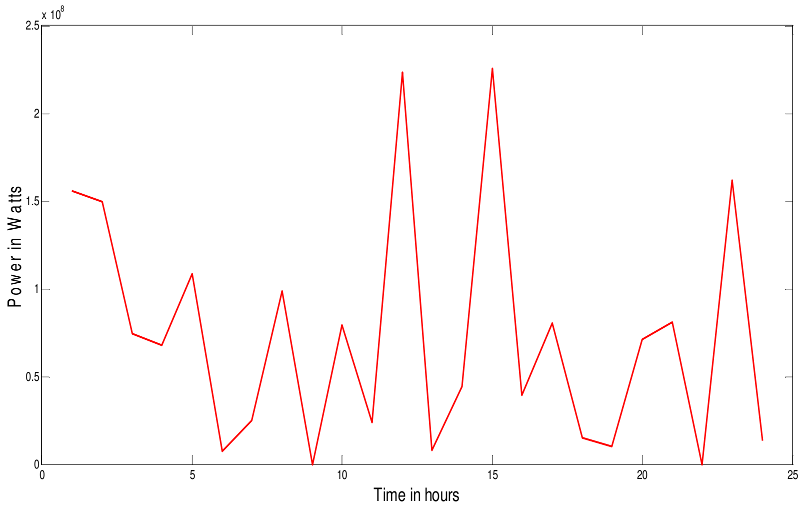

Fig6: Forecasted Wind power curve

4.2 Formation of fixed (Un Controllable) and variable (Controllable) load curves

To form the fixed and variable load curves it has been considered that these curves follow total load curve. Fixed load is taken as 80% and variable load is taken as 20% of total available load. From the above two considerations, fixed and variable load curves are formed for RTS 24 and IEEE 14 bus systems. Figures 7 and 8 show the fixed and variable load curves for RTS 24 bus system. Similarly, figures 9 and 10 show the fixed and variable load curves for IEEE 14 bus system.

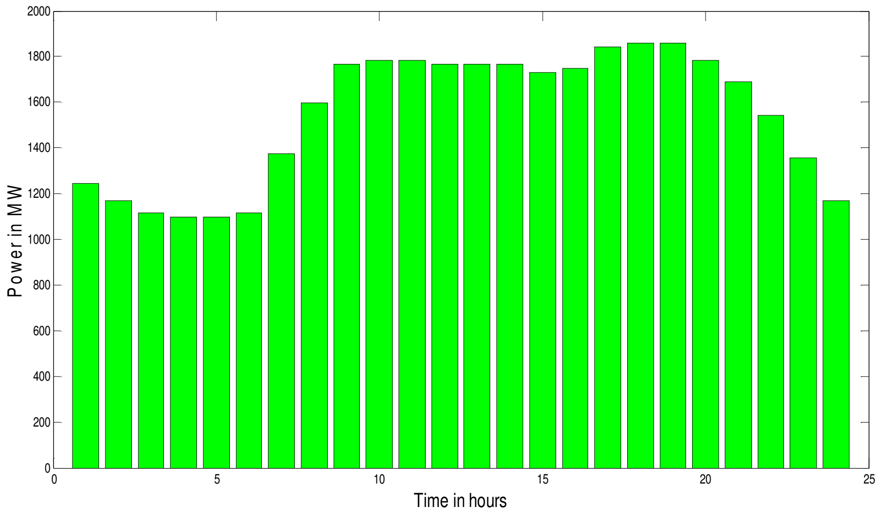

Fig7: Fixed load curve for RTS 24 bus system

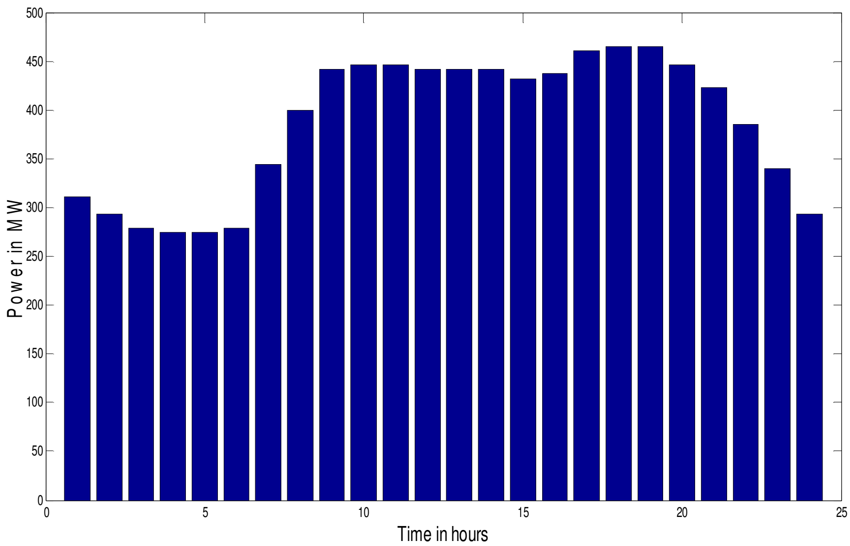

Fig8: Controllable load curve for RTS 24 bus system

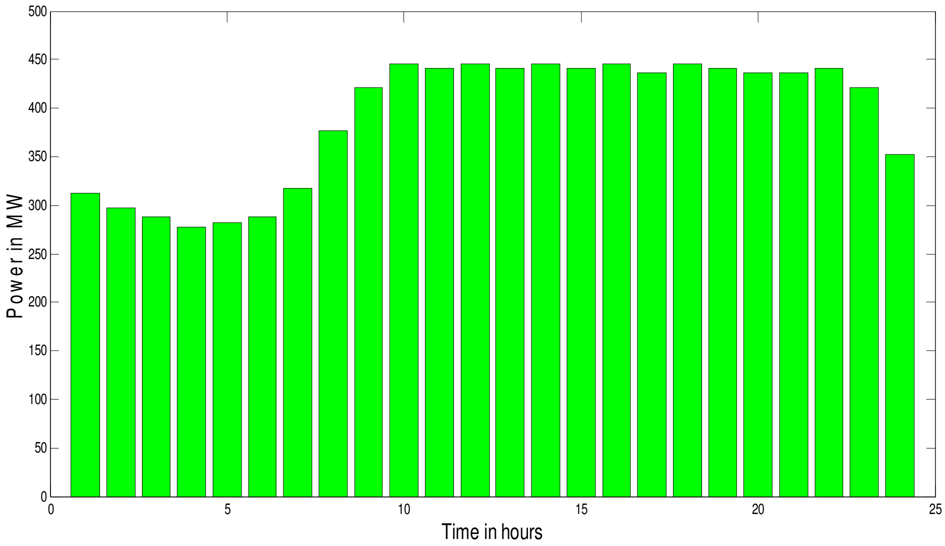

Fig9: Fixed load curve for IEEE 14 bus system

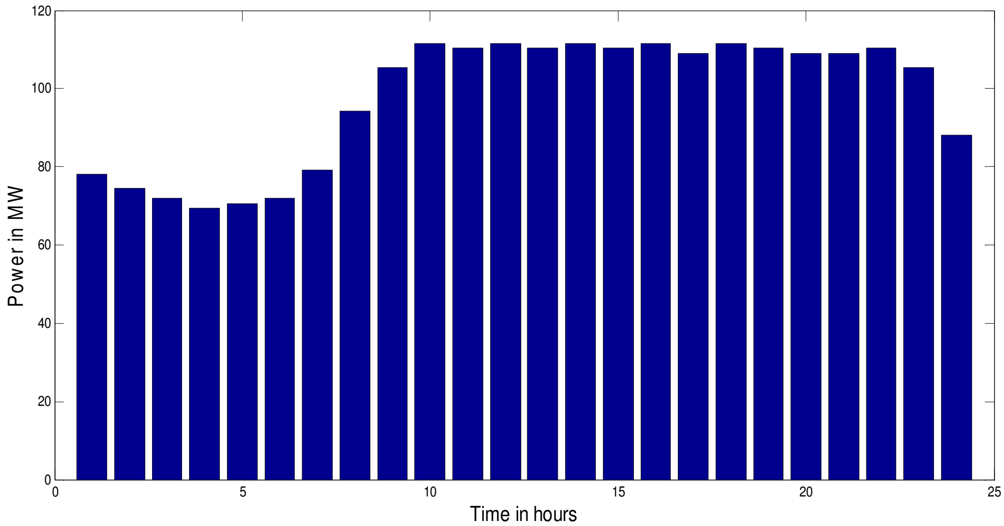

Fig10: Controllable load curve for IEEE 14 bus system

4.3 Formation of objective curve

Objective function formulation (including wind power) depends on:

1. Desired load factor (load factor to be achieved, i.e. around 95%)

2. Availability of wind power

Steps to build objective function

1. Total load for 24 hours is distributed according to the desired load factor.

2. In the objective function maximum wind power utilization is allowed. Based on available (predicted) wind power, objective function can accommodate wind power which is obtained from wind power curve, without disturbing the tolerable load factor. In this method wind power is normalized between 0 to 1 and each hour probability (percentage) has been calculated. Based on probability if wind power is more than a particular limit (here limit is set as 75%) of total wind power, then that wind power will be utilized in the

peak (of the load curve) and remaining wind power (less than 75% limit) will be allowed into a base load curve.

3. This allows load to draw more power from wind farms when the wind generation is excess, without losing load factor.

4.4 Problem solution Using Genetic Algorithm

Genetic Algorithm (GA) is an evolutionary based optimization technique which is inspired by natural evolution, such as selection, crossover, mutation and inheritance. Selection of chromosome length is significant in evaluation process, as it depends on the variables to be determined and encoded in the chromosome. In this paper string length has been taken as 288 and population size is 40. 12 types of controllable loads have been assumed and are available on transmission side. A chromosome length of 288 bits (24(hours)*12(type of possible loads)) has been selected in such a way that each controllable load can be distributed throughout the 24 hours [1]. Load distribution is done in such a way that it meets the objective curve. Total 12 types of controllable loads having different consumption ratings distributed for 24 hours is shown in table1. In table1 symbol '■' indicates the presence of controllable load and symbol '□' shows it's absence. Controllable (variable) load will be combined with fixed load using Genetic Algorithm in order to match the objective function.

Table 1 Controllable load distribution using GA

	1hr	2hr	....	24hr
Type 1	■	□		□
Type 2	□	■		■
Type 3	□	■		□
⋮				
⋮				
Type 12	■	□		■

Fitness of each chromosome is calculated using the following formula. In this the second term in the denominator represents the mismatch. If the mismatch value is less than tolerance value, then the problem is converged, otherwise it has to follow the sequence of steps in genetic algorithm (flow chart) as is shown in figure 7. A tolerance value of 1kW is considered.

Here error or mismatch is defined as (Power from Load curve) – (Power from objective function curve)

$$Fitness = \frac{1}{1 + \sum_{t=1}^{24} \left(P_{Load}(t)\right) - \left(Objective(t)\right)}$$

Objective function consists of two parameters such as wind power incorporation and desired load factor. It has to utilize available wind power fully and improve the load factor.

Selection (reproduction) is the first operator applied on population and the present work uses roulette wheel parent selection for reproduction. In roulette wheel, the wheel space has been allocated based on fitness of the chromosome. Crossover is recombination of two individual chromosomes. Crossover progressively improves the fitness function value, as new offspring's (Childs) are generated. In this work uniform crossover is used. If the probability of crossover is 100% then, all new off springs are created by cross over. If probability of crossover is 0% then the off springs are exact copies of previous generation. Good crossover rate assures faster convergence. Purpose of using mutation is to create more diversity in the population and to avoid local minima and maxima. High mutation rate may lead to loss of good solutions from past generations. Elitism is the process of copying best fit chromosomes to the next generation without any genetic operations. Elitism can prevent loss of existing good solutions. This work uses Crossover rate of 0.8 (probability 80%), elitism percentage of 10%, mutation rate of 0.1. The maximum number of iterations is set as 1000.

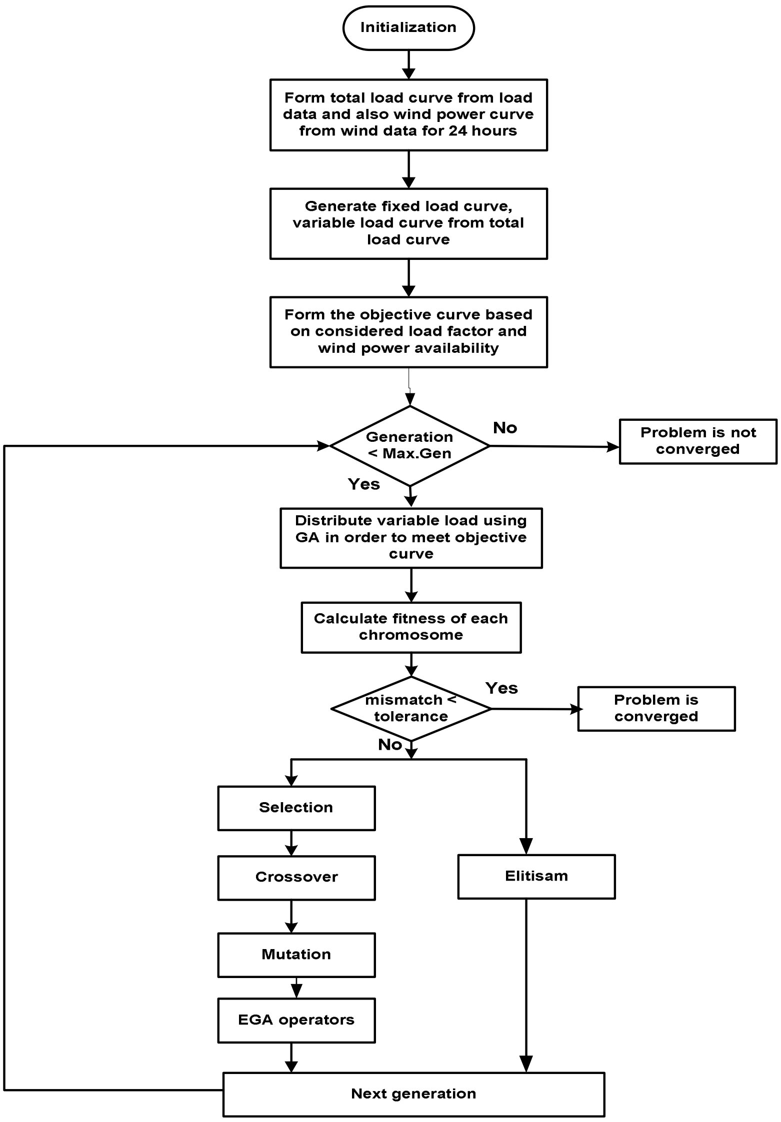

Fig11: Complete flow chart

6 Results &Discussion

In this paper RTS 24 bus system and IEEE 14 bus systems load data is considered for demand side management study. Peak load is shifted to valleys and controllable load is arranged using genetic algorithm and there by load factor is improved and available wind power is fully utilized. Genetic algorithm has been used for load management study. Results show that, the load curve approaches the objective curve after demand side management in respective systems. Fig.13 and fig. 15 show the DSM curves for RTS 24 and IEEE 14 bus systems and their respective genetic algorithm convergence characteristics are also shown in fig.12 and fig.14. From fig.13 and fig.15 i.e. the load curves before and after DSM, it is very clear that loads have been shifted in such a way as to accommodate maximum imported wind power and improve load factor. From both load curves it can be verified that, sum of load for a particular day (24 hours) is same (equal) in magnitude. Load factor is defined as the ratio of average load to the maximum load. In this paper higher load factor is achieved with utilization of available wind energy. Therefore in RTS 24 bus system load factor is improved from 0.83 to 0.878 where as in IEEE 14 bus system it is improved from 0.81 to 0.852. Load factors in RTS 24 bus and IEEE 14 bus systems before and after DSM are shown in table 2 below.

Table 2 Load factors before and after DSM

	Load factor before DSM	*Load factor after DSM*
IEEE 14 Bus System	0.81	0.852
RTS 24 Bus System	0.83	0.878

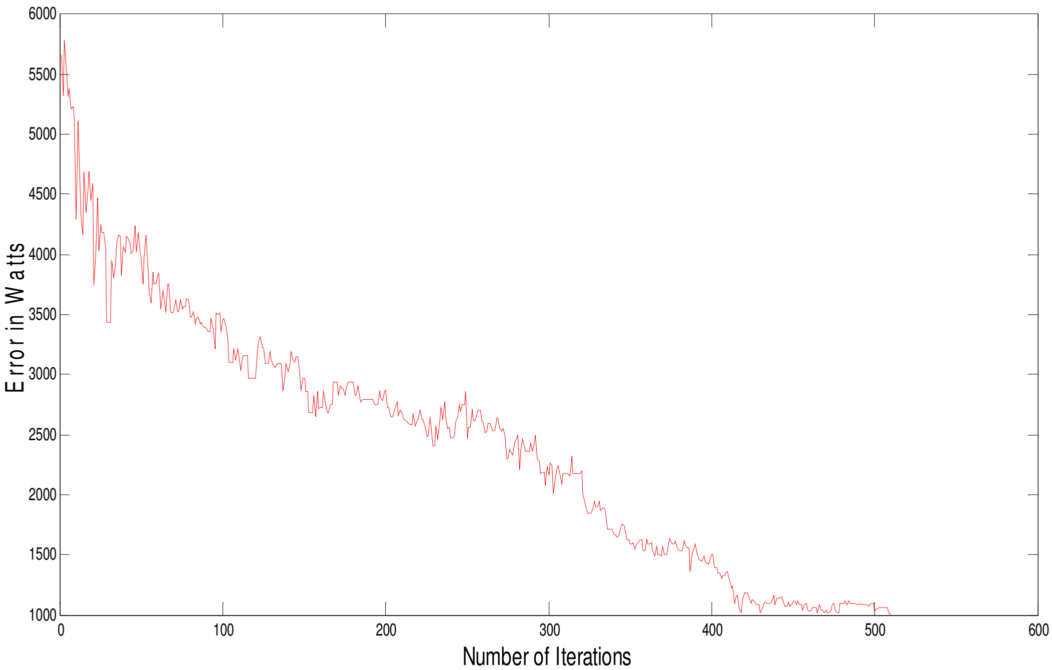

Fig12: Convergence Characteristics for RTS 24 Bus system

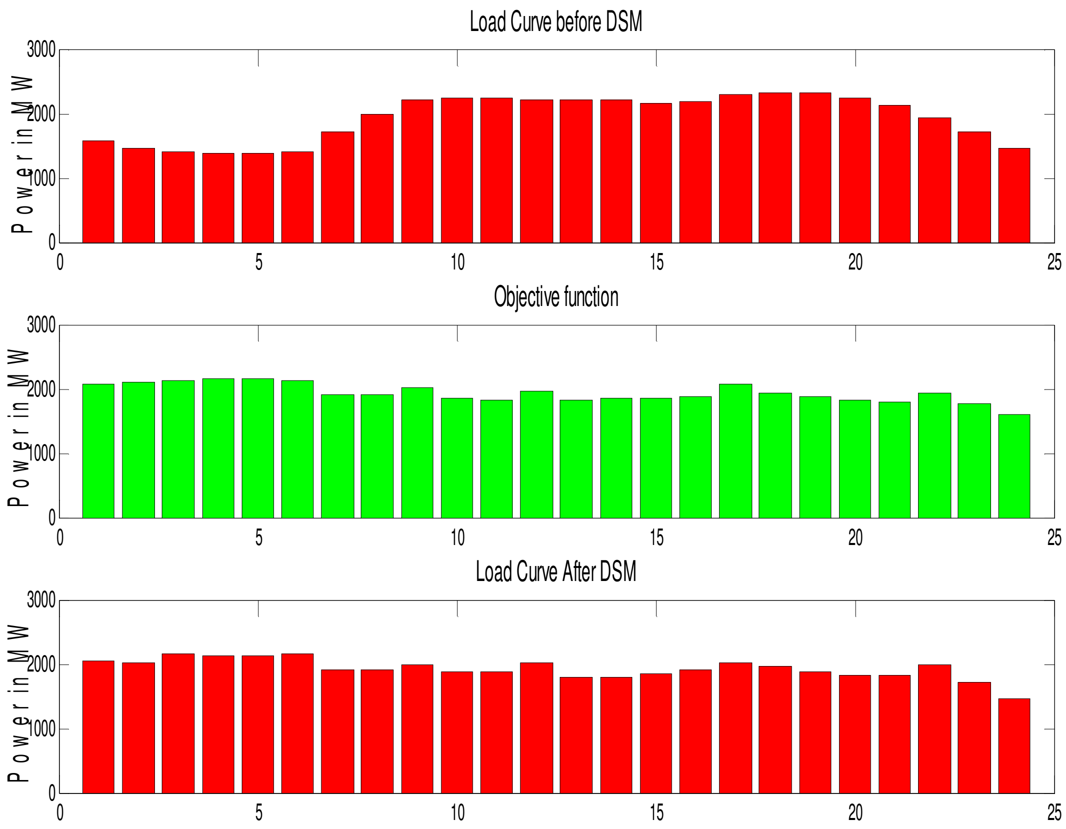

Fig13: Demand Side Management Curve for RTS 24 bus system

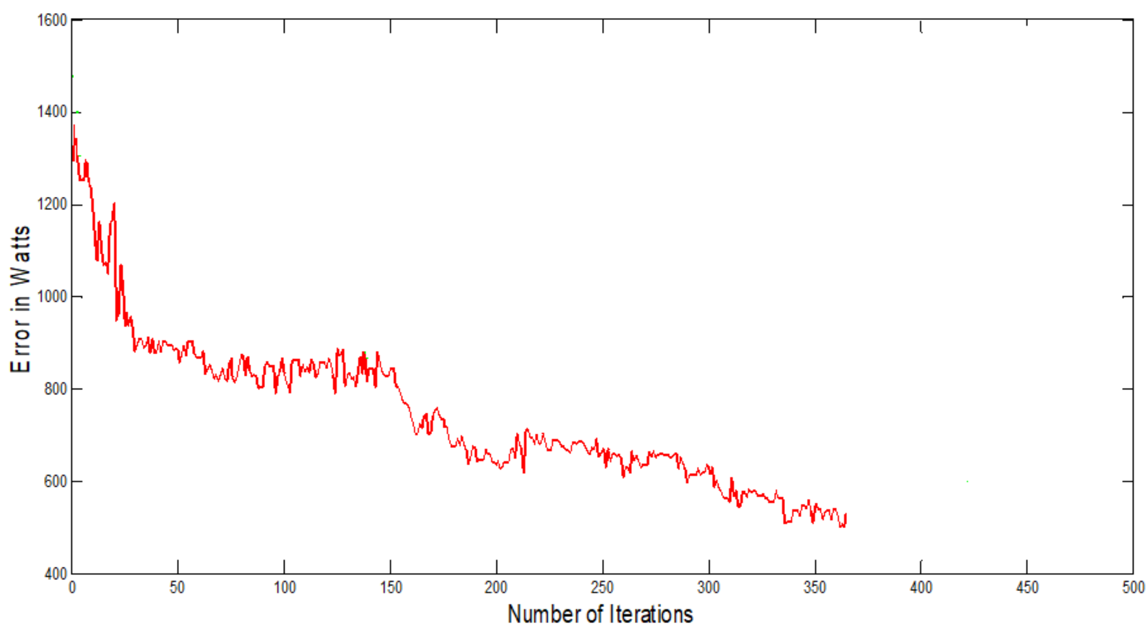

Fig14: Convergence Characteristics for IEEE 14 Bus system

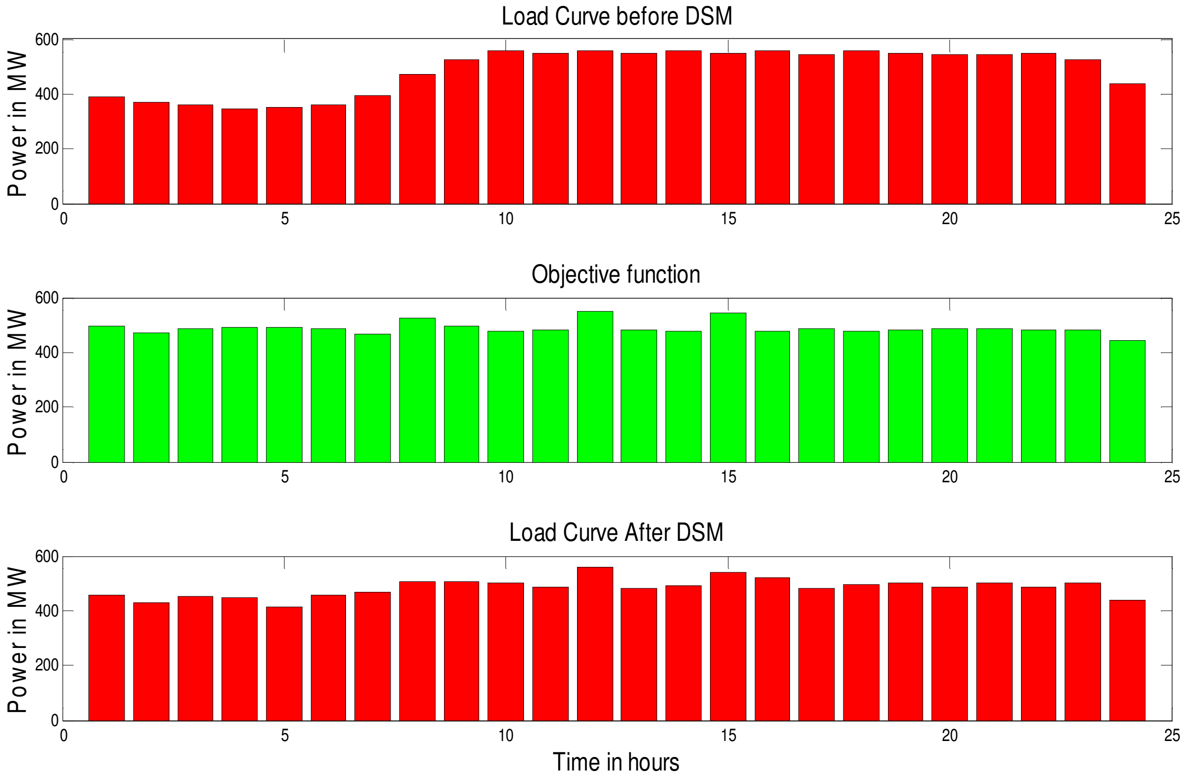

Fig15: Demand Side Management Curve for IEEE 14 bus system

7. Conclusion

Demand side management plays vital role in future smart electric grids. Also, renewable generation and integration form an important part of future power system. In this paper, a Genetic Algorithm approach is proposed for load management study. Objective function formulated accommodates utilization of available wind power to full extent and maintains specified load factor. Controllable (variable) load is distributed on fixed load in such a way that load curve meets the defined objective function. The genetic algorithm proposed, minimizes the error and improves the fitness value. A day ahead (24 hours) DSM study is carried out, which will be helpful in power system planning and operation studies. Case studies using RTS 24 bus system and IEEE 14 bus system show effective management of loads and improved load factors. Also wind power curve resemblance has been observed in load curve after DSM.

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