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ORIGINAL CONTRIBUTION

Demand-Side Management in an Indian Village

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Abstract The development of modern society is centered on energy, in particular the use of electrical energy. The increasing financial, social and ecological restrictions that hinder the construction of new plants and electric power transmission lines have led to the inclusion of demand-side management (DSM) techniques in the planning studies of electrical systems, called "minimal cost planning" or "integrated resource planning." Madhya Pradesh Paschim Kshetra Vidyut Vitran, District-Dhar, Tehsil-Manawar, Singhana Village Dedali B, in India spends a lot of money on energy bills. There is a need of energy management system in this village. The energy audit of Singhana, Village Dedali B, Dhar, Madhya Pradesh, India is conducted to study to energy management pattern and identify the energy saving measures thereof. Energy auditing has been conducted for village area of Patelpura and Ningwalpura to estimate the daily, monthly and annual energy consumption. The annual energy consumption of village Patelpura and Ningwalpura is estimated as 10,200 kWh in 2018. Presently, the village using utility power, but, at the time of power curtailment, a number of irrigation pumps of 3 HP, 5 HP, 7 HP are running through diesel generators to backup for the power outing. The village has a scope of energy management for energy saving and electricity bill reduction, adopting a proper approach. In this paper, the demand-side management approach is used for energy saving which is implemented to save the 15% of energy and 20–25% of cost reduction in electricity bills of the village. This paper is aimed to validate the demand-side management using Binary Particle Swarm Optimization Algorithm. The problem is mathematically formulated as a DSM optimization problem with constraints along with an objective of peak to average ratio and cost reduction. MATLAB is used as a simulation tool.

Keywords BPSO · Demand response · Demand-side management · Distributed generation · Electric distribution company · Smart grid

Introduction

Generally, the level of economic and social development of humanity is directly related to the use of energy. For example, to generate mobility, heat, productivity, electricity, etc. Specifically, electricity is a form of energy that has become popular in recent years, being present in all the daily and productive aspects of people and society [1].

From the aforementioned, it is evident that there is a continuous growth in electricity consumption, forcing the generation of electricity to increase, and which is limited by the decrease in oil reserves and the environmental impact [2, 3].

Historically and in most cases to date, electricity generation is carried out in a decentralized manner, that is, with few large power plants located far from the load centers. In this context, the growth in demand has drawbacks related to: greater exploitation of non-renewable resources, construction of plants and extensive transmission lines, difficulty in obtaining road permits, higher energy losses, less efficiency, worsening of the levels of power quality, lower reliability, high costs, among others [4, 5].

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Currently, there are several mechanisms to reduce the aforementioned problems, these are: Smart Grid (SG), Distributed Generation (DG), Demand Response (DR), among others. The common denominator of the aforementioned are the smart grids, which unify the traditional Electric Power Systems (EPS) with telecommunications, thus achieving, dynamically and efficiently manage generation and loads [3, 5–9].

Regarding Distributed Generation, it is understood as any small-scale technology that generates electricity and that is installed near the load centers; Examples of DG are photovoltaic (PV), wind, biomass, micro and mini hydraulic installations, etc., that is, non-conventional renewable plants, mainly [5, 6]. The idea of demand response (DR) arises because currently the primary sources are limited, and it is applied to avoid expanding the EPS and to improve the quality and service of electrical energy when it is compromised [10–12].

The DR's incentives are generally of the tariff type, although sometimes the electric distribution company (EDC) can intervene directly in the load. The DG mechanisms currently in use are: real-time energy price, time of use, critical peak price, incentive plans, demand management for reliability and any other innovative idea [12]. Each of these mechanisms is detailed in the theoretical framework.

The village is growing population and developing. There is a scope of energy savings and electricity bill reduction through demand-side management. The village has different types of residential, commercial, industrial and irrigational loads. Collecting and scheduling the load data, the energy consumption and the electricity bill can be reduced. From the aforementioned, in the present study an energy management methodology is developed to optimize the response to the demand for smart micro grid [13, 14].

The data is observed and collected from Madhya Pradesh Paschim Khetra Vidyut Vitran, District-Dhar, Tehsil-Manawar, Singhana, and Village-Dedli B. This work contains the following objectives:

- Peak load reduction
- Cost reduction
- Peak-to-Average Ratio Reduction

Theoretical Framework

Smart Grids

These new intelligent networks (smart grids or SG) can be defined in two ways. The term, "European," indicates that smart grids are electrical networks that can intelligently integrate the behavior and actions of all users connected to them—producers, consumers and those who exercise both activities—in the goal of providing electricity in an efficient, sustainable, economically viable and safe manner. A second definition, from the US Department of Energy, specifies more clearly the objectives which are assigned to an intelligent network, through the common thread, than the security of the system. According to this definition, a smart grid network must integrate the characteristics or allow the following performances to be achieved [15]:

- Self-healing against disruptive events.
- Allow the active participation of consumers through the modification of their demand (Demand-side management or demand response).
- React and protect themselves against physical attacks and hacking;
- Provide quality electricity adapted to all needs.
- Accommodate all production or storage technologies.
- Allow the emergence of new products, services and markets.
- Optimize the use and management of assets.

The term SG can encompass several technologies. In fact, on the upstream (manufacturers) or downstream (consumers) markets, SGs will take the form of smart communicating meters measuring production or actual consumption in real time. The information given by these meters may be unidirectional or bidirectional, some leaving the possibility to a supplier or a Transmission System Operator (TSO) or Distribution (DSM) to control loads remotely. On the other hand, on transport or distribution networks, SGs will be the communicating instruments (sensors and communication networks) which will make it possible to transmit to the manager information on the state of the network in real time. When SGs are mentioned, it is therefore not only smart meters that are highlighted but also an instrumentalization in communication infrastructures (sensors, transmission and data storage networks) of transport networks, but also of distribution networks which are connected to renewable energy production or storage means. These new means of production or energy management require a modification in the optimization of the systems, optimization facilitated by the data flows which will be measured over very short periods of time (10 min or less). The electrical grids of the future, given the heavy investment procedures, will be quite similar to those of today. The main differences will come from the current procedures for planned replacements and investments. On the other hand, investment in means of communication is likely to be massive in the coming years to better manage demand, decentralized means of production, storage and fleets of electric vehicles which are being developed in many Europeans countries [3, 9, 15].

Smart Grid and Electricity Management on the Demand Side

There are several definitions for the concept of Smart Grid, but all converge to the use of digital and communication elements in the networks that carry the energy. These elements make it possible to send a range of data and information to the control centers, where they are treated, assisting in the operation and control of the system as a whole [16]. Demand-side management (DSM) in smart grid authorizes consumers to make informed decision regarding their energy consumption pattern and helps the utility in reducing the peak load demand during an energy stress time. This result in reduced carbon emission, consumer electricity cost and increased grid sustainability [17]. This range of data and information provided by the Smart Grid network allows greater control and management of electricity by the concessionaire and the consumer. It is thus possible to implement in the residence a better method for energy management and for the electric utility to implement demand-side management (DSM).

By implementing the DSM, it is also possible to implement a new energy tariff system that seeks to distribute the load during the day, the horo-seasonal tariff system.

In short, the smart grid, or Smart Grid, makes it possible to collect information about the entire path traveled by electric energy since its generation, through its distribution and consumption [18].

The Smart Grid system provides all the information necessary to prepare a correct management plan and optimize the use of electricity, in addition to facilitating the continuous management necessary for it.

The information acquired by the smart grid allows the use and consumption of electricity to be optimized both by the consumer, by the residential electricity management plan, and by the concessionaire who, in possession of this data, can better control and manage electrical power network. The intelligent residential energy management system (IREMS) is used for the optimal scheduling of household appliances and sizing of RESs and ESS [19]

With the smart grid, the consumer at home can obtain real-time information on their electricity consumption profile, as well as previous data on it, since the system has a standard for data storage and measurements [20].

Proposed Methodology

System Model

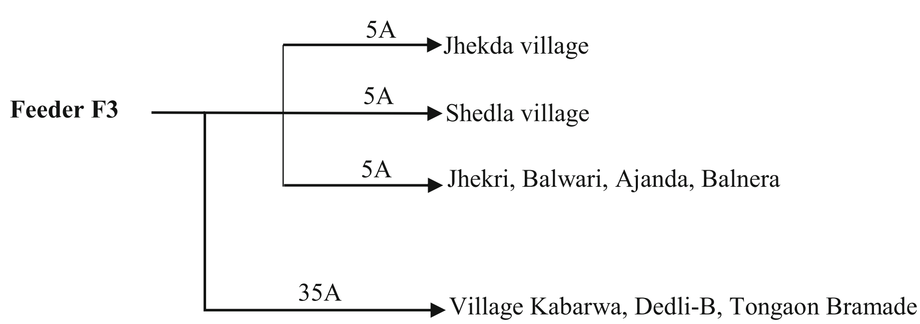
Figure 1 shows the block diagram for proposed demand-side management. The data is observed and collected from Madhya Pradesh Paschim Khetra Vidyut Vitran, District-Dhar, Tehsil-Manawar Singhana village Dadli-B. Rest of methodology is expressed in the following headings.

Data to be used

The village singhana Dedali B, Area of Patelpura and Ningwalpura is around 3 km. Here is power flow distribution path through feeders in different direction in village.

Feeder 1—Gandhwani (33 KV)
Feeder 2—Lohari (33 KV)
Feeder 3—(NVDA + Jhapli) (33 KV)
Feeder 4—Singhana 2 (33 KV)

Feeder F1: Village bramada, Dadli-B, Tongaon, Kabarwa (Rabi season—120A, A.P. 35A)
Feeder F2: Jhekda, Shedla, Jhenderi, Baldari, Ajanda, Balnera village (Rabi season—120A, A.P. 40A)



Mathematical Formulation for Demand-Side Management

The formulated DSM strategy operates the connectivity time of each shiftable appliances in the consumer side in

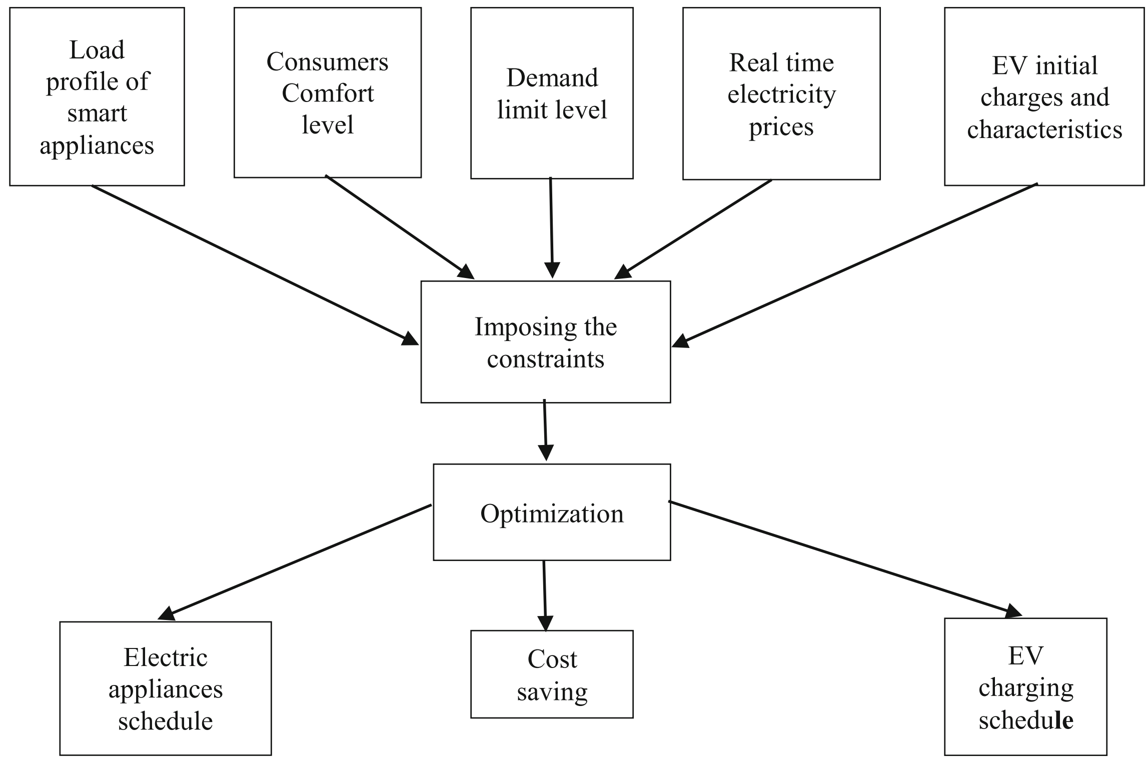


Fig. 1 Workflow for proposed DSM implementation

such a way that brings the actual load consumption curve nearer to the objective—calculated load consumption curve values. Proposed load shifting technique of DSM is mathematically written as follows with equations from Eqs. (1) and (2).

$$\sum_{i=1}^{N}(\text{Present Load }(t) - \text{Desired Load }(t))^2 \tag{1}$$

Subject to constraints:

- Number of shiftable appliances cannot be negative.
- Number of shiftable appliances cannot be more than the availability of appliances where desired load (t) is the preferred load curve at time t proportional to the parameter chosen, and present load (t) is the real time consumption at time t. The present load (t) is given by the following equation:

$$\text{Present Load }(t) = \text{Forecast}(t) + \text{Connect}(t) - \text{Disconnect}(t) \tag{2}$$

$$\text{Connect}(t) = \sum_{t=1}^{N}\sum_{k=0}^{n}(X_{kit} * P_{1k}) + \sum_{i=1}^{j-1}\sum_{i=1}^{t-1}\sum_{k=1}^{D} X_{ki(t-1)}P_{(1+l)k}, \tag{3}$$

where X_{kit} is the quantity of appliances of type k that are shifted from time step i tot, D is the quantity of appliance types, and are the power consumptions at time steps 1and (1 + l) respectively for appliance type, and is the total duration of consumption for an appliance categorized as type 1.

Similarly Disconnect can be defined as follows:

$$\text{Disconnect}(t) = \sum_{q=t+1}^{t+m}\sum_{k=1}^{D}(X_{kit} * P_{1k}) + \sum_{i=1}^{j-1}\sum_{q=t+1}^{t+m}\sum_{k=1}^{D} X_{ki(t-1)q}P_{(1+l)k} \tag{4}$$

The number of appliances to be shifted to be positive cannot be a negative value, i.e., $X_{\text{kit}} > 0$. The number of appliances shifted away from a time step cannot be more than the number of appliances available for control at the time step:

$$\sum_{t-1}^{N}(X_{\text{kit}}) \leq \text{ctrlable}(i), \tag{5}$$

where ctrlable(i) is the number of appliances of type available for control at time step i.

Objective Function

The objective function is to minimize the cost and optimal load schedule for every household appliances in each smart home.

$$\text{objective function} = \min \sum_{i=1}^{N} (F), \tag{6}$$

where $F = \text{Total Cost}$

$$\text{Total Cost} = \sum_{t=1}^{T} l_1 f_1(t) + l_2 f_2(t) +, \ldots, l_n f_n(t), \tag{7}$$

where t is the cycle start time for the devices, n is number of devices and $(l_1, l_2, \ldots, l_n)$ are the loads that refer to the participation of each portion in the composition of the objective function. The constraints from Eqs. (1) to (5) are considered for the simulation. The BPSO applying binary variables to minimize the cost and is given by the following heading (Fig. 2).

Binary Particle Swarm Optimization (BPSO)

The Particle Swarm Optimization (PSO) is a population-based evolutionary optimization technique that evolves according to iterations. The population is called a swarm. Consider an unrestricted minimization problem of a function f. Each particle represents a possible solution to the optimization problem. During each iteration, each particle accelerates toward its best individual position, as well as toward the best global position discovered by some of the particles in the cluster. This means that if a particle finds a promising new solution, all the other particles in the cluster will move in that direction, exploring this most promising region.

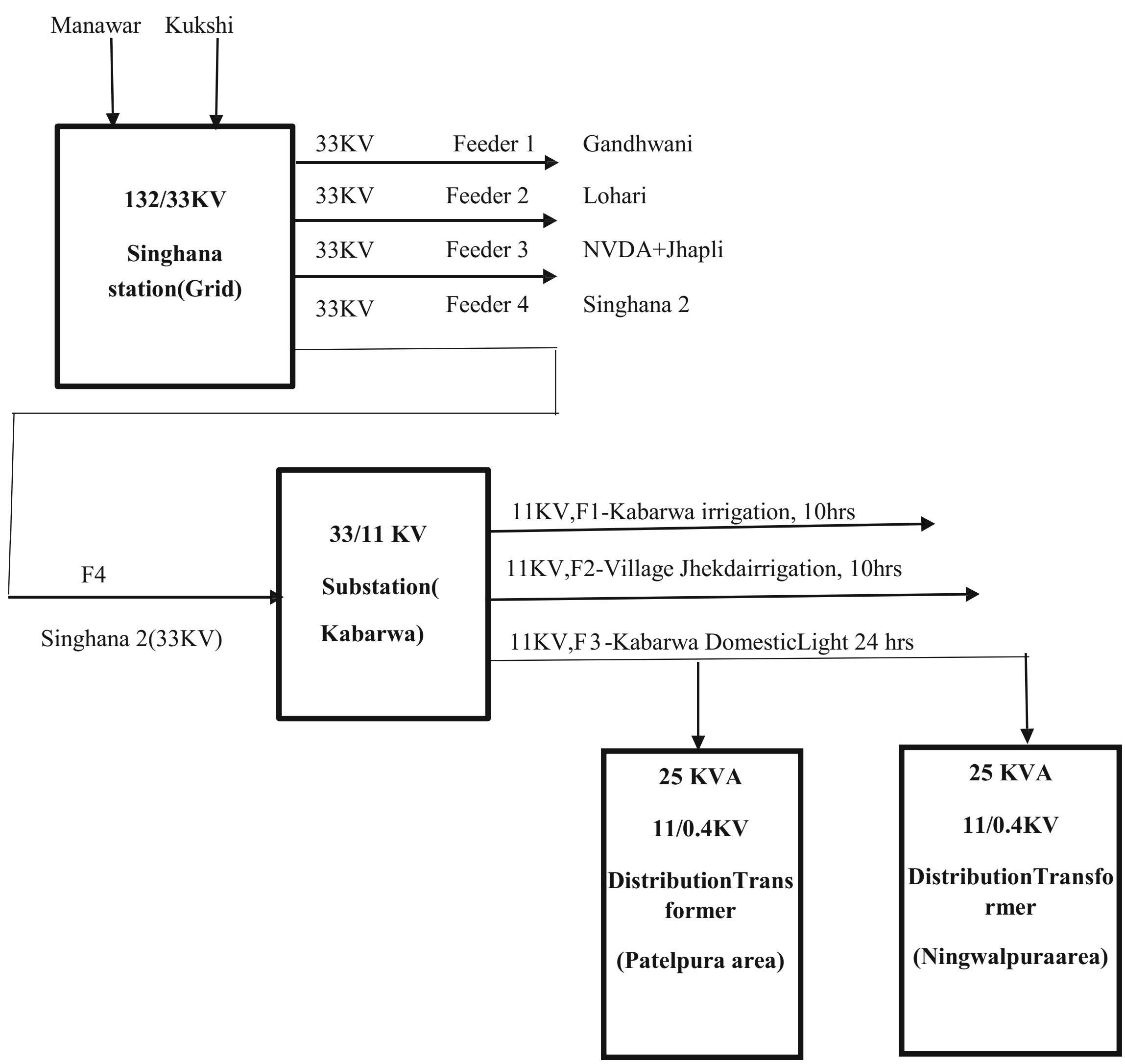


Fig. 2 Flow chart of power distribution of village Dadli-B

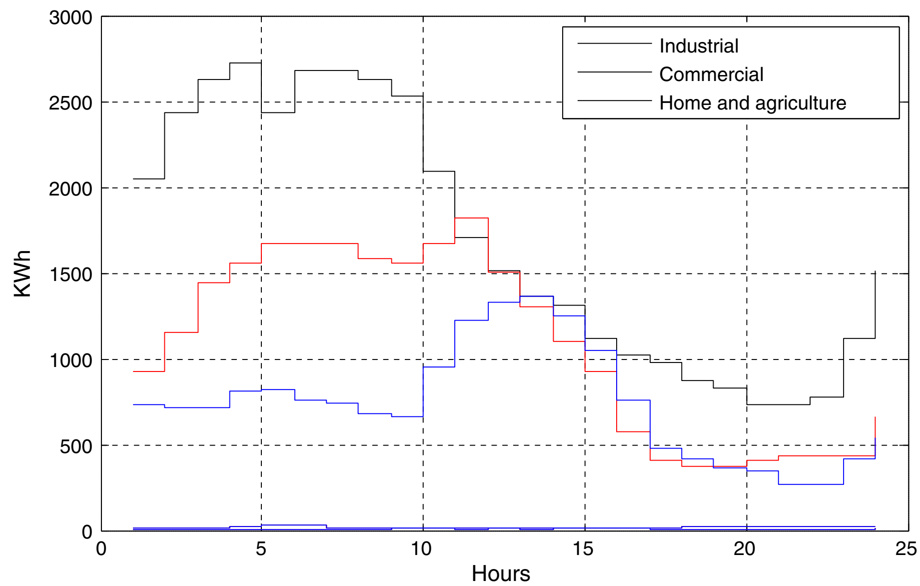


Fig. 3 Comparative input of industrial, commercial and home load

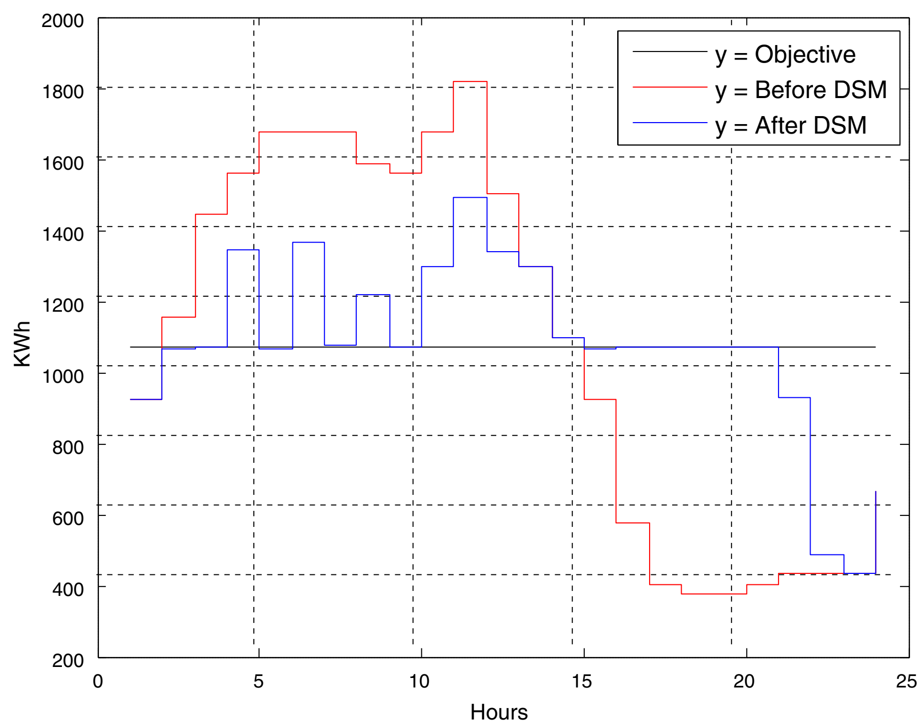


Fig. 4 Comparative study of scheduling algorithm before and after demand response for commercial load

Table 1 Result comparison for commercial load

Parameters	Without DSM	With DSM optimized by BPSO	% Reduction
Peak load (kw)	1366	1046.5	23.25
Cost	2302.90	2136.43	7.22
PAR ratio	1.85	1.42	23.24

If s denotes the size of the cluster, each individual $1 \leq i \leq s$ has the following attributes:

- Current position for the ith individual in the search space $x_i = (x_{i1}, x_{i2}, \ldots, x_{iD})$.
- Current speed $v_i = (v_{i1}, v_{i2}, \ldots, v_{iD})$
- The best position of a particle defined as p_i
- The best position obtained from the population as g_i

During each iteration, the optimization method looks for the optimal solution by updating the velocity and position

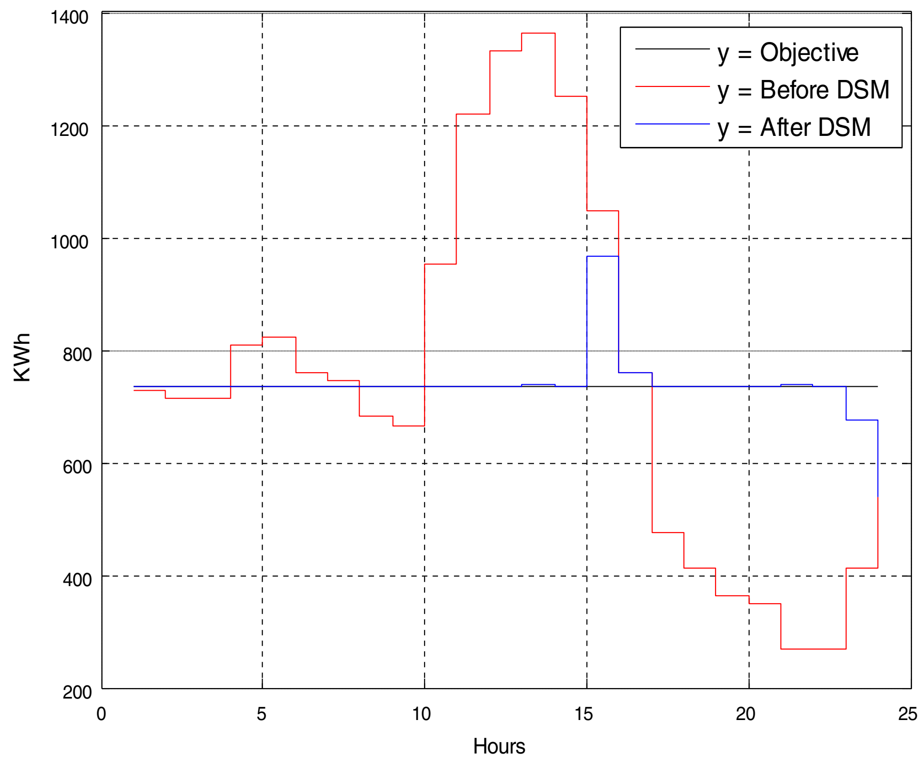


Fig. 5 Comparative study of scheduling algorithm before and after demand response for home and agricultural load

Table 2 Result comparison for home and agricultural load

Parameters	Without DSM	With DSM optimized by BPSO	% Reduction
Peak load (kw)	756	687	9.12
Cost	1035	967	6.57
PAR ratio	1.23	0.96	21.95

vectors of each particle according to the following equations:

$$v_{id}^{t+1} = w * v_{id}^{t} + c_1 * r_{1i}\left(p_{id} - x_{id}^{t}\right) + c_2 * r_{2i}\left(g_{id} - x_{id}^{t}\right) \quad (8)$$

$$x_{id}^{t+1} = x_{id}^{t} + v_{id}^{t+1}, \quad (9)$$

where t denotes the tth iteration, $d \in D$ dimension of the search space, c_1 and c_2 denote the acceleration coefficients, w is called the weight of inertia where r_{1i} and r_{2i} is a sequence of random numbers uniformly in the range $(0,\ 1)$.

The value of each component for the vector v_i, can be limited to the interval $[-v_{\max}, v_{\max}]$ to reduce the probability of the particles leaving the search space. The weight of inertia is typically a linear variation from 0.4 to 0.9 during the generations. The acceleration coefficients c_1 and c_2, which control how far a particle will move in a single iteration, both coefficients have a value of 2.0 [21].

The particle swarm optimization algorithm was originally proposed to solve problems with real variables. However, many optimization problems, such as the problem of detecting spatial clusters, occur in a discrete search space. For this reason [22] presents a binary approach to the method. Equation (9) is still applied to update the speed, where x_{id}, p_{id} and g_{d} are restricted to 1 or 0. The speed in the binary approach indicates the probability that the element of the corresponding position assume value 1. A sigmoid function $s(v_{\mathrm{id}})$ is introduced to transform v_{id} into the interval $(0,\ 1)$. The binary particle swarm optimization algorithm updates the position of each particle according to the following formulas:

$$x_{\mathrm{id}} = \begin{cases} 1, & \text{rand } () < s(v_{\mathrm{id}}) \\ 0 & \text{Otherwise} \end{cases}, \quad (10)$$

where $(v_{\mathrm{id}}) = \frac{1}{1+\exp^{-v_{\mathrm{id}}}}$, and rand () is a uniform random number generator in the interval $(0, 1)$.

Simulation Results

Figure 3 explains the industrial,commercial and home and agricultural load distribution according to hours.It can be seen for home and agriculture peak demand is somewhere at morning 5–10 A.M., i.e., approximately 2800 KWH.

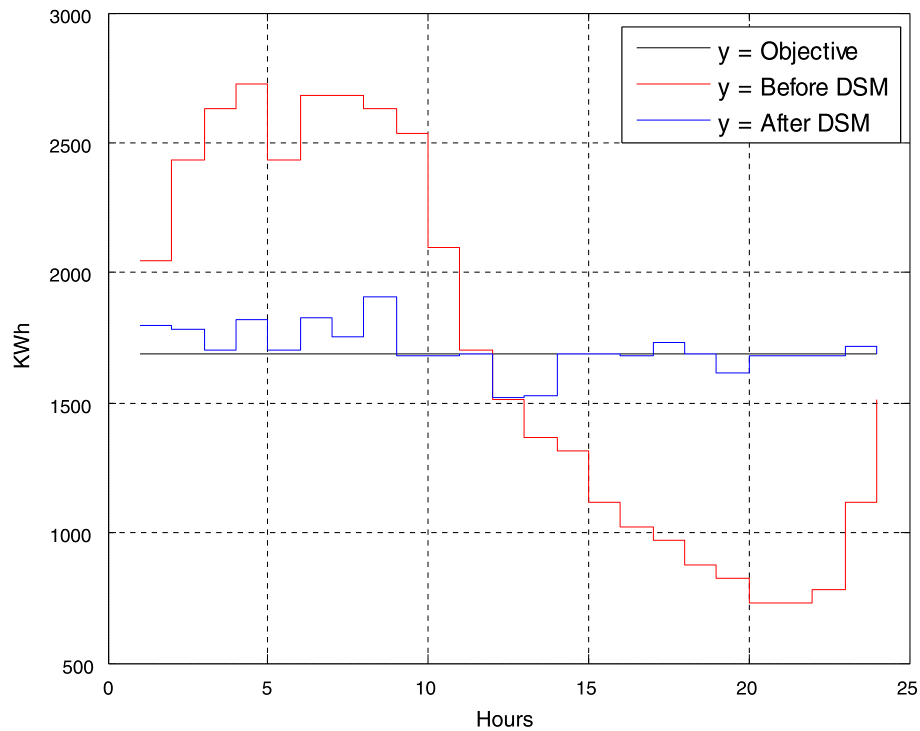


Fig. 6 Comparative study of scheduling algorithm before and after demand response for industrial load

Table 3 Result comparison for industrial load

Parameters	Without DSM	With DSM optimized by BPSO	% Reduction
Peak load (kw)	1567	1346.5	14.07
Cost	2802.90	2196.43	21.63
PAR ratio	1.85	1.42	23.24

Similarly Industrial and commercial demand shifts from 12 to 4 P.M. Afterward, the demands goes low till 4 P.M. to 11 P.M.

Figure 4 demonstrates the commercial load distribution with respect to hours. The above graph represents the random behavior of Load distribution where peak load varies from 1600 to 1900 KWH and the lower side is 400 KWH, according to the hour shifts. It can be seen clearly the shifts of load after applying the demand-side management peak load is reduced to 1400 KWH and Lower range is somewhere as 450 KWH.

Table 1 shows the optimization algorithm efficiency after applying the DSM. It can be observed clearly that the peak load before DSM was 1366 KW and after binary particle swarm optimized DSM it is 1046.5 KW, which is a reduction of 23.5% in peak load. When it is compared with cost there is a reduction of 7.22% with BPSO DSM.

A comparative study of scheduling algorithm for demand response with and without DSM for residential and agriculture load has been performed in the developed algorithm. Simulation results are shown in Fig. 5. It is clear from Table 2, that there is 7.22% reduction in cost with DSM optimized by using BPSO. Similarly for industrial load also, Fig. 6 shows the comparison of scheduling algorithm with & without DSM and Table 3 gives comparative analysis with and without DSM for scheduling algorithm for industrial load which reduces 7.22% in cost and 23.24% PAR ratio.

Conclusion

In this paper, binary particle swarm optimization algorithm has been utilized in order to obtain an optimal solution for scheduling the devices within in the area of Madhya Pradesh state of India. For scheduling purposes, data has been collected from Madhya Pradesh Paschim Khetra Vidyut Vitran, District-Dhar, Tehsil-Manawar, Singhana Village Dadli B. The proposed scheduling proved to be quite valuable in the context of the infrastructure to be built in homes to enable optimal load management in a smart grid, especially when considering the future insertion of smart appliances and the perspective of smart grids. The simulation results clearly shows the reduction in peak load demand, total cost incurred. The profit obtained in industrial load DSM was more than that of commercial and residential load. This is due to large ratings devices used in industries. So, shift of even a single controllable device during peak time, can provides a percent cost reduction in case of Industrial Loads.

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Declarations

Conflict of interest The authors declare that they have no conflict of interest.

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