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Hybrid optimization implemented for distributed generation parameters in a power system network

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ABSTRACT

This paper presents a novel hybrid optimization algorithm for optimizing the Distributed Generation (DG) parameters in deregulated power system which improves the stability, reduces the losses and also increases the cost of generation. This Hybrid algorithm which includes Fuzzy-Genetic Algorithm (FGA) is used to optimize the various DG parameters simultaneously. The various parameters taken into consideration are their type, location and size of the DG devices. The simulation was performed on a distribution system and modeled for steady state studies. The optimization results are compared to the solution given by another search method like Genetic Algorithm (GA) and Micro Genetic Algorithm (MGA). The results reveal the benefits of the proposed method, for solving simultaneous combinorial problems of DG devices in a power system network.

Introduction

DG means a small-scale power station for the need of satisfying local load different from a traditional or large Central power plant [1]. Right from traditional to non traditional, there are various methodologies used in the application of DG. The DG introductions have technical merits in fuel cells, photovoltaic, biomass, wind, geothermal and gas turbine. It includes voltage profile improvement, loss reduction and improves system reliability.

In a highly congested area the benefit of DG is more predominant [2]. The location of DG should be carried out considering its size and location. The placement should be optimal in order, for maximum customer benefit and minimum congestion of DG implemented in the network. The improper placement will lead to reduction in system losses and sometimes it may even collapse the entire system.

The two broad paradigms for maximizing welfare is cost free and non cost free methods. The marginal cost involved is nominal (not capital cost) in the former method. The later method includes generation rescheduling and prioritization and curtailment of loads/Transactions.

Numerous techniques are proposed so far to address the benefits of DGs in power system. In [3] short term the wind power forecasting is proposed by clustering based bad data detection module and a neural network based forecasting module. This paper deals the maximum amount of wind energy which can be utilized in power sectors. The location of DG placement on the basis of Location Marginal Pricing (LMP) is proposed in [4]. The investment planning strategy of DG devices for reducing the reactive power losses by switching of shunt capacitors is given in [5]. Mithulananthan has used simple and efficient method for placement of DG devices to reduce the losses [6]. Celli has used a penetration level assessment for the placement of DG [7]. Moghadass has modeled different DG units based on power flow studies by using backward/forward algorithm [8]. Zareipour has given current status and challenges in Distributed generation [9]. The author [10] suggests heuristic rules and fuzzy multiobjective approach for optimizing power system network configuration. In the analytical study [11], for various distributed load profiles optimal place of the DGs are determined centrally in radial systems to minimize the total losses. Modeling of distributed generations in a three phase distributed load flow and modeling of wind farms is derived in [12]. GA based optimization technique (which can give near optimal results), suitable for multi-objective problems like DG allocation with optimal power flow (OPF) calculations has been used by [13]. The planning of DG with the reliability index is proposed in [14]. Optimal location and sizing of DG parameters are

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0142-0615/

simulated in IEEE system using GA, MGA and Simulated Annealing (SA) in [15–17]. It proves the promising way of placement of DG at the right location using appropriate technology which will solve problems faced in power systems.

The objective of this paper is to develop an algorithm for finding and choosing the optimal location of DG devices, for power loss reduction, which relieves congestion and customer benefit maximization, based on various test cases such as Generation rescheduling, load curtailment and with generation rescheduling with load curtailment with DG devices. Placing the DG devices at the right location is justified using modified IEEE distribution system and in real time India utility system. For the proposed objective function all cases are tested by simultaneous optimization of location, type and size using FGA algorithm which gives faster convergence and can also handle complex optimization problem.

Rest of the paper is organized as follows: mathematical expressions for finding optimal sizes and location are discussed in section 'Mathematical modeling of DG devices'. Section 'Objectives of distributed generation planning' represents the objectives of distributed generation planning with problem formulation. Section 'Hybrid method for optimal placement and sizing of DG' presents Hybrid method implementation for optimal sizing of DG and Section 'Simulation results' gives simulation studies and numerical results obtained. Finally, the major contributions and conclusions are summarized in Section 'Conclusion'.

Mathematical modeling of DG devices

DG devices

The DG size is very important for placing it in a particular bus as the losses decrease to a minimum value and start increasing above the size of DG (i.e. the optimal DG size) at that location [18]. The increase in size leads to maximize the losses value and it may overshoot the values of the losses in the base case. The proper location of DG plays an important role in minimizing the losses, maximizing the customer benefit and minimizing the voltage deviation index. The modeling of DG is very important to achieve the objective.

The Unity power factor modeling is done in PV cell, wind as a variable reactive model and gas turbine is modeled as a constant voltage model. A DG source has a constraint and it can be formulated as

$$P_G^{\min} \leqslant P_G \leqslant P_G^{\max}$$

Considering the output with reactive power of the DG, as it plays a major role, the bus connected to the DG can be modeled in three major cases [19] based on their characteristics in terms of real and reactive power delivering capability as follows:

(1) Type 1: DG which injects Real Power only.
(2) Type 2: DG which injects Reactive power only.
(3) Type 3: DG injecting Real Power but consuming Reactive Power Q.

The primary energy of DG may be injected to grid by a synchronous or asynchronous electric machine which is directly connected to the grid or by means of power electronic interface or a combination of electric machine and power electronic interface. The modeling of different DGs is done as follows:

In general Distributed generation is considered as an electric power source connected directly to the distribution system [20].

Modeling of PV cell

The PV system converts solar energy into electrical energy. The DC power output is converted via an inverter into AC power so that it is compatible with the grid. The DG model depends on control circuit and in general it is designed to control P and V independently which is modeled as a PV node [21]. When P and Q are controlled independently it is modeled as a PQ node.

The power factor is unity and the necessary condition for minimum loss is given by Eq. (2).

$$P_i = P_{\mathrm{DGi}} - P_{\mathrm{Di}} = \frac{1}{A_{ij}} \sum_{\substack{j \neq 1 \\ j \neq i}}^{n} [(A_{ij})P_j - B_{ij}Q_j) \tag{1}$$

From the above equation we obtain the following relationship

$$P_{\mathrm{DGi}} = P_{\mathrm{Di}} - \frac{1}{A_{ij}} \sum_{\substack{j \neq 1 \\ j \neq i}}^{n} [(A_{ij})P_j - B_{ij}Q_j) \tag{2}$$

A_{ij} and B_{ij} = loss coefficients.
P_j = real power injected to bus j.
Q_j = reactive power injected to bus j.
N = number of buses.

Synchronous condensers such as gas turbines

Gas Turbines convert the potential energy saved in fossil fuels from chemical to heat and then heat to mechanical. Synchronous generator is rotated which is directly connected to the grid.

Synchronous condenser DG provides only reactive power to improve voltage profile. To determine the optimal DG placement, the loss equation has to be differentiated on either side with respect to Q_i. The power factor for type 2 will be zero and the optimal DG size for every bus in the system is given by Eq. (3)

$$Q_{\mathrm{DGi}} = Q_{\mathrm{Di}} - \frac{1}{A_{ij}} \sum_{\substack{j \neq 1 \\ j \neq i}}^{n} [(A_{ij})Q_j - B_{ij}P_j) \tag{3}$$

Modeling of wind turbine

The AC output power of these units is converted by a power electronic based rectifier and an inverter to grid compatible AC power. In an induction generator both active and reactive powers are functions of slip.

$$\begin{aligned} P &= P(V,s) \\ Q &= Q(V,s) \end{aligned} \tag{4}$$

where P and Q are the active and reactive produced, the induction generator slip is denoted by 's' and the bus voltage is 'V'. Assuming the dependency of Q is very low and P is constant the expression (5) can be reduced as follows:

$$\begin{aligned} P &= P_s = \text{constant} \\ Q &= f(V) \\ Q &= \sqrt{(E_q|X_d)} - P^2 - \frac{V^2}{X_d} \end{aligned} \tag{5}$$

No load voltage E_q is maintained constant and X_d is the synchronous reactance and V is the generator terminal voltage. The parameters of wind turbine include cut-in wind speed and rated wind speed and typical values of them are 3.5 m/s, 25 m/s and 14 m/s.

$$P_{\mathrm{wind}}(t) = 0.5\alpha\rho(t)A\upsilon(t)^2 \tag{6}$$

where α is the Albert Betz constant, $\rho(t)$ is air density, A is area swept by turbine rotor, and $\upsilon(t)$ is the wind speed. Maximum power rating of wind station is fixed by taking averages of all day powers calculated by using the equation. For this type of DG the power factor varies between 0 and 1. The maximum DG capacity for renewable DGs like Solar and Wind is calculated from the average power estimated by irradiance and wind speed. The average power generated by the wind turbine is 0.471 p.u.

Objectives of distributed generation planning

Social welfare maximization

Total Social Welfare (TSW) is the additive nature of

Customer Surplus + Supplier Surplus

The two parameters are measured in monetary units and it is given in dollar in this paper. In particular customer surplus is the net difference between the economic value of electricity to customer and the cost of acquiring the electricity and the supplier surplus is the difference between electricity sales revenue and supply cost.

Customer Surplus = Customer Utility − Electricity Cost
Supplier Surplus = Sales revenue − Supply Cost

The schedule has to be developed to set the generation level in order to obtain an economic objective function.

The central planner maximizes.
TSW = (Customer Utility − Electricity Cost) + (Sales Revenue − Supply Cost).

Since the supplier receives what the consumer pays, as Electricity cost and sales revenue are similar those two parameters gets cancelled and result in the following equation.

$$\text{Max TSW} = \sum_{i=1}^{ND}(d_i P_{Di}^2 + e_i P_{Di} + f_i) - \sum_{j=1}^{NG}\left(a_j P_{Gj}^2 + b_j P_{Gj} + c_j\right) - \sum_{k=1}^{NG}\left(g_k P_{DGk}^2 + h_k P_{DGk} + l_k\right) \quad (7)$$

The objective function is formulated as a difference between the quadratic benefit curve submitted by the buyer (DISCO) and quadratic bid curve supplied by the seller (GENCO) minus the quadratic cost function supplied by DG owner. This objective function will give the total surplus measured in each group.

Subject to operational constraints, such as real and reactive power balance, voltage profile limits and the power flow limits.

P_{Gj} and P_{DGK} are the active power output of generator and Distributed generator K,
a_j, b_j; c_j; g_k, h_k and l_k are the cost coefficients.

The system considers the demand of ith customer P_{Di} term with energy benefit coefficients d_i; e_i; and f_i representing demand elasticity. ND and NG are the number of demands and generators, respectively. Therefore, the above equation maximizes the difference between total benefit and total cost (i.e. social welfare).

(1) *Equality constraints*: The network is modeled via the power balance equation at each node in the network. The sum of power flows, active and reactive power, injected into a node minus the power flows extracted from the node has to be zero.

$$P_i = P_{Gi} + P_{DGi} - P_{Di}$$
$$Q_i = Q_{Gi} - Q_{Di}$$

(2) Inequality constraints

Generation limits: The generating plants have a maximum and minimum generating capacity beyond which it is not feasible to generate due to technical or economic reasons. Generating limits are specified as upper and lower limits for the real and reactive power outputs.

Real power generation limits:

$$P_{Gi}^{min} \leqslant P_{Gi} \leqslant P_{Gi}^{max}$$

Reactive power generation limits:

$$Q_{Gi}^{min} \leqslant Q_{Gi} \leqslant Q_{Gi}^{max}$$

Line flow limit: The line flow limit specifies the maximum power that a given transmission line is capable of transmitting under given conditions. The limit can be based on thermal or stability considerations. Thermal limits are usually considered for shorter lines. The following constraint checks the absolute power flow both at sending and receiving ends of particular line which should be within the upper limit of the line.

$$S_{ij} \leqslant S_{ij}^{max}$$
$$S_{ji} \leqslant S_{ji}^{max}$$

Bus voltage limit: Voltage limits refer to bus voltage to remain within an allowable narrow range of levels.

$$V_i^{min} \leqslant V_i \leqslant V_i^{max}$$

For base case OPF,

$$P_{DGi} = 0$$

For load bus,

$$P_{Gi} = 0$$

where
N = total number of buses in the system;
P_{Gi} = total real power generated at bus i;
P_{Di} = total real power demand at bus i;
P_{DGi} = the power supplied by the DG at bus i;
V_i = the voltage at bus i;
δ_i = the power angle at bus i;
B_{ij} & G_{ij} = the susceptance and the conductance of the line ij;
Q_{Gi} = reactive power generated at bus i;
P_{Gi}^{max} and P_{Gi}^{min} = upper and lower real power generation limits of generator at bus i;
Q_{Gi}^{max} and Q_{Gi}^{min} = upper and lower reactive power generation limits of generator at bus i;
V_i^{max} and V_i^{min} = upper and lower limits of voltage at bus i;
S_{ij} and S_{ji} = the complex power transfer from bus i to bus j and from bus j to bus i.

The bus having the maximum customer benefit and minimum cost, will be the optimum location of DG. This in turn will maximize the Total Social Welfare where the utility and the customer will be benefitted simultaneously [22].

Loss minimization

Distributed Generation Planning deals with the optimal allocation of distributed generation, to obtain maximum benefit by minimizing total real power loss in the system [23]. The resistances in the overhead lines and in the underground cables are the cause for the line losses in the distribution network.

As the DG capacity increases the power flow from the grid to the distribution network reduces to meet the demand and hence the total losses decreased. The loss in the system can be calculated using the below equation

$$P_L = \sum_{i=1}^{N}\sum_{j=1}^{N}[\propto_{ij}(P_iP_j + Q_iQ_j) + \beta_{ij}(Q_iP_j + P_iQ_j)] \quad (8)$$

where $\propto_{ij} = \frac{r_{ij}}{V_i V_j}\cos(\delta_i - \delta_j)$

$\beta_{ij} = \frac{r_{ij}}{V_i V_j}\sin(\delta_i - \delta_j)$

$Z_{ij} = r_{ij} + jx_{ij}$

are the *ij*th element of $[Z_{\text{bus}}]$ matrix.

$$\propto_i = \frac{\partial P_L}{\partial P_i} = 2\propto_{ii} P_i + 2\sum_{\substack{j\neq 1\\ j\neq i}}^{n}[(\propto_{ij})P_j - \beta_{ij}Q_j) \tag{9}$$

Sensitivity Index is evaluated at each bus by using the values obtained from the base case load flow. The bus having the lowest loss sensitivity factor will be the best location for the placement of DG.

Congestion minimization

Congestion is the important factor that can hinder the trade of power in the entire network. If a large enough capacity is available on the system, we can allocate the power supply and demand so as to maximize social welfare. As the margins of transmission capacity become scarce, there is a greater chance that the trade has to be altered because of congestion.

The CONgestion INDex (CONIND) is given by

$$\text{CONIND} = \sum_{k\in B}\beta_k (P_k \div P_k^{\max})^2 \tag{10}$$

where P_k is the active power flow on branch *k*, and $P_k{}^{\max}$ is the capacity, *B* is the set of all branches. By minimizing the above equation, power flows can be kept away from congestion as much as possible. β_k $(0 \leqslant \beta_k \leqslant 1)$ represents the weighting factor which varies between 0 and 1 that reflects the relative importance of the congestion in the network. At any instant distribution systems can fall into emergency operating conditions if a major fault occurs. The objective of congestion Index is to take action or control measures to relieve congestion of distribution networks. The bus having the minimum congestion percentage will be the optimum location of placement of Distributed Generation.

Hybrid method for optimal placement and sizing of DG

Fuzzy logic

Heuristic methods may be used to solve complex optimization problems. In the power system area, it has been used in stability studies, load frequency control, unit commitment and reactive compensation in distribution networks.

In this paper rules are established for determining the advantage of having the DG devices in the right location. The bus voltage (BV) and the power loss (PL) are the fuzzy variables; they are functions of each bus, used to verify where the DG devices are located. PL can be calculated for each bus; it indicates the sensitivity of the power loss reduction function as expressed in (7). It is essential for DG device location. The Fuzzy rules are established by considering the first two extreme situations:

(1) Low bus voltage and high MPL where DG devices are essential.
(2) High voltage and low PL where DG devices are less important.

The allocation of DG devices is based on the bus voltage and power loss is shown in Figs. 1–3. As BV and PL are crucial factors in the distribution network, rules are based on those two parameters. The triangular membership function is justified among other member functions by training the data and the results are compared with the MAPE (Mean Average Percentage Error) to find less percentage error% to find best Member Functions.

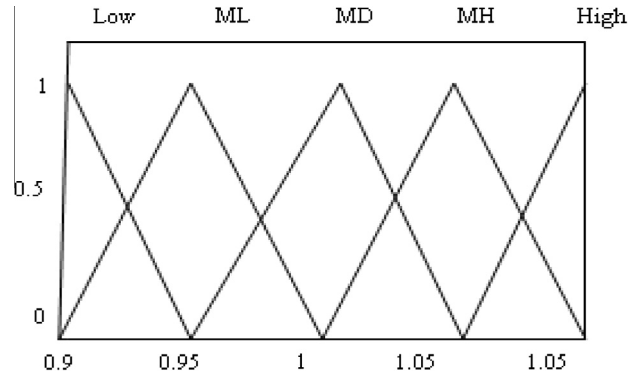

Fig. 1. Bus voltage (p.u).

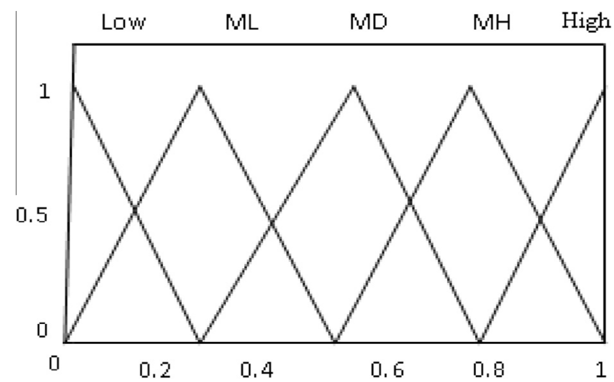

Fig. 2. Power loss (p.u).

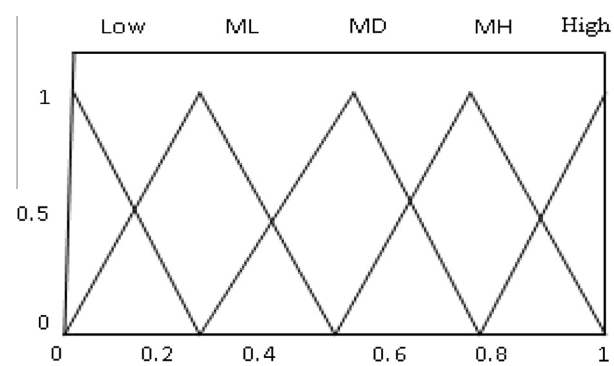

Fig. 3. DG allocation–selectivity.

The fuzzy rules are evaluated and listed in Table 1. This rule set plays a major role in the selection of DG parameters which is possible only by optimization techniques. Since the search space is large and also power system is a huge and complex structure computational techniques prove to be the greatest success for analyzing new trend or to give a solution to this type of complex problem.

The fuzzy rules are evaluated and listed in Table 1.

Genetic algorithm

Heuristic methods may be used to solve complex optimization problems. Thus it is able to give a good solution to a certain problem in a reasonable computation time, but they do not assure to

Table 1
Fuzzy rules.

Power loss	Voltage				
	Low	Medium Low	Medium	Medium high	High
Low	Medium low	Medium low	Low	Low	Low
Medium low (ML)	Medium	Medium low	Medium low	Low	Low
Medium (MD)	Medium	Medium	Medium low	Low	Low
Medium high (MH)	Medium high	Medium high	Medium	Medium low	Low
High	High	Medium high	Medium	Medium low	Medium low

reach the global optimum. The GAs (Genetic Algorithm) starts with random generation of initial population and then the selection, crossover and mutation are produced until the best population is found.

The disadvantage of GAs is the high processing time consumption due to evolutionary concept, based on random processes that cause the algorithm to be quite slow. In general a MGA can work with small populations (nearly 5–10 individuals) and this reduces the processing time. The frequent reproductions occurring inside a small population, where the desirable genetic characteristics emerge quickly, also avoid the mutation process because after a certain number of generations, the best chromosomes are maintained and the remaining ones are randomly selected generated ones. Accordingly, some numbers of individuals are selected for such a group. Then the grouping is repeated and the individuals are selected to form couples to begin the crossover. But if the search space is large and if the combinorial optimizations are involved, single computational intelligence will not give a feasible result.

Objective function

The main objective of this paper is to study the effect of placing and sizing the DG in all system indices. Multi objective optimization is performed by combining the all indices with appropriate weights. The Objective Function is given as,

$$F(\mathrm{Min}) = (W_1 * \mathrm{PL} + W_2 * \mathrm{TSW} + W_3 * \mathrm{CONIND}) \quad (11)$$

Subjected to the constraint

$$\sum_{k=1}^{2} W_K = 1$$

where $W_k \in [0, 1]$.

The weights are indicated to give the corresponding importance to each impact indices for the penetration of DGs. In this analysis Total Social Welfare (TSW) is given large importance with the weightage value 0.4, Power Loss (PL) with 0.3 and CONIND with 0.3.

Encoding

The main objective of the optimization is to find the best locations for the given number of DG devices within the defined constraints. The configuration of DG device is obtained by three parameters: the location of the devices, their types and their rated values. Each individual is represented by N_{DG} number of strings, i.e., and number of DG devices to be used for this optimization problem.

The first values of each string indicate the location information i.e., the node in which the DG should be connected and which can take values from 1 to number of load buses in the network.

The second value of the string represents the type of the device. PV Cell for 1 Wind Turbine for 2 Gas turbine for 3 and zero for no device is connected.

The last value represents the DG size and can take values from 0 to 10 MW

Initial population

The initial population is generated from the following parameters. N_{DG} is the number of DG devices to be located, the possible location of the devices i.e., $N_{location}$, types of the devices i.e., N_{types}.

Initially, a set of N_{DG} number of strings are produced. For each string the first value is randomly chosen from the possible locations $N_{location}$.

The second value, which represents the types of DG devices, is obtained by randomly drawing numbers among the selected devices.

The third value of each string, which contains the rated values of the DG devices, is randomly selected between +1 and −1. To obtain the entire initial population, the above operations are repeated N_{ind} times. The objective function is computed for every individuals of the population.

The objective function is defined in order to quantify the impact of DG devices on the state of power system network. The inverse of the objective function is used to compute the fitness value of each individual in the population.

$$\mathrm{Fitness} = 1/\mathrm{Objective\ function} + 1$$

Reproduction

In this paper the biased Roulette wheel selection is used for reproduction, according to their fitness values; the individual is selected to move to a new generation.

Crossover

Crossover is a technique which is used to rearrange the information between the two different individuals and produce a new one. The crossover is applied in each successive generation with a certain probability, known as the crossover fraction or rate. A large crossover rate decreases the population diversity, but in this problem a higher exchange of genetic material is needed. In this paper, two point crossovers are employed and the probability (P_C) of the crossover is 0.75.

Mutation

The mutation rate is highly connected with the crossover fraction. The mutation mechanism used in this study implies generating a random gene number and flipping the bit found at that position. Mutation is used for random alteration of bits of string position. The probability of mutation is lesser than 0.05.

Hybrid optimization (FGA)

Two stages are proposed in this study. In the first stage Fuzzy Logic is applied to reduce the search space and it is used as a global optimizer. The second stage follows a genetic Algorithm which works only with the previously known buses and it is used as a local optimizer. The stagnation and premature convergence can be overcome by hybrid optimization which is more suitable for the problem having more non-convexity. The Hybrid method consists of the following steps:

(1) Calculate the bus voltage and power, considering a power system without DG devices.
(2) Determine the bus voltage (BV) defined for each bus and the power loss (PL).

Table 2
Voltage deviation table with and without DG.

S. no	Voltage range (p.u)	Total number of buses (bus number)	
		Without DG	With DG
1	0.51–0.64	4(3, 6, 15, 29)	NIL
2	0.65–0.74	6(2, 13, 17, 21, 22, 28)	NIL
3	0.75–0.84	7(1, 5, 8, 9, 11, 23, 25)	NIL
4	0.85–0.95	9(7, 12, 16, 18, 19, 24, 26, 27, 30)	02(4, 13)
5	0.95–1.05	4(4, 10, 14, 20)	25(1, 2, 3, 5, 6, 7, 8, 9, 10, 12, 14, 15, 16, 17, 19, 20, 21, 22, 23, 24, 25, 26, 28, 29, 30)
6	1.05–1.1	NIL	3(11, 18, 27)

Table 3
Loss with loading conditions.

Types of load	Bus location	Optimal DG Size (p.u)	Power loss with DG	Power loss without DG
Peak load	12	0.68	7.32	11.43
Medium load	7	0.47	5.21	8.56
Low load	21	0.13	2.56	4.89

(3) Apply Fuzzy Logic to determine the subgroup of buses in which the DG device locations have more advantages.
(4) On the basis of the subgroup, randomly generate a P size population and go to step 6.
(5) On the basis of the subgroup, randomly generate a $P - 1$ size population.
(6) Determine the fitness function of each chromosome.
(7) Carry out the crossover operation.
(8) Calculate the fitness function value of the new chromosome.
(9) Repeat steps 7 and 8 until the best chromosome is reached; print the best chromosome and discard the others.
(10) Repeat steps 5–9 n times; the best individual are obtained after m consecutive generations.

Line overloads can be overcome by Generation Rescheduling alone. The hybrid method reduces the computational expenses by attempting the four cases in each stage. When all the controls available fails to maintain the security of the system operation, load shedding is used as the last tool to make the black out to be minimum.

Simulation results

The power flow studies are carried out with the help of VC++ software package. The modified distribution system which has 30 bus and 32 segments is used to verify the effectiveness of the proposed algorithm. It is assumed that all the loads are fed from the substation located at node1. It consists of 30 buses, totalling 4.43 MW of real power and 2.73 MVAR of reactive power loads respectively. The initial value of n_{DG}, which indicates the number of DG devices to be simulated and is defined as: PV cell is 1, Wind Turbine is 2 and Gas Turbine is 3. In the proposed optimization study for considering the power system network, the different types of DG device and their optimal locations allow maximization in customer benefit and reduction in losses. The location of DG in various buses with the rated values clearly indicate the increase in customer benefit along with the decrease in loss and congestion and it is tabulated in Table 3. Also the buses which have different voltage ranges are tabulated in Table 2.

The convergence characteristic of fitness function is shown in Figs. 4 and 5. It is seen that the convergence function converges smoothly to the optimum value without any abrupt oscillations. This shows the convergence reliability of the proposed algorithm. From the graph it can also be inferred that the customer benefit

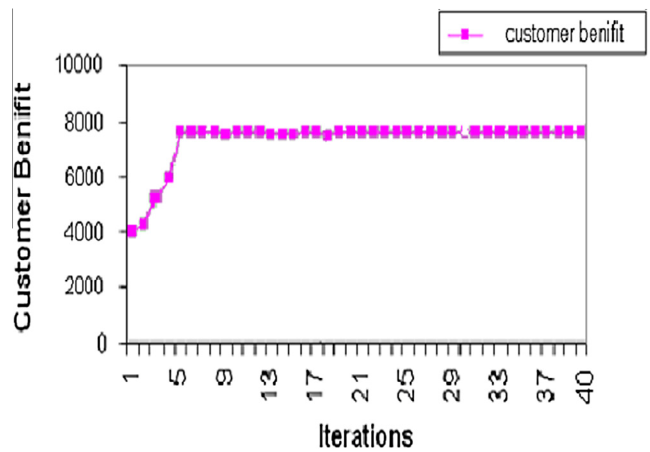

Fig. 4. Iteration (vs.) customer benefit.

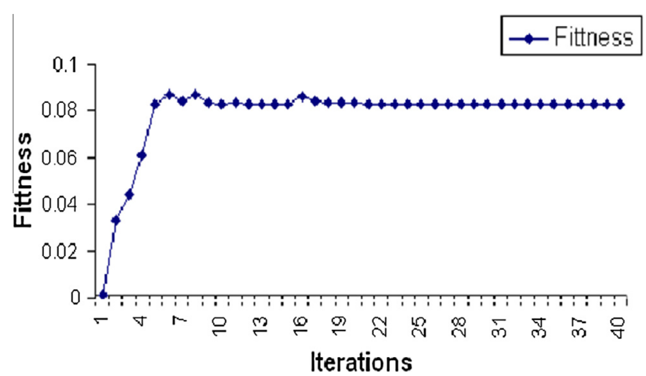

Fig. 5. Iteration (vs.) Fitness.

becomes almost constant after some iterations. The solutions found by the FGA clearly indicate more locations; also the power loss reduction and welfare maximization are efficient compared to the Micro Genetic Algorithm (MGA) approach. The location of DG device in various lines is simulated using Hybrid method and the rated value for PV cell/wind turbine/gas turbine is automatically chosen and the corresponding increase in Total Social Welfare and the reduction in loss are also tabulated in Table 3.

The given load data are taken as 100% loading conditions and the loading capability with and without DG is analyzed and it is given in Fig. 6. The loading capability is increased to twice the normal loading condition and the real power flows in various lines as given in Fig. 7.

The Power loss with and without DG for different loading conditions is tabulated in Table 3 and the optimal corresponding size of the DG is also indicated. The bus number and the corresponding DG size and real power loss are given in Fig. 8.

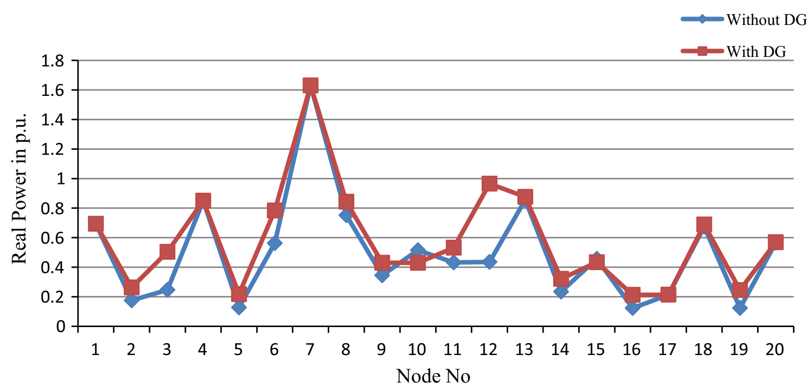

Fig. 6. Normal loading conditions.

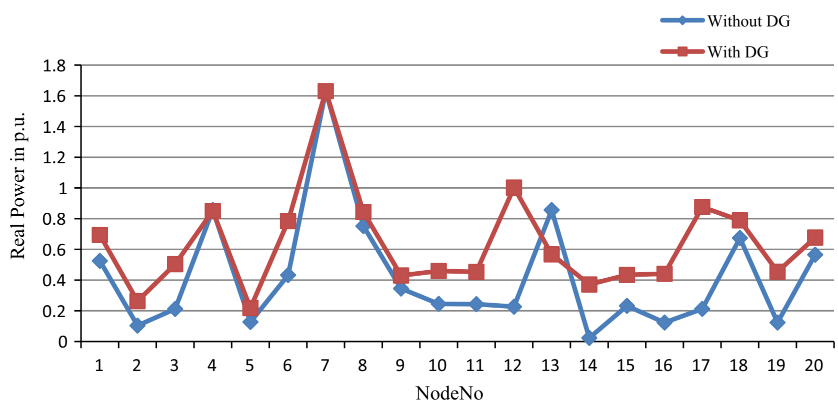

Fig. 7. Twice the normal loading condition.

The location of DG device in various lines is simulated using Hybrid method and the rated value for PV cell/wind turbine/gas turbine is automatically chosen and the corresponding increase in Total Social Welfare and the reduction in loss are also tabulated in Table 4.

IEEE 30 bus system

IEEE 30 bus modified distribution system is considered as a test system in this work and on comparing the result and also on a closer look Hybrid Algorithm outperforms the GA and MGA. The following case studies are simulated and the results are tabulated.

Case (i) Generation Rescheduling (140↑)
Case (ii) Generation Rescheduling with DG Devices (150↑)
Case (iii) Generation Rescheduling with load shedding (155↑)
Case (iv) Generation Rescheduling with load shedding and DG Devices (155↑)

The table below indicates the Generation cost and Real Power Loss for different case studies and the comparison is done among three methods and it is tabulated in Table 5.

The validation of objective function for different cases is compared with FGA, GA and MGA. The results reveal that Hybrid method gives the best result compared to the individual optimization methods.

For the above test system four case studies have been simulated separately to find out a clear dimension in the power system and the results shown in Tables 6–9 give the total generation, total load, loss, objective function and the corresponding time taken for the GA and FGA is indicated (see Fig. 9).

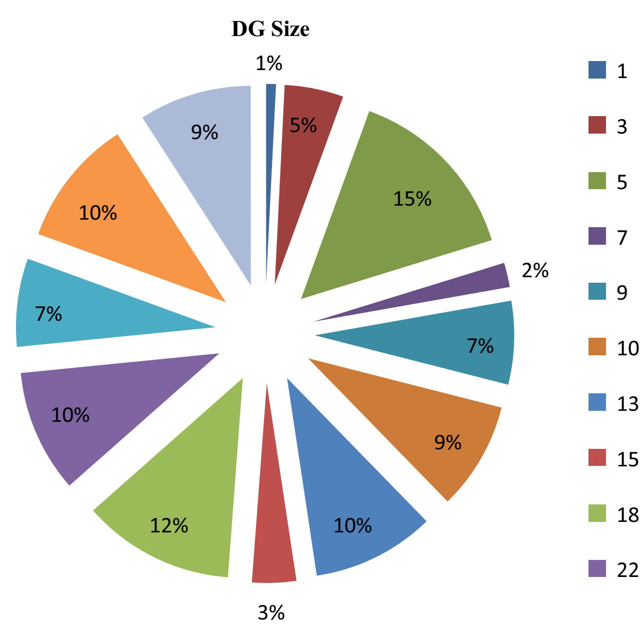

Fig. 8. Loss with DG size.

Indian utility-NTPS23 bus system

The Indian utility Neyveli Thermal Power Station (NTPS)-23 bus test system is shown in Fig. 10. It is a practical Indian utility system which has 22 transmission lines and four generators. A 100 MVA.

Table 4
Hybrid optimization.

GA					MGA				
Line	Device	Rated value in MW	% increase in TSW	% power loss reduction	Line	Device	Rated value in MW	% increase in TSW	% power loss reduction
(a) GA (vs) MGA									
1	1	3.8	0.67	3.98	1	1	3.16	2.8	1.1
2	3	0.35	2.86	8.56	2	2	2.98	3.7	5.45
4	1	3.6	8.67	5.76	4	1	3.34	17.67	56.89
6	2	2.8	12.78	0.53	16	3	1.98	12.78	11.89
8	2	3.7	12.42	2.06	18	2	2.72	25.87	6.78
12	1	1.8	11.86	19.00	22	1	3.76	9.78	2.97
17	2	1.9	18.97	36.78					
22	3	2.2	12.76	32.78					
23	1	3.12	7.43	32.78					

FGA				
Line	Device	Rated value in MW	% increase in TSW	% power loss reduction
(b) Fuzzy + Genetic Algorithm (FGA-Hybrid)				
1	3	3.16	2.8	1.1
2	2	2.98	3.7	5.45
4	1	3.34	9.67	56.89
7	3	2.6	13.74	0.61
9	2	1.6	12.89	5.87
15	2	2.1	17.89	7.67
16	3	1.98	12.78	11.89
18	2	2.72	25.87	6.78
21	3	2.1	13.89	7.99
22	1	3.76	9.78	2.97
23	1	3.12	7.43	32.78
28	3	3.1	33.89	82.89

Table 5
Generation cost and real power for 4 cases (IEEE System).

Case studies	Load increased (%)	Generation cost in ($/h)			Real power loss in MVA		
		Hybrid	GA	MGA	Hybrid	GA	MGA
Case (i)	130	1003.47	983.67	997.56	29.78	16.78	21.49
Case (ii)	150	1047.67	985.23	995.67	30.77	23.89	19.44
Case (iii)	150	1077.45	984.89	999.23	28.67	19.27	25.23
Case (iv)	155	1053.23	988.78	1000.23	35.56	28.11	24.89

Table 6
Case (I) generation rescheduling (130↑).

Bus no	Hybrid (FGA)	GA	MGA
Total gen (MW)	266.78	268.88	268.87
Total load (MW)	263.84	263.84	263.84
Total loss (MVA)	24.43	17.56	17.23
Objective function (S/h)	**1023.34**	**985.56**	**985.56**

The bold value indicates the ultimate result of the case studies. It signifies the altogether result of the three problems mentioned.

Table 7
Case (II) generation rescheduling with DG devices (150↑).

Bus no	Hybrid (FGA)	GA	MGA
Total gen (MW)	284.45	286.75	286.77
Total load (MW)	281.23	281.23	281.23
Total loss (MVA)	25.78	19.56	19.24
Objective function (S/h)	**1052.43**	**984.23**	**981.56**

The bold value indicates the ultimate result of the case studies. It signifies the altogether result of the three problems mentioned.

Table 8
Case (III) generation rescheduling with load shedding (155↑).

Bus no	Hybrid (FGA)	GA	MGA
Total gen (MW)	278.69	283.62	283.63
Total load (MW)	277.73	277.73	277.73
Total loss (MVA)	28.34	19.32	18.45
Objective function (S/h)	**1046.87**	**978.45**	**975.34**

The bold value indicates the ultimate result of the case studies. It signifies the altogether result of the three problems mentioned.

Table 9
Case (IV) generation rescheduling with load shedding and DG Devices (155↑).

Bus no	Hybrid (FGA)	GA	MGA
Total gen (MW)	286.42	287.72	285.67
Total load (MW)	283.74	283.74	283.74
Total loss (MVA)	26.78	19.56	19.85
Objective function (S/h)	**1054.35**	**984.76**	**983.21**

The bold value indicates the ultimate result of the case studies. It signifies the altogether result of the three problems mentioned.

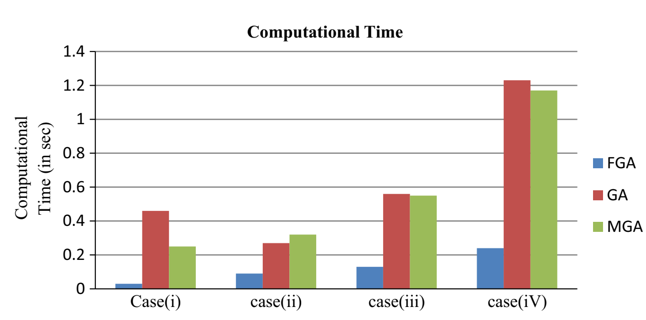

Fig. 9. Computational time for various cases.

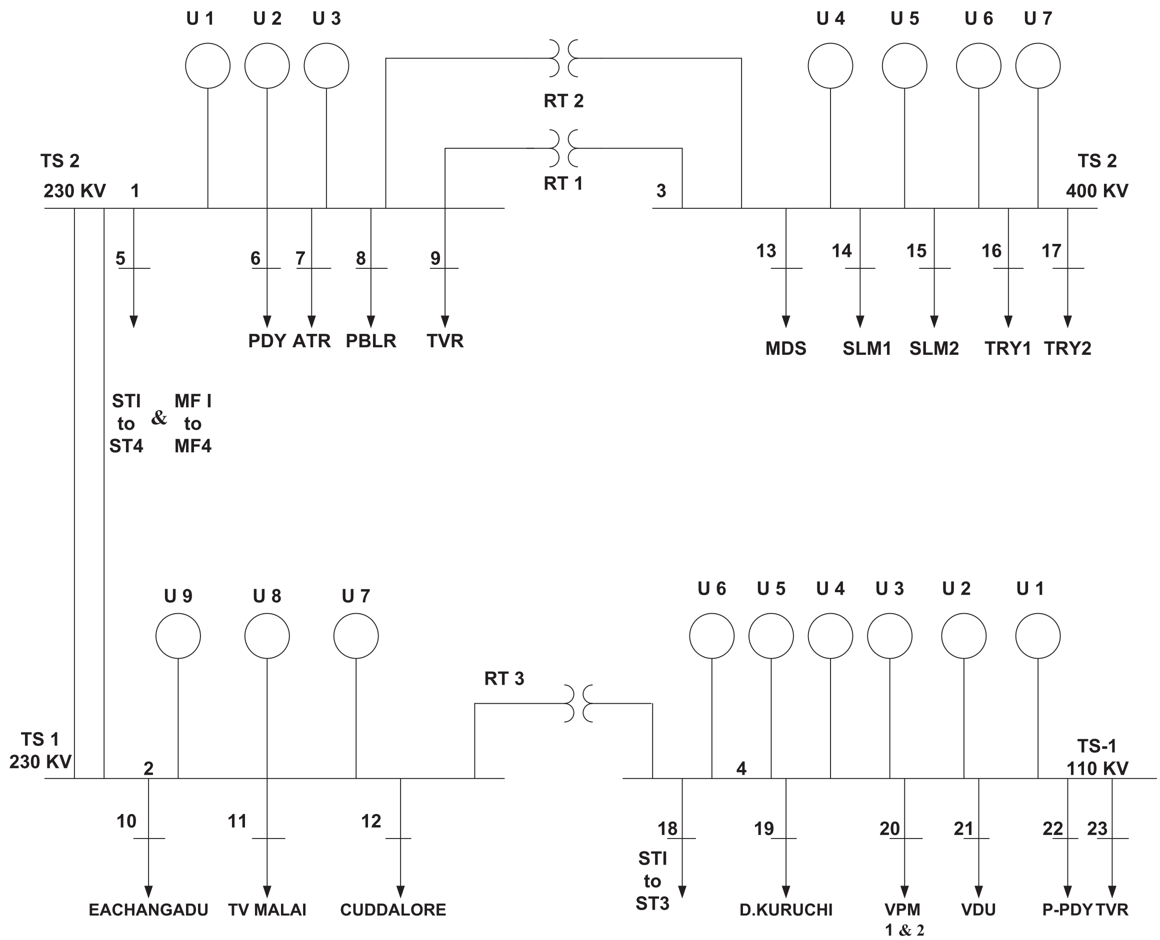

Fig. 10. Indian utility-NTPS single line diagram.

Table 10
Indian utility (NTPS) 23 bus data.

Bus no	Area code	Locations
1.	TS-2 (230KV)	Thermal Station-2 (230KV)
2.	TS-1 (230KV)	Thermal Station-1 (230KV)
3.	TS-2 (400KV)	Thermal Station-2 (400KV)
4.	TS-1 (110KV)	Thermal Station-1 (110KV)
5.	ST1-ST4&MT1MT4(230KV)	Station Auxillaries
6.	PDY(230KV)	Pondy
7.	ATR(230KV)	Attur
8.	PBLR(230KV)	Perambalur
9.	TVR(230KV)	Thiruvarur
10.	Eachangadu (230KV)	Eachangadu
11.	TV malai (230KV)	Thiruvannamalai
12.	Cuddalore (230KV)	Cuddalore
13.	MDS (400KV)	Madras
14.	SLM1 (400KV)	Salem-1
15.	SLM2 (400KV)	Salem-1
16.	TRY1(400KV)	Trichy-1
17.	TRY2(400KV)	Trichy-1
18	ST1-ST3(110KV)	Station Auxillaries
19.	D.Kuruchi(110KV)	Deva kuruchi
20	VPM 1& 2	Villupuram
21.	VDU(110KV)	Vadakuthu
22.	P-PDY(110KV)	Pondicherry
23.	TVT(110KV)	Thiruvarur

400 kV base is chosen. To justify the efficiency of the hybrid algorithm a real time system data is taken and all the crucial four cases are simulated and tabulated (see Tables 10–15).

The results below give the total generation, total load, loss, objective function and the corresponding time taken for the simulation which is indicated. It is observed that FGA takes lesser converging time than GA. The results indicate that Hybrid combination is superior to GA in all aspects.

Since application of the DG devices practically has difficulties in political, social and in economic sectors. The results reveal the maximization of social welfare with minimized congestion by optimizing the type, size and location simultaneously.

Table 11
Generation cost and real power for 4 cases (NTPS System).

Case studies	Load increased (%)	Generation cost in ($/h)		Real power loss in MVA	
		GA	FGA	GA	FGA
Case (i)	130	643.56	997.56	16.78	21.49
Case (ii)	150	665.78	995.67	23.89	19.44
Case (iii)	150	672.41	999.23	19.27	25.23
Case (iv)	155	643.34	1000.23	28.11	24.89

Table 12
Case (i).

Bus no	GA	FGA
Total generation (MW)	237.73	267.73
Total load (MW)	212.21	262.21
Loss (MVA)	15.72	15.77
Time (s)	0.11	0.10
Objective function ($/h)	**874.32**	**873.32**

The bold value indicates the ultimate result of the case studies. It signifies the altogether result of the three problems mentioned.

Table 13
Case (ii).

Bus no	GA	FGA
Total generation (MW)	233.39	283.42
Total load (MW)	234.67	278.67
Loss (MVA)	32.56	32.57
Time (sec)	0.56	0.059
Objective function ($/h)	**982.07**	**985.45**

The bold value indicates the ultimate result of the case studies. It signifies the altogether result of the three problems mentioned.

Table 14
Case (iii).

Bus no	GA	FSA
Total generation (MW)	213.39	268.42
Total load (MW)	225.67	278.67
Loss (MVA)	31.56	29.57
Time (sec)	0.78	0.065
Objective function ($/h)	**912.07**	**996.45**

The bold value indicates the ultimate result of the case studies. It signifies the altogether result of the three problems mentioned.

Table 15
Case (iv).

Bus No	GA	FGA
Total generation (MW)	244.39	283.42
Total load (MW)	245.67	278.67
Loss (MVA)	26.56	31.57
Time (sec)	0.98	0.02
Objective function ($/h)	**952.07**	**1002.45**

The bold value indicates the ultimate result of the case studies. It signifies the altogether result of the three problems mentioned.

Conclusion

In this paper, a proposed hybrid method is found to be more efficient for solving the locations of a given number of DG devices in a power system. Three different types of DG devices are simulated y for energy management: PV, wind and Gas Turbine. A sample 30 bus modified distribution system and a real time Indian utility has been tested for Customer benefit maximization and loss minimization Furthermore, the location of DG devices, their types and rated values are optimized for different loading conditions simultaneously.

The hybrid approaches results have merit when compared to solutions obtained from other search methods (non-traditional methods). This method reduces the search space and decreases the execution time; also it changes to reach the global optimal location. The simulation results clearly indicate the efficiency of the proposed algorithm. Also Hybrid approaches deserve future investigations.

This Problem when implemented will lead to a greater revolution in the power sector industry. The optimization techniques prove to be the greatest asset when some problems in high voltage engineering and in Power system technology cannot be solved using conventional techniques.

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