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OPTIMAL PLACEMENT OF SWITCHES IN DG EQUIPPED DISTRIBUTION SYSTEM by PARTICLE SWARM OPTIMIZATION

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Abstract: Optimal placement of switching devices is a very important for distribution networks' planning, operation and cost minimization. Further identifying optimal placement of switches is typical if the distribution system consists of Distributed Generators (DGs). Generally DGs are used to reduce the losses, to improve the voltage profile and to increase the reliability of the system. Further in order to improve the system behavior it is required to place the switching devices at the optimal locations. This work finds the optimal configuration of the DG equipped distribution system with optimally placed switching devices. In this work a Particle Swarm Optimization was used achieve the goal and results are compared with the existing GA method.
Keywords: Distributed Generators (DG), Optimal allocation of Switches, Minimization of Cost, and Particle Swarm Optimization.

I. INTRODUCTION

Growth of Electric power demand is a critical issue of every power utilities as they have to supply good quality of power to all the consumers with the least cost and with least interruptions. Increasing the capacity of a substation is the general solution for the additional load demands but involves the high cost because increasing the capacity of a substation will leads to go for increasing the distribution, transmission and generation capacities which further requires huge amount of money. To overcome the above problem a small capacity generating stations (such as solar, wind, diesel) of less capacity (normally less than 10MW) are going to be installed and are called as Distributed Generators (DGs). Optimal placement of such DGs will not only meets the growth in power demand and also decreases the power losses and improves the voltage regulation and reliability too. Many papers were published on the optimal placement of DGs [1-4]. [1] Reported some successive experiences of DG happed in central Virginia Electric Cooperative. [2] Proposes a method for DG planning based on genetic algorithm. The paper aimed on the cost evaluation. [3] Proposed some processes for DG planning that also permit the incorporation of distribution automation and demand side management. [4] Proposed some guidelines for DG planning. Some papers also worked with the impact of various aspects on DG equipped Distribution Systems. At present the research is going on DG impact on distribution system on relay protection fault location [5], islanding algorithm [6], and reliability evaluation [7]. Reference [8] optimizes the placement of protection devices to improve the system reliability with DG.

In general DG generation has random, intermittent and fluidity in its output. When DG is in islanding operation, the DG impact on the distribution system reliability depends on the probability that the DG can maintain an island. The greater the probability of island formation, the shorter the desire outage time and obviously the reliability of the system will be higher. This work by considering the random variation nature of the DG output and the system load curve, we allocate the optimal number and locations of switching devices.

In recent years, distributed generation technology has developed greatly. Specifically as IEEE 1547-2003 standard issued, distributed power's islanding operation is much accounted of people for improving the efficiency of electrical power system. Distributed generation is expected to play an imported role in the emerging power systems[10]. Presently DG impact on distribution system is studied on relay protection fault location[11], islanding algorithm[12] and reliability evaluation[13]. Reference[14] optimizes the placement of protection devices to improve reliability of distribution system with DG. But in that paper DG is taken as conventional generation stations. It can not properly reflect DG impact on reliability.

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II. PROBLEM FORMULATION

In DG equipped distribution system, considering the randomness of the DG output, for the load points on DG side, the reliability is not only depends with the location of switches but also influenced by the islanding probability. If the islanding probability of the load point is too low, even though the load point is within the island, it may also be interrupted due to lack of output of DG, the reliability will not improve. So when the number of disconnect switches is increased, outage costs will not necessarily reduce.

A. Objective Function:

Switch Optimization model of DG equipped distribution system can be represented in the objective function as

$$\text{Objective Function} = \min f(I_{cost}, M_{cost}, O_{cost}) \qquad \text{….(1)}$$

Where, I_{cost} is switch investment cost

M_{cost} is operation and maintenance cost

O_{cost} is desire outage cost

B. Constraints:

Subjected to a Constraints of

$$R \geq R_o \text{ and} \qquad \text{….(2)}$$

$$W_{ENS} \leq W_{max} \qquad \text{….(3)}$$

Where R is the system reliability index under a chosen switch configuration, Ro is the reliability level that planning requires

Equation 3 is the expected energy not supplied constraint; W_{max} is the maximum lack of power supply that can be defined as

$$Wmax = 8760(1-R_{ASAI})\, P_L \qquad \text{….(4)}$$

Where P_L is the total load of the system, R_{ASAI} is the reliability on service in total that planning requires.

Investment Costs of the switches can be calculated based on the life of switch and number of switches in the system as

$$I_{cost} = N_K C_S \frac{i(1+i)^P}{(1+i)^P - 1} \qquad \text{….(5)}$$

Where N_k is the number of switches, Cs is the investment cost of each switch, i is the discount rate, P is the service life of the switch

The operation and maintenance cost of the switch is calculated based on the scale-coefficient and is given by

$$Mcost = I_{cost}.\eta \qquad \text{….(6)}$$

Where $\boldsymbol{\eta}$ is the scale coefficient that operation and maintenance costs account for the investment

The customer Interruption cost can be calculated by using weighted average of average electricity price conversion factor and ratio of output value to unit electric energy consumption and is given by

$$O_{cost} = C_C.W_{ENS} \qquad \text{….(7)}$$

$$C_C = \alpha 1.K + \alpha 2.b.d \qquad \text{….(8)}$$

Where W_{ENS} is expected energy not supplied,

C_C is economic loss of power units, α1 is weighting coefficient of average electricity price conversion factor, α2 is ratio of output value unit electric energy consumption, K is the ratio of output value unit electric energy consumption b is the ratio of unit price of electricity blackouts and average electricity price and d is average electricity price.

C. Calculation of Expected Energy not supplied (W_{ENS}):

The reliability of the system for switching configuration is different in which expected outage index W_{ENS} is considered to evaluate the monetary value of reliability. In this work DG impact on the expected outage is considered.

Consider a simple radial network as shown in figure. 1 which is consisting of n feeder sections. The left side of each section is meant to install switches. Let a DG is placed on section k and all other sections are connected with load and all the load branches are equipped with fuses.

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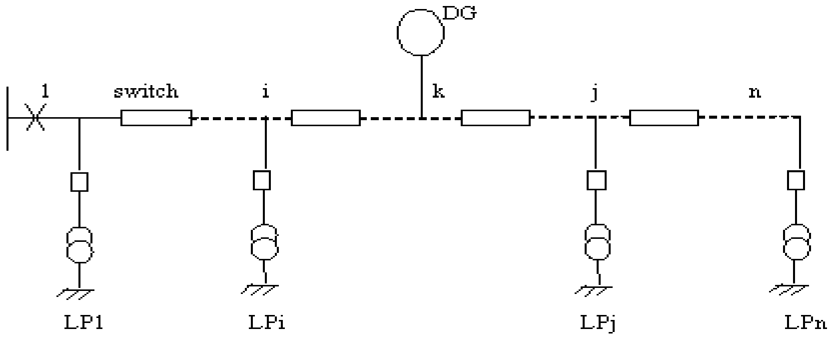

Figure 1. Radial Distribution System with switching devices with DG at bus *k*

For the above system the Expected Energy not supplied of load point 'i' is given as

$$W_{ENS} = \sum_{i=1}^{n} t_{ui} P_{Li} \quad \text{....(9)}$$

Where t_{ui} is the expected outage time and is calculated based on the islanding probability of load point 'i'

$$t_{ui} = IPLP_i . t_{IS,i} + (1 - IPLP_i) t_{C,i} \quad \text{....(10)}$$

Where $t_{IS,i}$ is the outage time of load point 'i' when it is within the island that DG can form

$t_{C,i}$ is the outage time of load point 'i' when it is not within the island

P_{Li} is the total load connected to load point 'i'

When the load point 'i' is included in the island that DG can form its outage time $t_{IS,i}$ can be calculated as the procedure given in [9].

Calculation of Islanding Probability of load point 'i' (IPLPi):

The islanding probability of a load point 'i' is different for load points placed before and beyond the location of DG

$$IPLP_i = IPB_{j,i} . IPH_{j,i}$$

Where IPBj,i is the probability that the load demand is smaller than the amount of DG output

IPHj,i is the probability that DG can supply full of its output and no failure encountered in the time Interval "j"

above two probabilities' can be calculated as

$$IPHj,i = P(PDG \geq Gj) . P(NT) \quad \text{....(11)}$$

$$P(NT) = 1 + (\lambda_{Gj}^{+} - \lambda_{Gj}^{-})T \quad \text{....(12)}$$

Where P(PDG≥Gj) is the probability that the DG output is greater than the island load, P(NT) is the probability that DG does not leave its state to a lower generation state, λ_{Gj}^{+} is the rate of transition to higher generation levels and λ_{Gj}^{-} is the rate of transition to lower generation levels. After calculating the islanding probability of each time intervals by the above procedure and substituted into equation (10) the desire outage time of each load point is calculated for each time interval. If total time interval of 24 hours is divided into n time intervals then total desire outage time of each load point is calculated from the following equation

$$t_{ui} = \frac{1}{n} \sum_{j=1}^{n} t_{ui,j}$$

In the above t_{ui} is the expected outage time of load point *'i'* in the time interval Tj from equation (10)

III. Computational Algorithm of PSO for Switches Optimization in DG equipped Distribution System

In this section, the procedure for solving the switches optimization problem using Particle Swarm Optimization is presented to obtain the optimal number and its location of sectionalizing switches in a DG enhanced distribution system. Here mainly the PSO was utilized to determine the number of sectionalizing switches and its optimal location in a distribution system (in which already a DG is equipped) to minimize the total cost of the system and at the same time to achieve the required degree of reliability.

The procedural steps used in the Switches Optimization Problem using PSO are given below:

A. Representation of individual Particle:

The existence of a switch at all candidate locations is set as a gene, and many genes constitute an individual. Each individual within the population represents a candidate solution for the Switches Optimization problem. For

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example if n candidate locations are there to install switches in a distribution system in which the DG is installed at bus 'k' then the trial location vector will be

Xi = [n, x1, x2, x3………., xn] for all candidate locations of DG

In the above n is the number of sectionalizing switches and x1, x2…….,xn are candidate locations of sectionalizing switches

B. Algorithm:

1. Input the data and initialize the parameters. For each particle, the position and velocity vectors will be randomly initialized with the same size of the problem dimension
2. Calculate the Investment cost, Maintenance Cost, Customer Interruption cost and Reliability of the System under basic system configuration
3. Randomly generate the initial population (array) of particles with random positions and velocities based on dimensions in the solutions space. Set the iteration count k=0
4. Set the Fitness value (total cost that includes investment, operation and Customer Interruption costs) for each particle (pbest) and store the particle with the best fitness value (gbest)
5. For each particle if the reliability of the system is greater than or equal to the set value and $W_{ENS} \leq W_{max.}$ Calculate the total cost of the system
6. Choose the particle associated with the minimum individual best Pbest of all the particles and set the value of this Pbest as the current overall best Gbest
7. Update the velocities and position of the particle using equations

$$V_{id}^{k+1} = \omega.V_{id}^{k} + C1 * rand() * \left(Pbest_{id} - S_{id}^{k}\right) + C2 * rand * \left(Gbest_{id} - S_{id}^{k}\right) \quad ....(11)$$

$$S_{id}^{k+1} = S_{id}^{k} + v_{id}^{k+1},\ i = 1,2 \ldots..n \text{ and } d = 1,2 \ldots \ldots m \quad ....(12)$$

8. If the iteration number reaches the maximum limit go to setp 9. Otherwise set iteration index k=k+1 and go back to step 3
9. Print the optimal solution to the target problem. The best position includes the optimal number and optimal location of switches

III. RESULTS AND ANALYSIS

The proposed optimal allocation of switches in a DG enhanced distribution system by PSO is tested on two test systems viz., an IEEE 8 and IEEE 12 bus systems. The proposed algorithm has been implemented in MATLAB 7.0 version on Pentium IV, 2.4 GHZ Personnel Computer with 4 GB RAM.

At each test system, 100 trails were performed using the proposed method to observe the solution quality, convergence characteristic, and execution time. The parameters used in PSO to get the optimal solution of the problem are given in Table 1

Table 1 PSO parameters and their setting values for solving value Based optimal DG placement problem

PSO Parameter	Population Size	No. of Generations	w_{max}	w_{min}	C_1, C_2
Value	10	100	0.9	0.5	3, 1

The optimal number of switches and their locations, the expected energy not supplied and the total cost of the system with required value of the reliability is presented. It has been observed the solutions that were obtained by using the Particle Swarm Optimization for the Optimal Switching locations problem, the number of switches to be used in the system has reduced and hence total cost of the system has also decreases for the same level of reliability required.

A. Example 1:

An IEEE-8 bus radial distribution system shown in figure 2, consisting of 8 buses or nodes and 7 lines is considered here as test case and the DG is assumed to be located at bus 6. For this network there is a provision to install 6 switches at x1, x2, x3, x4, x5 and x6. The line data and load data of the system has taken from [9]. The optimum number of switches, their location and EENS is given in Table.2.

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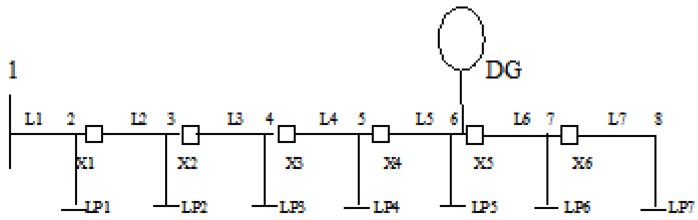

Figure 2. IEEE 8-bus system with DG at bus number 6

Table 2 Test Results for IEEE-8 bus system.

Configuration/method	No. of Switches	Location of Switches	EENS (MWh)	Total Cost(Million Yuan)	Reliability
Existing GA	5	X1, X3, X4, X5, X6	12.1972	17.7520	99.988
Proposed PSO	4	X1, X2,X3, X6	12.44625	15.5243169	99.988

From the results given in Table 2 it is observed that by applying the proposed PSO for switches optimization problem the number of switches is reduced from 5 to 4, and the total cost of the system has reduced from 17.7520 Million Yuan to 15.52432 Million Yuan and the Expected Energy Not Supplied has been slightly increased from 12.1972 to 12.44625 for the same degree o f reliability of 99.988%. The convergence characteristic of PSO for the IEEE-8 bus system is shown in figure 3.

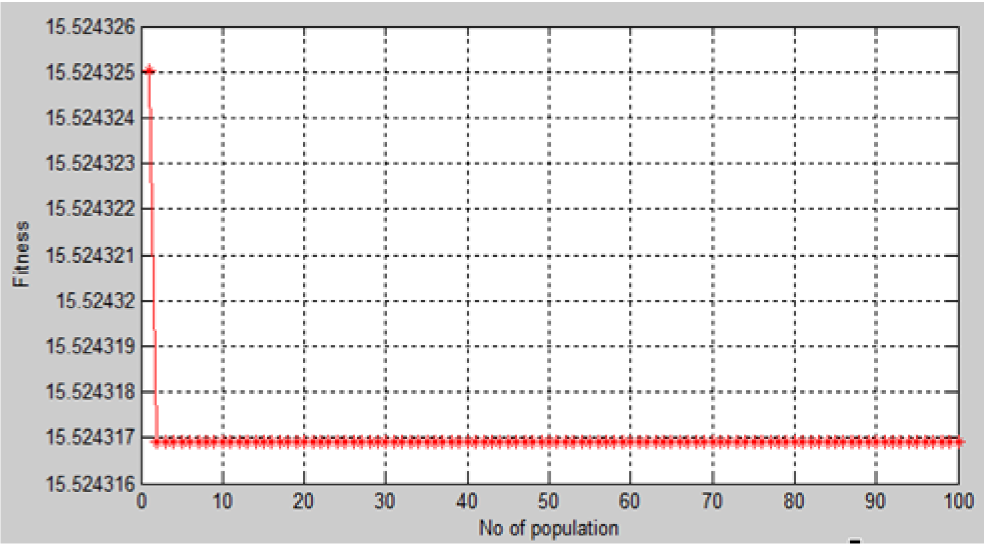

Figure 3 Convergence Characteristics of PSO for IEEE-8 bus system

B. Example 2:

An IEEE-12 bus radial distribution system shown in figure 4, consisting of 12 buses or nodes and 11 lines is considered here as second test case and the DG is assumed to be located at bus 9. For this network there is a provision to install 11 switches at x1 to x11. The convergence characteristics of PSO for the IEEE-12 bus system is shown in figure 5. The optimum number of switches, their location and EENS is given in Table.3.

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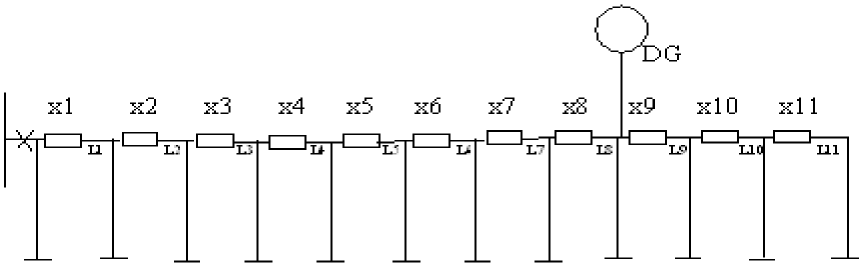

Figure 4 IEEE 12-bus system with DG at bus number 9

Table.3 Results for IEEE-12 bus system.

Configuration/method	No. of Switches	Location of Switches	EENS (MWh)	Total Cost(Million Yuan)	Reliability
Existing GA	10	X1, X2, X3, X4, X5, X6,X7, X8, X10, X11	10.89562	34.25478	99.988
Proposed PSO	8	X1, X2 ,X3, X4, X5, X6, X8, X10	10.99125	31.14495	99.988

From the results given in Table 3 it is observed that by applying the proposed PSO for switches optimization problem the number of switches is reduced from 10 to 8, and the total cost of the system has reduced from 34.25478 Million Yuan to 31.14495 Million Yuan and the Expected Energy Not Supplied has been slightly increased from 10.89562 to 10.99125 for the same degree o f reliability of 99.988%. The convergence characteristic of PSO for the IEEE-12 bus system is shown in figure 5.

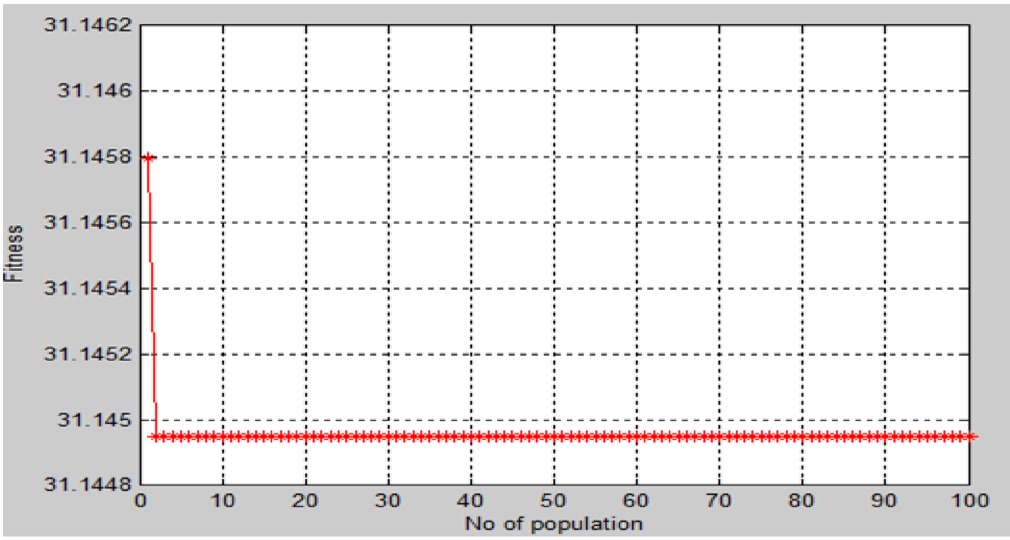

Figure. 5 Convergence Characteristics of PSO for IEEE-12 bus system

IV.CONCLUSIONS

A Particle Swarm Optimization for finding the Optimal number of switches and their location in distribution systems with DGs is proposed and successfully tested on two test systems. From the results obtained it has been observed that by placing the switches at their optimal locations the cost of the system has reduced considerably for the same degree of reliability and the results obtained are compared with the existing other optimization technique GA and it has proved that PSO can gives best results.

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