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Power system reconfiguration in a radial distribution network for reducing losses and to improve voltage profile using modified plant growth simulation algorithm with Distributed Generation (DG)

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ABSTRACT

Network reconfiguration which is constrained non linear optimization problem has been solved for loss minimization, load balancing, etc. for last two decades using various heuristic search evolutionary algorithms like binary particle swarm optimization, neuro-fuzzy techniques, etc. The contribution of this paper lies in considering distributed generation which are smaller power sources like solar photovoltaic cells or wind turbines connected in the customer roof top. This new connection in the radial network has made unidirectional current flow to become bidirectional there by increasing the efficiency but sometimes reducing stability of the system. Modified plant growth simulation algorithm has been applied here successfully to minimize real power loss because it does not require barrier factors or cross over rates because the objectives and constraints are dealt separately. The main advantage of this algorithm is continuous guiding search along with changing objective function because power from distributed generation is continuously varying so this can be applied for real time applications with required modifications. This algorithm here is tested for a standard 33 bus radial distribution system for loss minimization and test results here shows that this algorithm is efficient and suitable for real time applications.

1. Introduction

The per capita Electrical energy consumption of any country is an indication of its growth and the quality of life of the people, it is used widely in buildings for Heating, Ventilation and Air conditioning (HVAC) in countries like USA (for heating) and in Gulf countries (for cooling). The electrical energy is also used in industries for manufacturing and in traction for transporting. Major source for power generation is still coal which is burned to produce power and carbon dioxide which is the main reason for global warming because it obstructs the reflection of sunlight back from Earth. The Thermal power plants are located either near coalmines or near ports and energy travels long distance to consumers with higher voltages in steps to reduce losses. Radial type of distribution is used because it is easy to operate and set protection devices in a unidirectional power flow. A distribution generation (DG) uses distributed generation units (DGU) which generates electrical power from a nearby energy sources on the type of availability like the solar cells or concentrators, wind turbine, etc. which reduces strain on the main transmission line, increases reliability, reduces cost of power generation and saves non-renewable power resources. There is always an uncertainty of loads on different feeders with respect to time so reconfiguration a method to open few sectionalizing switches and closing few tie switches called distribution network reconfiguration (DNR) has been dealt for last two decades with an objective to reduce power loss, to balance loads and to improve voltage profile, etc. by using different algorithms which can give faster convergence for deciding the switches in DNR, to decide the value of power that can be drawn from DGU in DG.

The network reconfiguration which itself is a complex combinatorial problem has been further complexed by addition of DG as it has many advantages. Merlin and Back (1975) first proposed this reconfiguration using branch technique the problem was 'n' line section switches will have 2^n possible system configurations which will consume more calculation time. Shirmohammadi and Hong (1989) suggested a heuristic algorithm based on Merlin and Back (1975) but without simultaneous switching of feeder reconfiguration. Civalnar et al. (1988) suggested a heuristic algorithm where a simple formula for branch exchanged power loss calculation was developed considering only one pair of switching operation at a

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time. Das (2006) used an algorithm based on fuzzy logic. The genetic algorithm was used by Nara et al. (1992) later Zhu refined the genetic algorithm by introducing competition in cross over and mutations (Zhu, 2002). Sathishkumar and Jayabarathi (2012) used chemo taxis on bacterial growth in bacterial foraging optimization algorithm, Imran and Kowsalya (2014) found good fire works in fireworks algorithm, all the above methods used only reconfiguration which is opening or closing the sectionalizing or tie switches in a distribution system without considering DG.

Radial distribution system is generally used as it is easy to design, operate and to place the protective devices. The power flow is unidirectional from generating station to the consumer by stepping up and down the voltages so as to have a minimum power loss in transmission system. The power flow was unidirectional upto the introduction of the distributed generating units (DGU), these units use locally available energy sources to generate power but the power flow has become bidirectional sometimes causing instability in the operation of the system. The renewable energy sources with thyristor controls are widely used to harvest optimal power, innovative use of idle solar power controllers in night for reactive power control are carried out for optimal usage (Varma et al., 2011). The DGU may be sometimes a parked hybrid or electric vehicle connected to grid for supplying power during peak consumption periods and charging the batteries during non-peak periods thereby earning some money for consumer due to difference in energy cost during peak and other periods as demonstrated by university of Delaware in United states of America (USA) in their vehicle to grid project.

The placing and sizing of DG in distribution systems has been studied using Lagrangian based method by Rosehart and Nowicki (2002) later Celli et al. (2005) using genetic algorithm. Wang and Nehir (2004) used analytical methods. Agalgaonkar et al. (2004) used standard market design (SMD) frame work. All the above methods explain about the effects of placing DG in a distribution system without reconfiguration.

The simultaneous reconfiguration and placing DG with proper sizing has been shown by Rao et al. (2013) using harmony search algorithm (HSA) which worked on creating harmony in music principles. Artificial bee colony algorithm based on onlooker and scout bee's was used by Murthy et al. (2012). Nayak (2014) used hyper cube ant colony algorithm based on pheromone scent tracking by ants inside hypercube frame work. All the above methods explain about simultaneous DG placement with reconfiguration advantages over only reconfiguration and only DG options for radial distribution system. Now a days where power networks are deregulated so reconfiguration with DG is meaningful and realistic for real time applications in power industry.

The load as well as the generation varies with time continuously so an evolutionary algorithm which can deal with variations in load and generation is the Plant Growth Simulation Algorithm (PGSA) which is based on the plant growth process the root is the initial point of growth which is similar to initialization, then growth of the trunk and branches occur from nodes which is like searching for optimal values. Modification in evolutionary algorithms is done to make the convergence faster for making them suitable for real time applications. In this paper modification on the PGSA has been carried out and simulations are carried out to demonstrate the advantage of faster convergence of the proposed algorithm (MPGSA) over other algorithms for applications in DNR with and without DG.

The main advantage of MPGSA is that constraints and objective function are dealt separately.

2. Distributed generation (DG)

There are various types of DGU like solar Photovoltaic panels which can supply only real power at unity power factor. Some DGU can supply real as well as reactive power like solar thermal turbo-alternators, biomass or biogas turbo-alternators, wind turbines. In this paper we have considered only 3 numbers of DGU with capacity of 2 M.W working at unity power factor.

There are many benefits of distributed generation like loss reduction, greener environment, improved utility of system, reliability, voltage support, improved power quality, transmission and distribution capacity release and many more (Wu et al., 2010).

3. Problem identification

3.1. Objective function of the problem

The objective function of the problem is formulated so as to get maximum power loss reduction in distributed system which is the sum of power loss reduction due to reconfiguration as well as connection of DGU, which is subject to the voltage, current and power flow constraints as shown below:

$$\begin{aligned}
&\textit{Maximize} f = \max \cdot \left(\Delta P_{Loss}^{R} + \Delta P_{Loss}^{DG}\right) \\
&\textit{Subjected to } V_{\min} \le |V_k| \le V_{\max} \\
&\textit{and } \left|I_{k,k+1}\right| \le \left|I_{k,k+1,\max}\right| \\
&\sum_{k=1}^{n} P_{GK} \le \sum_{k=1}^{n} \left(P_k + P_{Loss,k}\right).
\end{aligned} \tag{3.1}$$

3.2. Power flow equations

Power flows in a distributed system are calculated by using the following set of simplified recursive equations which are used to calculate the real and reactive power flows for finding the power losses

$$\begin{aligned}
P_{k+1} &= P_k - P_{Loss,k} - P_{L,k+1} \\
&= P_k - \frac{R_k}{\left|V_k^2\right|}\left\{P_k^2 + \left(Q_k + Y_k\left|V_k^2\right|^2\right)^2\right\} - P_{Lk+1} \\
Q_{k+1} &= Q_k - Q_{Loss,k} - Q_{L,k+1} \\
&= Q_k - \frac{X_k}{\left|V_k^2\right|}\left\{P_k^2 + \left(Q_k + Y_{k1}\left|V_k^2\right|^2\right)^2\right\} - Y_{k1}\left|V_k^2\right| \\
&\quad - Y_{k2}\left|V_{k+1}^2\right| - Q_{Lk+1}
\end{aligned} \tag{3.2}$$

$$\begin{aligned}
\left|V_{k+1}^2\right| &= \left|V_k^2\right| + \frac{R_k^2 + X_k^2}{|V_k|^2}\left(P_k^2 + Q_k^2\right) - 2\left(R_k P_k + X_k Q_k\right) \\
&= \left|V_k^2\right| + \frac{R_k^2 + X_k^2}{|V_k|^2}\left(P_k^2 + Q_k^2\right) - \left(Q_k + Y_k\left|V_k^2\right|^2\right) \\
&\quad - 2\left(R_k P_k + X_k\left(Q_k + Y_k V_k^2\right)\right).
\end{aligned} \tag{3.3}$$

The calculation of the power loss in the line section connecting buses k and $k+1$ is given by

$$P_{Loss}(k, k+1) = R_k \cdot \left(\frac{P_k^2 + Q_k^2}{\left|V_k^2\right|}\right). \tag{3.4}$$

The power loss of the feeder, $P_{T,Loss}$ may be calculated by adding the losses of all line sections of the feeder, which is

$$P_{T,Loss} = \sum_{k=1}^{N} P_{Loss}(k, k+1). \tag{3.5}$$

3.3. Power loss using network reconfiguration

The use of reconfiguration in a radial distribution network is to identify a best configuration which can give a minimum power loss without violating the operation constraints. The operating constraints here are voltage limits, current capacity of the feeder feeding each and every bus always. The power loss of a line section connecting buses between k and $k+1$ after the reconfiguration of network is calculated as

$$P'_{Loss}(k, k+1) = R_k \cdot \left(\frac{P_k'^2 + Q_k'^2}{\left| V_k'^2 \right|} \right). \quad (3.6)$$

Total power loss in all the feeder sections, $P'_{T,Loss}$, can be found by adding up the losses in all line sections of the network. Which expressed as

$$P'_{T,Loss} = \sum_{k=1}^{N} P'_{Loss}(k, k+1). \quad (3.7)$$

3.4. Loss reduction using network reconfiguration

The difference of power loss before and after reconfiguration (3.5)–(3.7) which is the Net power loss reduction, ΔP^R_{Loss}, is given as

$$\Delta P^R_{Loss} = \sum_{k=1}^{N} P_{T,Loss}(k, k+1) - \sum_{k=1}^{N} P'_{T,Loss}(k, k+1). \quad (3.8)$$

3.5. Power loss reduction using DG installation

By connecting a distribution generation units in a radial distribution system at optimal locations give several advantages like reducing line losses, improving voltage profile, reducing peak demand reduction in overloading of distribution lines, reduction in environmental pollution and distribution systems. The power loss when a DG is installed at an arbitrary location in the network is calculated as

$$P_{DG,Loss} = \frac{R_k}{V_k^2}\left(P_k^2 + Q_k^2\right) + \frac{R_k}{V_k^2}\left(P_G^2 + Q_G^2 - 2P_kP_G - 2Q_kQ_G\right)\left(\frac{G}{L}\right). \quad (3.9)$$

Net power loss reduction, ΔP^{DG}_{Loss}, in the system is the difference in power loss which is before and after connecting a DG unit.

$$\Delta P^{DG}_{Loss} = \frac{R_k}{V_k^2}\left(P_G^2 + Q_G^2 - 2P_kP_G - 2Q_kQ_G\right)\left(\frac{G}{L}\right). \quad (3.10)$$

The positive sign of ΔP^{DG}_{Loss} shows that the system loss are reduced with the installation of DG, whereas the negative sign of ΔP^{DG}_{Loss} indicates that DG causes the system loss to increase.

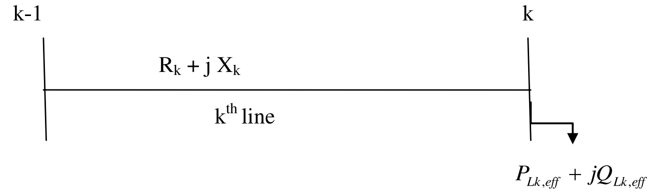
Where

ΔP^R_{Loss}—Total real power loss reduction due to reconfiguration
ΔP^{DG}_{Loss}—Total real power loss reduction due to connection of DGU
$P'_{T,Loss}$—Total power loss in all the feeders
R_k—Resistance in bus k
X_k—Reactance in bus k
$V_{\min}$—Minimum bus voltage
$V_{\max}$—Maximum bus voltage.

4. Implementation of loss sensitivity factor method to find optimal location of DG

Sensitivity analysis is used to calculate sensitivity factors of candidate bus locations for installing DG units in the system. Calculating sensitivity factors of these candidate buses will help in reducing the search space of finding optimal location.

A line section is considered which has an impedance of $R_k + jX_k$ and a load of $P_{Lk,eff} + jQ_{Lk,eff}$ which is connected between $k-1$ and k buses as shown below.



Active power loss in the kth line between $k-1$ and k buses can be calculated by

$$P_{lineloss} = \frac{\left(P^2_{Lk,eff} + Q^2_{Lk,eff}\right) R_k}{V_k^2}. \quad (4.1)$$

Now, the loss sensitivity factor (LSF) can be found using the equation for locating DGU

$$\frac{\partial P_{lineloss}}{\partial P_{Lk,eff}} = \frac{2 * P_{Lk,eff} * R_k}{V_k^2}. \quad (4.2)$$

4.1. Steps involved for the implementation of sensitivity factor method to find optimal location for DG

Step 1: Run the base case load flow.
Step 2: Find the sensitivity factor using Eq. (4.2) and rank the sensitivity in descending order to form priority list.
Step 3: Select the bus with the highest priority and place DG at that bus.
Step 4: Change the size of DG in "small" steps and calculate loss for each by running load flow.
Step 5: Store the size of DG that gives the minimum loss.
Step 6: Compare the loss with the previous solution. If loss is less than previous solution, store this new solution and discard previous solution.
Step 7: Repeat step 4 to step 6 for all buses in the priority list.

5. Modified plant growth simulation algorithm (MPGSA)

The plant growth simulation algorithm (PGSA) is based on the plant growth process, where a plant grows a trunk from its root; some branches will grow from the nodes on the trunk; and then some new branches will grow from the nodes on the branches. Such process is repeated, until a plant is formed. Based on an analogy with the plant growth process, an algorithm can be specified where the system to be optimized first "grows" beginning at the root of a plant and then "grows" branches continually until the optimal solution is found which has been used for DNR by Wang and Cheng (2008) but MPGSA gives result quickly when compared to PGSA for our simultaneous DG and reconfiguration and DNR requirement.

5.1. Probability model of plant growth

A probability model for optimization is established based on the plant growth, in the node (Y) on a plant a function $g(Y)$ has been introduced for describing the environment, If the value of $g(Y)$ is less the environment for growing a new branch is better. The algorithm is explained briefly as follows, the growth of the trunk is from its root B_0. If here are k nodes and $B_{M1}, B_{M2}, \ldots, B_{MK}$ is having better environment than the root B_0 on the trunk M. If the function $g(Y)$ of the nodes $B_{M1}, B_{M2}, \ldots, B_{MK}$ and B_0

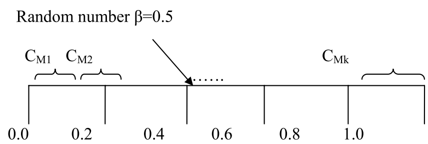


Fig. 5.1. Morphactin concentration state space. (β = Instead of random number it is fixed as 0.5.)

satisfies $g(B_{MI}) < g(B_o)$ then the concentration of chemical morphactin responsible for plant growth $C_{M1}, C_{M2}, \ldots, C_{MK}$ of the nodes $B_{M1}, B_{M2}, \ldots, B_{MK}$ shall be found by using the equation as followed the equation (5.1).

$$\begin{cases} C_{Mi} = \dfrac{g(B_0) - g(B_{Mi})}{\Delta_1} \quad (i = 1, 2, \ldots, k) \\ \Delta_1 = \displaystyle\sum_{i=1}^{k} (g(B_0) - g(B_{Mi})). \end{cases} \tag{5.1}$$

The importance of Eq. (5.1) is that the morphactin a chemical mainly responsible for plant growth, its concentration in any node is based on the relative magnitude of the gap between the environmental functions between the root and the corresponding node in overall nodes, which actually describes the relationship between the concentration of chemical morphactin to environment which is the vital factor for growth of the plant and where branches will grow.

The morphactin concentrations can be derived as $\sum C_{M1} = 1$, $C_{M1}, C_{M2}, \ldots, C_{Mk}$ of the nodes $B_{M1}, B_{M2}, \ldots, B_{Mk}$ form a state space shown in Fig. 5.1. The Selection of a random number β in between number [0, 1], is like throwing a ball in the interval which can drop into any one of $C_{M1}, C_{M2}, \ldots, C_{Mk}$ in Fig. 5.1, then that selected node called preferential node will take priority in the growth process for going a new branch in the next step. If random number β drops into C_{M2}, which means $\sum_{i=1}^{1} C_{Mi} < \beta \leq \sum_{i=1}^{2} C_{Mi}$ then the node B_{M2} will grow a new branch m. If there are q nodes $B_{m1}, B_{m2}, \ldots, B_{mq}$ is the environment of growth than morphactin concentrations are $C_{m1}, C_{m2}, \ldots, C_{mq}$. The morphactin concentrations of the nodes M has to be calculated for all nodes except for nodes where plant growth has already occurred due to which the concentration value becomes zero. The calculation can be carried out by summing up the related terms of the nodes on branch m and excluding the related terms of the node in which plant growth has already occurred. The main contribution of this paper lies in fixing a value for β as 0.5 which is based on number of trial and error combinations values tried between 0 to 1 so there is no random search for value of β which makes the algorithm faster and more suitable for real time application. So this algorithm is called as modified PGSA algorithm.

$$\begin{cases} C_{Mi} = \dfrac{g(B_0) - g(B_{Mi})}{\Delta_1 + \Delta_2} \quad (i = 1, 3, \ldots, k) \\ C_{Mj} = \dfrac{g(B_0) - g(B_{Mj})}{\Delta_1 + \Delta_2} \quad (j = 1, 2, \ldots, q) \\ \Delta_1 = \displaystyle\sum_{i=1 i\neq 2}^{k} (g(B_0) - g(B_{Mi})) \\ \Delta_2 = \displaystyle\sum_{j=1}^{q} (g(B_0) - g(B_{Mi})). \end{cases} \tag{5.2}$$

The morphactin concentrations of all nodes will form a new state space except the one node which has already grown. The branch having highest morphactin concentration will grow in the next step and this repeats till plant is fully grown. The plant growth is modelled as follows the nodes of the plant is like solutions possible. The environment $g(Y)$ function is like objective function.

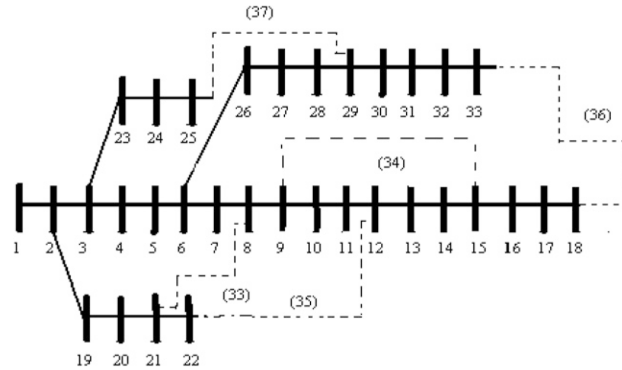


Fig. 6.1. The base configuration of the 33-bus radial distribution system.

The length of trunk and branch is like possible search spaces. The initialising of the solution is the root of the plant. When the plant growth occurs in the branch having highest morphactin concentration called preferential growth is like searching optimal values. The growth node will form the initial value for next search operation. Thus the plant growth also called as plant photo tropism is used in solving optimization problem.

6. Test system description, simulation results and analysis

6.1. Test system description

Fig. 6.1 shows a radial three phase balanced 12.66k.v, 33-bus distribution system.

The base configuration of the system is having a single supply point with 33-buses, 3 laterals, 37 branches, 5 loops or tie switches (switches 33–37) which are kept normally open is shown in dotted lines which is closed only during fault condition to maintain continuity of supply or can be closed to change circuit resistance to reduce losses. The total real power for base configuration is 3715 kW, 2300 kvar with a real power loss of 202.67 kW.

6.2. Assumptions and constraints

(1) The capacity of the system is $S_{base} = 100$ MVA and $V_{base} = 12.66$ kV.
(2) Three small generators which are operated with a power factor of unity (i.e.) injecting only
Real power is assumed for connection with the system in cases 3, 4 and 5 (ex) solar photo voltaic system.
(3) The DG can be connected to any load bus based on loss sensitivity factor.
(4) The capacity of DG sizes is limited upto 2 M.W per bus.
(5) The upper voltage limit is 1.05 p.u and lower voltage limit is 0.9 p.u
(6) Only one DG is allowed in each bus.
(7) The load model is used with a uniform constant power for simulation and voltage of primary bus is 1.0 p.u.

6.3. Simulation results and discussion

The method proposed was implemented by simulation using Mat-lab programs and run using a personal computer with $i-7$ processor having 4 GHz speed and 6 GB RAM the time taken for each case was noted. For validation of the effectiveness of the algorithm proposed it was implemented on a 33-bus radial distribution system for comparing with other techniques found in literature for achieving the function of reduction in real power loss.

Table 6.1
Bus voltage magnitudes of 33-Bus system.

Bus No.	Case-1	Case-2	Case-3	Case-4	Case-5
1	1.0000	1.0000	1.0000	1.0000	1.0000
2	0.9971	0.9975	0.9972	0.9974	0.9974
3	0.9835	0.9869	0.9875	0.9882	0.9886
4	0.9763	0.9824	0.9832	0.9843	0.9851
5	0.9693	0.9778	0.9789	0.9806	0.9817
6	0.9508	0.9666	0.9680	0.9715	0.9784
7	0.9473	0.9659	0.9674	0.9709	0.9788
8	0.9337	0.9653	0.9678	0.9716	0.9793
9	0.9274	0.9624	0.9694	0.9698	0.9774
10	0.9215	0.9618	0.9691	0.9688	0.9763
11	0.9206	0.9684	0.9689	0.9688	0.9764
12	0.9191	0.9683	0.9682	0.9718	0.9867
13	0.9084	0.9659	0.9698	0.9692	0.9742
14	0.9067	0.9649	0.9699	0.9684	0.9734
15	0.9193	0.9574	0.9585	0.9689	0.9744
16	0.9179	0.9367	0.9696	0.9596	0.9737
17	0.9168	0.9546	0.9687	0.9524	0.9730
18	0.9052	0.9536	0.9677	0.9482	0.9756
19	0.9666	0.9958	0.9952	0.9959	0.9957
20	0.9630	0.9802	0.9784	0.9829	0.9812
21	0.9623	0.9769	0.9738	0.9794	0.9772
22	0.9917	0.9734	0.9704	0.9768	0.9738
23	0.9799	0.9833	0.9839	0.9846	0.9851
24	0.9732	0.9767	0.9774	0.9780	0.9784
25	0.9699	0.9754	0.9672	0.9647	0.9751
26	0.9489	0.9647	0.9764	0.9701	0.9729
27	0.9464	0.9622	0.9740	0.9682	0.9725
28	0.9349	0.9510	0.9735	0.9599	0.9733
29	0.9267	0.9429	0.9760	0.9641	0.9783
30	0.9232	0.9395	0.9728	0.9617	0.9763
31	0.9190	0.9354	0.9792	0.9604	0.9724
32	0.9181	0.9345	0.9787	0.9604	0.9759
33	0.9178	0.9343	0.9773	0.9614	0.9760

Case-1: The 33 bus radial distribution is without reconfiguration of feeders and without connection of distributed generators (Base case-scenario-1).
Case-2: The system in case-1 is reconfigured by opening/closing the sectionalizing and tie switches (Reconfiguration-scenario-2).
Case-3: The same as case-1 but with a connection of 3 Nos. of DG units without reconfiguration (no reconfiguration but only DG connection-scenario-3).
Case-4: Reconfiguration first then DG units are connected (two step operation of first reconfiguration of feeders next connecting DG units-scenario-4).
Case-5: Simultaneous operation of reconfiguration and connection of DG units (one step operation or executing reconfiguration and connecting DG units at the same time-scenario-5).

Tables and graphs:

Tables 6.1 and 6.2 show that compared to available evolutionary algorithms the MPGSA give a better solution for voltage improvement as well as reduction in power loss. In the five cases compared for any algorithm the simultaneous reconfiguration with DG allocation gives least power loss and with MPGSA it is 72.23 kW which is for case 5 (scenario-5).

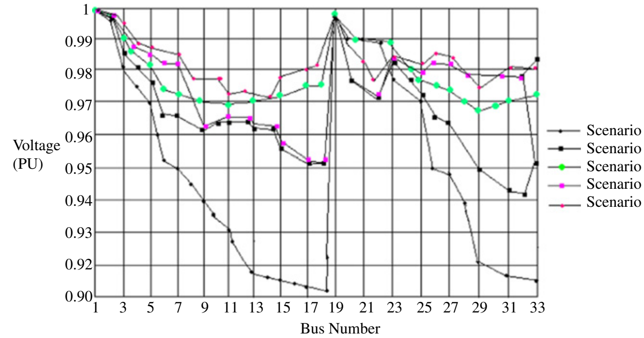


Fig. 6.2. Voltage profile of 33 bus system at five different cases.

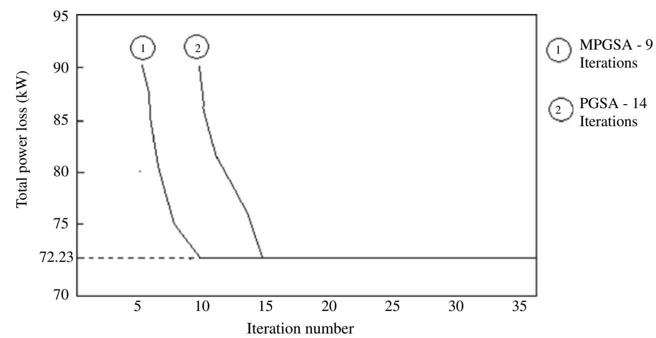


Fig. 6.3. Comparison between PGSA and MPGSA various buses for case-5.

The graph 6.2 shows the voltage profile for all cases but case 5 shows a better voltage profile improvement out of all five cases. In Table 6.3 various methods available in the literature are compared. For ant colony algorithm inside a hypercube framework (HC-ACO) where optimization is done based on pheromone segregation which is a scent deposited by Ants which take different routes but after some time all Ants follow one optimal route because in that route Ants have been able to do more shunting operations from their colony to food available place and so the scent strength is high in that optimal route, in HC-ACO (Nayak, 2014) Manas Ranjan Naick has computed values for all cases except for case 4 (DG connection after reconfiguration), harmony search algorithm (HSA) was used by Rao et al. (2013) all cases values were compared with other algorithms. For MPGSA and PGSA all values are computed values. For case 2 in Fig. 6.3 (reconfiguration) plant growth simulation algorithm (PGSA) was already used by Wang and Cheng (2008) and values are available in literature for comparison and it matches with our computed values but our proposed method using modified plant growth simulation algorithm (MPGSA) which takes a shorter time will be useful in real time applications.

The graph in Fig. 6.3 shows that for case 5 the MPGSA gives a faster result compared to PGSA. For real time applications where computational time is important with least iterations MPGSA is suitable especially in applications where DG units generation and

Table 6.2
Comparison of results using MPGSA (proposed method).

Item	Case-1	Case-2	Case-3	Case-4	Case-5
Real power loss (kW)	202.67	139.5	95.42	92.87	72.23
V_{min} (p.u)	0.9052	0.9343	0.9585	0.9482	0.9724
Switches opened	33, 34, 35, 36, 37	7, 9, 14, 32, 37	33, 34, 35, 36, 37	7, 9, 13, 32, 37	7, 14, 10, 28, 31
Location of DG	–	–	17,18,33	31,32,33	18,32,33
Size of DG (MW)	–	–	0.1058 0.5900 1.0812	0.2469 0.1795 0.6645	0.6311 0.5568 0.5986

Table 6.3
Comparison of Simulation results of 33-Bus system.

Method	Item	Case-2	Case-3	Case-4	Case-5
MPGSA (Proposed method)	DG placement	–	17,18,33	31,32,33	18,32,33
	DG size	–	1.777	1.0909	1.7865
	Open switches	7, 9, 14, 32, 37	33, 34, 35, 36, 37	7, 13, 9, 32, 37	7, 10, 14, 28, 31
	Real power loss (kW)	139.5	95.42	92.87	72.23
	% Real power loss	31.16	52.92	54.17	64.36
	V_{min} (p.u)	0.9343	0.9585	0.9482	0.9724
	No of iterations	6	8	9	9
	Time (s)	0.4	0.6	0.7	0.7
PGSA (Wang and Cheng, 2008) (only for case 2)	DG placement	–	17,18,33	31,32,33	18, 32, 33
	DG size	–	1.777	1.0909	1.7865
	Open switches	7, 9, 14, 32, 37	33, 34, 35, 36, 37	7, 13, 9, 32, 37	7, 10, 14, 28, 31
	Real power loss (kW)	139.5	95.42	92.87	72.23
	% Real power loss	31.16	52.92	54.17	64.36
	V_{min} (p.u)	0.9343	0.9585	0.9482	0.9724
	No of iterations	7	10	12	14
	Time (s)	0.5	1	1.1	0.9
HC-ACO (Nayak, 2014) (only for case 2,3 and 5)	DG placement	–	18,17,32		33,32,31
	DG size	–	1.7402		1.0994
	Open switches	7, 14, 9, 32, 37	33, 34, 35, 36, 37		7, 14, 9, 17, 37
	Real power loss (kW)	136.30	96.34		93.45
	% Real power loss	32.74	52.46		53.89
	V_{min} (p.u)	0.938	0.9504		0.9556
HSA (Rao et al., 2013)	DG placement	–	18,17,33	32,31,30	32,31,33
	DG size	–	1.7256	1.0909	1.6684
	Open switches	7, 14, 9, 32, 37	33, 34, 35, 36, 37	7, 14, 9, 32, 37	7, 14, 10, 32, 28
	Real power loss (kW)	138.06	96.76	97.13	73.05
	% Real power loss	31.88	52.26	52.07	63.95
	V_{min} (p.u)	0.9310	0.9670	0.9479	0.9700
GA (Rao et al., 2013)	DG placement	–	–	–	
	DG size	–	1.6044	1.448	1.9633
	Open switches	33, 9, 34, 28, 36	33, 34, 35, 36, 37	33, 9, 34, 28, 36	7, 10, 28, 32, 34
	Real power loss (kW)	141.60	100.1	98.36	75.13
	% Real power loss	30.15	50.60	51.46	62.92
	V_{min} (p.u)	0.9310	0.9605	0.9506	0.9766
RGA (Rao et al., 2013)	DG placement	–	–	–	
	DG size	–	1.777	1.100	1.774
	Open switches	7, 14, 9, 32, 37	33, 34, 35, 36, 37	7, 14, 9, 32, 37	7, 9, 12, 32, 27
	Real power loss (kW)	139.46	97.60	98.23	74.32
	% Real power loss	31.20	51.84	51.53	63.33
	V_{min} (p.u)	0.93515	0.9687	0.9479	0.9691

loads keep changing time to time. The flow chart 7.1 shows the method to implement the MPGSA algorithm. Table 7.1(a) gives the data for 33 bus system.

7. Implementation of modified PGSA to find the optimal power loss with DG

Step 1: According to the priority list formed using sensitivity factor, place DG of different sizes at the chosen bus.
Step 2: Calculate real power losses in the system using modified plant growth simulation algorithm (MPGSA) method for the selected values of DG.
Step 3: Compare the real power losses for every size of DGUs.
Step 4: Save the DG size corresponding to minimum real power loss.
Step 5: Continue Steps 2–4 for 50 iterations with 5 different sizes of DGU in every iterations (setting $N_{max} = 50$).
Step 6: Choose the best size among 50 values with minimum real power loss and print the corresponding DGU.

8. Conclusion

In this paper simultaneous reconfiguration and DG allocation for a 33 bus radial distribution system is proposed with a MPGSA algorithm. The results proves that the simultaneous reconfiguration with DG allocation give better results out of all other combinations. For this application of simultaneous reconfiguration and DG allocation the modified PGSA gives faster convergence compared to PGSA as seen from convergence graph in Fig. 6.3 which shows 72.23 kW as real power loss.

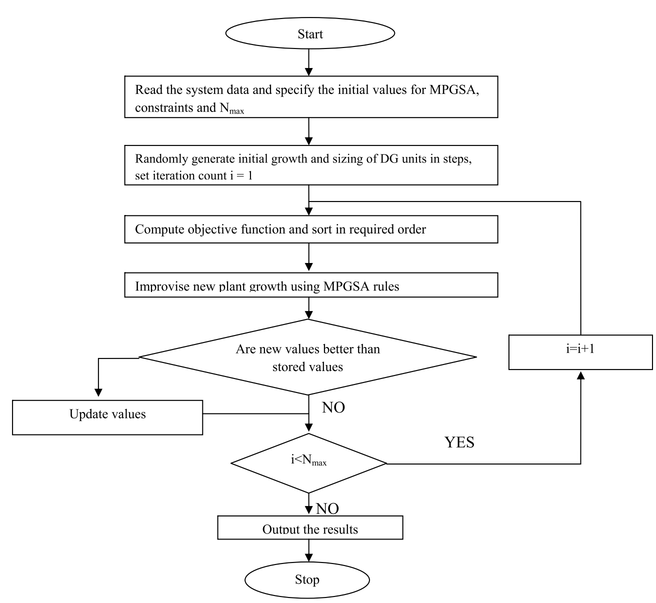


Fig. 7.1. Flowchart for modified plant growth simulation algorithm (MPGSA).

Table 7.1(a)
Test data for 33 bus test system.

S. No.	From bus i	Tobus $i+1$	$Ri, i+1$	$Xi, i+1$	P (kW)	Q (kvar)
1	1	2	0.0922	0.0477	100	60
2	2	3	0.493	0.2511	90	40
3	3	4	0.366	0.1864	120	80
4	4	5	0.3811	0.1941	60	30
5	5	6	0.819	0.707	60	20
6	6	7	0.1872	0.6188	200	100
7	7	8	1.7114	1.2351	200	100
8	8	9	1.03	0.74	60	20
9	9	10	1.04	0.74	60	20
10	10	11	0.1966	0.065	45	30
11	11	12	0.3744	0.1238	60	35
12	12	13	1.468	1.155	60	35
13	13	14	0.5416	0.7129	120	80
14	14	15	0.591	0.526	60	10
15	15	16	0.7463	0.545	60	20
16	16	17	1.289	1.721	60	20
17	17	18	0.732	0.574	90	40
18	2	19	0.164	0.1565	90	40
19	19	20	1.5042	1.3554	90	40
20	20	21	0.4095	0.4784	90	40
21	21	22	0.7089	0.9373	90	40
22	3	23	0.4512	0.3083	90	50
23	23	24	0.898	0.7091	420	200
24	24	25	0.896	0.7011	420	200
25	6	26	0.203	0.1034	60	25
26	26	27	0.2842	0.1447	60	25
27	27	28	1.059	0.9337	60	20
28	28	29	0.8042	0.7006	120	70
29	29	30	0.5075	0.2585	200	600
30	30	31	0.9744	0.963	150	70
31	31	32	0.3105	0.3619	210	100
32	32	33	0.341	0.5302	60	40
33	21	8	2.0000	2.0000	–	–
34	9	14	2.0000	2.0000	–	–
35	12	22	2.0000	2.0000	–	–
36	18	33	0.5000	0.5000	–	–
37	25	29	0.50000	0.50000	–	–

The results obtained with other evolutionary algorithms like genetic algorithm (GA), refined genetic algorithm (RGA), ant colony optimization algorithm in hypercube framework (HC-ACO), harmony search algorithm (HSA) are compared with the proposed method and the results show that performance of proposed MPGSA is better and is more suitable for practical applications because the objectives and constraints are dealt separately. The authors are in contact with local power distribution company to implement this algorithm in a real distribution system.

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