

Power Loss Minimization in Radial Distribution Networks Using Reconfiguration and DGs

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Abstract

A novel approach is proposed in this paper to achieve the objective of real power loss minimization and voltage profile enhancement. Network reconfiguration and allocation of various DG units are used to meet the objective. Selective particle swarm Optimization (SPSO) and novel analytical techniques are used to solve the problem of network reconfiguration and allocation of DG units simultaneously. A new constant, Power Voltage Sensitivity Constant (PVSC), has been proposed to solve the allocation problem. The formulated mathematical expression (PVSC) determines site and size of DG units. The level of DG penetration is considered in a range of 0–50% of total system load. A novel index is also proposed which incorporates level of DG penetration and % reduction in real power losses. Standard 69 bus system is used to validate the results obtained by proposed hybrid approaches. To show the efficacy and strength of the proposed hybrid approach, it has been compared with various techniques.

Keywords: Radial Distribution System, Network reconfiguration, Distributed Generation, Capacitor

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1. Introduction

As per Indian scenario significant part of the system losses (around 21%) are distribution losses. Therefore, myriads of efforts have been made for the reduction of losses in distribution networks like as: network reconfiguration, optimal allocation of distributed generation. Network reconfiguration is done by modifying the feeder topologies by proper handling of operation of sectionalizing and tie-switches and taking care of their open/close status at the time of emergency or normal operation. Modification of feeder topologies is an adequate and effective technique to minimize losses, enhance voltage stability and better load balance. A great deal of research & analysis has already been performed to solve the problem of reconfiguration of existing network. Merlin et. al [1] were first to evolve a scheme to minimize feeder loss using distribution network reconfiguration. They solved the problem using discrete branch and bound technique by formulating it as mixed integer non-linear optimization problem. Civanlar et. al [2] estimated the loss reduction by deriving a simple formula and performing switching operation between two feeders and adopted a branch exchange procedure for this. Lin Whei-Min et. al [3] suggested a modern technique to resolve the problem of reconfiguration of distribution feeder through which an effective network configuration could be developed to minimize losses. Shirmohammadi et. al [4] introduced a technique depends on an optimal flow pattern in which switches were made open one after another starting from a complete meshed system. Goswami et. al [5] presented an algorithm based on single loop optimal flow pattern, developed by changing the normally open states of switches, and making a normally close switch open having least value of current. Y. H. Song, et-al [6] derived a technique based on fuzzy controlled Evolutionary Programming for reconfiguration of feeders. A chain-table along with combined depth-first and breadth-first search schemes were adopted to further expedite the process of optimization. M.W. Siti et. al [7] demonstrated a mechanism for the reconfiguration of feeders of low-voltage and medium-voltage levels distribution network. They introduced a heuristic method for the loss minimization problem by phase balancing. The proposed technique can work at both voltage level simultaneously. K.R. Niazi et. al [8] educed a method that works with optimality conditions obtained from loss minimization configuration. The concept was to open the line section having minimum complex power. Chung-Fu Chang [9]

solved the problem of optimal capacitor allocation and feeder reconfiguration by employing Ant Colony Search algorithm. B. Amanulla et. al. [10] reformed the configuration of switches in the network using particle swarm optimization (BPSO) technique. In DG technology, the small generating units (1kW to 50 MW) are connected near the load side. The DG units may be renewable and non renewable energy sources. The renewable based distributed generation units have become a leading choice due to limitation of fossils fuels. Distributed generation (DG) devices can be deliberately sited to reduce real or reactive power losses, to enhance bus voltage profile, to improve load factors, reliability and efficiency in power systems. To utilize the benefits of DG technology, it is required to find out the exact position and size of Distributed Generation units in distribution systems; otherwise, it causes some unfavorable effects like increased real power losses, poor voltage profile and increased cost etc. Various researchers applied different approaches to solve the DG allocation problem. DG units was determined by particle swarm optimization (PSO) in [11]. Acharya et al [12] solve DG placement problem by analytical method in radial distribution system. Gozel and Hocaoglu [13] also used analytical approach to solve the problem in a faster way. In [14,15] author suggested GA based method to find the optimal position and size of DG units. Kean and Omalley [16] proposed constrained linear programming (LP) approach to solve the DG allocation problem in Irish system. Zhang X et.al [17] proposed a novel approach for optimal allocation of CHP based DG units for integrated energy model. In [18], Injeti and Kumar formulated an objective function to reduce real power losses and to improve voltage stability. The location of DG units is determined by loss sensitivity factor (LSF) and size of DG units is calculated by simulated annealing technique. S. Nawaz et al [19] presented sensitivity analysis technique and tested it on 33 bus system at different loading condition. Rajkumar Viral et.al [20] proposed an analytical approach to determine the best position and size of DG units in balanced distribution system to reduce real power. The various types of DG units are [21]:

- a. Type-I: Generate active power
- b. Type-II: Generate reactive power
- c. Type-III: Generate both active and reactive power
- d. Type-IV: Generate active power but consume reactive power

In this paper, network reconfiguration and allocation of various DG units are presented for active power loss minimization and voltage profile enhancement. Two different techniques are used to solve the problem. Selective particle swarm Optimization (SPSO) technique is used to evaluate the optimal tie switches and novel analytical method is proposed to determine size and site of various DG units. A new mathematical expression is formulated that is called PVSC (Power Voltage Sensitivity Constant). The constant evaluate size and location of any type of DGs at the same time. Type-I and II are used to solve the problem. Up to 50% penetration level of DG units is also taken into consideration, so that less size of DG units produce maximum loss reduction. A new Index DGPI is also introduced here. This index gives the value of percentage loss reduction for unit DG size. Standard 69 bus distribution system is considered as test system. The new tie switches are first evaluated then location & size of different types of DG units are determined for test system. The obtain results of test system showed that proposed approach gives better results than other approached mentioned in this paper.

2. Problem Formulation

This work presents a method to resolve feeder reconfiguration problem with DG & capacitor allocation in radial distribution system to minimize line losses and to get better bus voltages. The objective function of the problem is formulated in this section.

In Figure 1, single line diagram of the feeder is shown. The equations mentioned below are obtained from the single line diagram of the feeder.

The impedance of line section between bus i and $i+1$ is given as:

$$Z_{i,i+1} = R_{i,i+1} + j X_{i,i+1} \quad (1)$$

and load demand at bus i is:

$$S_{Li} = P_{Li} + j Q_{Li} \quad (2)$$

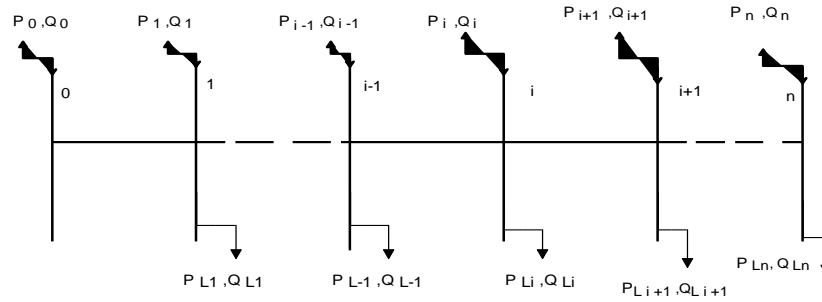


Figure 1. Single line diagram of main feeder

P_{i+1}, Q_{i+1} are the real and reactive power flow at the receiving end of branch $i+1$. The recursive equations for receiving end voltage are given by [22]:

$$P_{i+1} = P_i - P_{Li+1} - R_{i,i+1} \frac{(P_i^2 + Q_i^2)}{|V_i|^2} \tag{3}$$

$$Q_{i+1} = Q_i - Q_{Li+1} - X_{i,i+1} \frac{(P_i^2 + Q_i^2)}{|V_i|^2} \tag{4}$$

$$|V_{i+1}|^2 = |V_i|^2 - 2(R_{i,i+1} \cdot P_i + X_{i,i+1} \cdot Q_i) + (R_{i,i+1}^2 + X_{i,i+1}^2) \cdot \frac{(P_i^2 + Q_i^2)}{|V_i|^2} \tag{5}$$

Equations (3), (4) and (5) are known as distribution power flow equations. This procedure is known as forward update.

Similarly, a backward update is expressed as:

$$P_{i-1} = P_i + P_{Li} + R_{i,i+1} \frac{(P_i^2 + Q_i^2)}{|V_i|^2} \tag{6}$$

$$Q_{i-1} = Q_i + Q_{Li} + X_{i,i+1} \frac{(P_i^2 + Q_i^2)}{|V_i|^2} \tag{7}$$

$$|V_{i-1}|^2 = |V_i|^2 + 2(R_{i-1,i} \cdot P_{i1} + X_{i-1,i} \cdot Q_{i1}) + (R_{i-1,i}^2 + X_{i-1,i}^2) \cdot \frac{(P_{i1}^2 + Q_{i1}^2)}{|V_i|^2} \tag{8}$$

Where, $P_{i1} = P_i + P_{Li}$ and $Q_{i1} = Q_i + Q_{Li}$

Now, the real power loss of the line segment connecting among node i and $i+1$ is computed as:

$$WL(i,i+1) = R_{i,i+1} \frac{(P_{i1}^2 + Q_{i1}^2)}{|V_i|^2} \tag{9}$$

Total network power loss is determined by adding the losses of all line sections of feeder.

Total feeder power loss (WT Loss) =

$$\sum_{i=0}^{n-1} W_{L(i,i+1)} \tag{10}$$

2.1 Real Power Loss Minimization Using Feeder Reconfiguration

In a distribution system, the feeder reconfiguration problem is to determine optimal radial structure of the system which gives lowest amount of power loss whereas fulfilling the operating constraints under a certain load pattern. The operating constraints are voltage drop with in limit, current capability of the feeder should not exceed and radial configuration of the system should be maintained. The mathematical model of the feeder reconfiguration is presented as:

$$\text{Minimize } f_1 = \min (\text{WT Loss}) \quad (11)$$

$$\text{Subjected to } \begin{aligned} V_{\min} &\leq V_i \leq V_{\max} \\ |I_i| &\leq I_{\max} \end{aligned}$$

System should be radial.

2.2 Real Power Loss Minimization using Allocation of DGs

Mathematically, the DG placement problem can be formulated as a constrained nonlinear optimization model [23]:

$$\text{Minimize } f_2 = \text{P Loss} \quad (12)$$

$$\text{Subjected to: } \begin{aligned} g_1(x,z) &= 0 \\ g_2(x,z) &\leq 0 \end{aligned}$$

$g_1(x,z)$ and $g_2(x,z)$ are the set of equality and inequality constraints, respectively. Where, x is the state variables and z is the control variables. The control variables are power outputs of DG (P and Q). The state variables are bus voltage and line power flows.

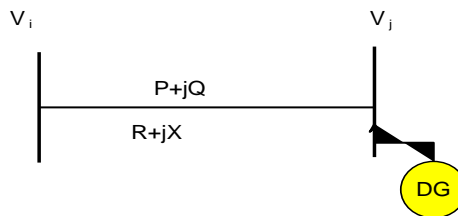


Figure 2. DG connected radial distribution network of i-j bus

The distribution network power loss is calculated by using:

$$P_{\text{Loss}} = \sum_{i=1}^n \sum_{j=1}^n R \frac{|V_i|^2 + |V_j|^2 - 2|V_i||V_j| \cos \delta_{ij}}{Z^2} \quad (13)$$

(a) Equality Constraints:

The arithmetical summation of all incoming and outgoing powers together with power losses for distribution system and power generated by DG units should be equal to zero.

(b) Inequality Constraints:

(i) The injected power by each DG units is restricted by its maximum and minimum limits as:

$$\begin{aligned} P_{DGj}^{\min} &\leq P_{DGj} \leq P_{DGj}^{\max} \\ Q_{DGj}^{\min} &\leq Q_{DGj} \leq Q_{DGj}^{\max} \end{aligned}$$

(ii) Bus voltage limits $0.95 \text{ pu} \leq V_i \leq 1.0 \text{ pu}$

(iii) The feeder should not go beyond the thermal limit of the line.

Where,

R : Line resistance between bus i and j;

X : Line reactance between bus i and j

Z : Line impedance;

V_i : Magnitude of voltage at bus i ;

V_j : Magnitude of voltage at bus j ;

δ_i : Angle of voltage at bus i ;

δ_j : Angle of voltage at bus j ;

P and Q: Active and reactive power flow from bus i to j;

2.3 Objective Function

The objective function of the problem is to minimize the line power loss of distribution system by satisfying operating constraints.

$$\text{Minimize } f = \min. (f_1 + f_2) \quad (14)$$

Subjected to:

- (i) $V_{\min} \leq V_i \leq V_{\max}$
- (ii) $|I_i| \leq I_{i,\max}$
- (iii) The arithmetical sum of all incoming and outgoing powers together with line losses for distribution network and power generated by DG units should be equal to zero.
- (iv) $P_{DG_i}^{\min} \leq P_{DG_i} \leq P_{DG_i}^{\max}$
 $Q_{DG_i}^{\min} \leq Q_{DG_i} \leq Q_{DG_i}^{\max}$
- (v) System should be radial.
- (vi) DG penetration level should not exceed 50% of total system load.
- (vii) The total reactive power generated should not exceed the reactive power load of the system.

3. Proposed Hybrid Approach

Two techniques are used to solve the problem i.e. SPSO, analytical technique .

3.1 Selective Particle Swarm Optimization Technique (SPSO)

Selective particle swarm Optimization is recently proposed artificial intelligence based approach for solving complex non linear combinatorial optimization problems. In [24] Gopinich proposed selective particle swarm optimization technique for the network reconfiguration problem which is modification to the Binary Particle Swarm Optimization to search in selective space.

Steps involved in Solving Distribution Network Reconfiguration Problem using SPSO: The Distribution network reconfiguration problem by Selective Particle Swarm Optimization is bifurcated in three steps:

- (i) Specifying the number of dimensions; Radial distribution network is designed as multiloop circuits but it is always operated in radial structure like an open loop to reassure the network in form of a tree. To identify the number of dimensions for network reconfiguration problem, all tie switches (normally open switches) must be closed. It will confer the number of loops. The number of loops equals the number of dimension in SPSO.
- (ii) Finding the search space for each loop or dimension; By closing all the tie switches, it will confer the number of loops. The branches non belonging to any of the loop will not be considered in the search space for any dimension. The search space for each dimension will be the branches belonging to the particular loop at this dimension. There may be possibility when some branches are common to two or more loop, than in that case the common branches will appear for one dimension only and this could be done randomly.
- (iii) To obtain global optimal solution from the search space using Selective Particle Swarm Optimization; After the number of dimensions specified , and finding the search space for each dimension, the optimal solution from the search space for each dimension would be identified by Selective Particle Swarm Optimization. [19]

3.2 Analytical Approach

An analytical approach has been proposed for allocation of various DG units. The Power Voltage Sensitivity Constant (PVSC) is proposed to determine the size and location of

DG units. This constant takes active power loss and voltage limits of individual buses in account and suggest the optimal location of the DG.

$$PVSC = \frac{V_{\max}}{V_{\min}} + \frac{P_{dgloss}}{P_{realloss}} \quad (15)$$

Where,

$P_{realloss}$: base case real power loss.

P_{dgloss} : active power loss after DG placement at ith bus.

V_{\max} is maximum bus voltage in pu after DG placement at ith bus.

V_{\min} is minimum bus voltage in pu after DG placement at ith bus.

For optimal placement of DG units the value of PVSC should be minimum.

Computational process for proposed analytical technique is explained:

Step 1: Run the base case load flow program and calculate real power loss $P_{realloss}$.

Step 2: Start with 5% DG penetration level and run load flow program.

Step 3: Calculate the real power loss of the system and "PVSC" values for each bus using eq. 15.

Step 4: Now vary the penetration of DG in minute step and compute real power loss by running load flow program.

Step 5: Store the size of DGs which gives least amount of real power loss.

Step 6: The bus, which has least "PVSC" value, will be the optimal location of DG unit.

Step 7: Repeat Steps 4 to 6 to find more location of DGs.

3.3 DG penetration Index (DGPI)

Most of the researchers did not consider DG penetration in their research. In many practical cases along with economic constraints the size of DG units are not pragmatic. In their paper the size of DG unit is very high. But the high size of DG unit will lead to high cost of the system.

In this paper a novel index, called DG penetration index, is proposed. The DGPI gives the % power loss reduction for unit size of DG.

$$DGPI = \frac{(\% \text{ power loss reduction})}{\text{Total DG size}} \quad (16)$$

Hence, for improvement of network performance the value of the DGPI should be maximum

4. Test Results

The IEEE 69 bus system has 12.66 kV and 100 MVA base values. It consists of 68 sectionalizing switches (normally closed) and 5 tie switches (normally open) [25]. The open switches are 69, 70, 71, 72 and 73 respectively. The total system load is 3.802 MW and 2.694 MVar. The base case real power loss of 69 bus system is 224.98 kW at nominal load and minimum bus voltage is 0.9092 pu. Three different loading conditions light (50% load), nominal (100% load) and heavy (160% load) load levels are used here.

Following cases are considered here:

Case I : Only Feeder reconfiguration (FR)

Case II : Only (type-I) DGs placement

Case III : Only (type-II) capacitors placement

Case IV : Only DGs placement after feeder reconfiguration

Case V : Only capacitors placement after feeder reconfiguration

Case VI : Simultaneous placement of DGs and capacitors after feeder reconfiguration

The summarized results of 69 bus system are shown in Table 1. The parameters of SPSO technique are Number of Particles 25, W_{\max} (initial weight) 0.8, W_{\min} (final weight) 0.5, Maximum no. of iterations 100, Acceleration constants 2. The first three buses are selected for DG allocation. The results of 69 bus system are compared with results of improved GA, improved PSO, improved CSA algorithms.

Table 1. Performance analysis of proposed method on 69-bus system at different load levels

Case	Items	Load Level			
		Light (50%)	Nominal (100%)	Heavy (160%)	
Base Case	Tie switches	69,70,71,72,73	69,70,71,72,73	69,70,71,72,73	
	Power Loss (kW)	51.61	224.980	652.47	
	Minimum Bus Voltage (pu)	0.956	0.9092	0.845	
(I) After Feeder Reconfiguration (FR)	Tie switches	14,58,61,69,70	14,58,61,69,70	14,58,61,69,70	
	Power Loss (kW)	23.60	98.595	264.6	
	Minimum Bus Voltage (pu)	0.9753	0.9497	0.917	
	% Loss reduction	54.24%	56.17%	59.44%	
(II) Only DGs placement	DG size in kW (Location)	320 (61) 280 (64)	320 (21) 950 (61) 550 (64)	380(21) 1570 (61) 750 (64)	
	Total DG size (kW)	600	1820	2700	
	Power Loss (kW)	24.86	76.87	209.5	
	Minimum Bus Voltage (pu)	0.979	0.970	0.948	
	% Loss reduction	53.36	65.83	67.42	
	(III) Only Capacitors Placement	Capacitor Size in kVAR and location	410 (61) 80 (21) 170 (64)	750 (61) 270 (21) 400 (64)	1500 (61) 240 (21) 600 (64)
		Total kVAR	660	1420	2340
Power Loss (kW)		36	147	408	
Min. bus voltage		0.966	0.931	0.887	
% Loss reduction		32.4	34.66	36.54	
(IV) DG placement after FR		DG size (Location)	600 (61) 180 (64) 140 (27)	1360 (61) 320 (64) 220 (27)	1700 (61) 600 (64)
	Total DG size (kW)	920	1900	2300	
	Power Loss (kW)	9.8	38	110	
	Minimum Bus Voltage (pu)	0.99	0.98	0.956	
	% Loss reduction	81%	83.1%	83.1%	
(V) Capacitor placement after FR	Capacitor size (Location)	200 (50) 580 (61) 120 (64)	350 (50) 1050 (61) 390 (64)	410 (50) 1020 (61) 460 (64)	
	Total Capacitor size (kVAR)	830	1790	1890	
	Power Loss (kW)	16.7	66.74	184.6	
	Minimum Bus Voltage (pu)	0.985	0.97	0.938	
	% Loss reduction	67.7%	70.3%	71.7%	
	(VI) Simultaneous Placement of DG and Capacitor after FR	Total DG size (kW)	920	1900	2300
Total Capacitor size (kVAR)		830	1790	1890	
Power Loss (kW)		2.7	9.63	41	
Minimum Bus Voltage (pu)		0.995	0.99	0.977	
% Loss reduction		94.7%	95.72%	93.7%	

The comparison of results at nominal load level is shown in Table 2. In proposed method the value of DGPI is 0.050 which is higher than other techniques. The minimum bus voltage is same in all techniques. The size of DG and capacitor is less in the proposed method as compared to others

Table 2. Comparison of results for 69 bus system at nominal load

Technique	Tie Switches	Total Capacitor size in kVAR	Total DG size in kW	% loss reduction	Min. bus Voltage (pu)	DGPI
IGA [26]	9, 12, 45, 56, 70	1800	2409	98.04	0.99	0.040
IPSO [26]	8, 12, 54, 64, 70	1800	2550	98.17	0.99	0.038
ICSO [26]	8, 69, 71, 70,73	1800	2689	98.07	0.99	0.036
Proposed	14,58,61,69,70	1790	1900	95.72	0.99	0.050

The comparison of results at light load level is shown in Table 3. In the proposed method the value of DGPI is 0.11 which is higher than other techniques. The minimum bus voltage is same in all techniques. The size of DG and capacitor is less in the proposed method as compared to others.

Table 3. Comparison of results (case IV) for 69 bus system at light load level

Technique	Tie Switch	Total Capacitor size in kVAR	Total DG size in kW	% loss reduction	Min. bus Voltage (pu)	DGPI
IGA [26]	9-13-54-64-71	900	1237	97.9	0.99	0.08
IPSO [26]	8-12-13-16-57	900	1274	98.03	0.99	0.077
ICSO [26]	8-12-55-73-70	900	1270	97.8	0.99	0.071
Proposed	14-58-61-69-70	920	830	94.7	0.99	0.11

The comparison of results at heavy load level is Table 4. In proposed method the value of DGPI is 0.040 which is higher than other techniques. The minimum bus voltage and % loss reduction is higher than any other method. The size of DG and capacitor is less in the proposed method as compared to others.

Table 4. Comparison of results (case IV) for 69 bus system at heavy load level

Technique	Tie Switch	Total Capacitor size in kVAR	Total DG size in kW	% loss reduction	Min. bus Voltage (pu)	DGPI
IGA [26]	12-16-58-64-69	1800	2582	93.26	0.958	0.036
IPSO [26]	14-58-64-69-70	1800	2710	93.27	0.958	0.034
ICSO [26]	12-17-58-64-69	1800	2689	93.24	0.958	0.034
Proposed	14,58,61,69,70	1890	2300	93.7	0.977	0.040

The comparison of bus voltages at light, nominal and heavy loading conditions are shown in Figure 3, 4, and 5 respectively. 5 different cases are considered for voltage profile comparisons i.e. base case, only network reconfiguration, DG allocation after reconfiguration, Capacitor allocation after reconfiguration, simultaneous placement of DG & capacitor after reconfiguration.

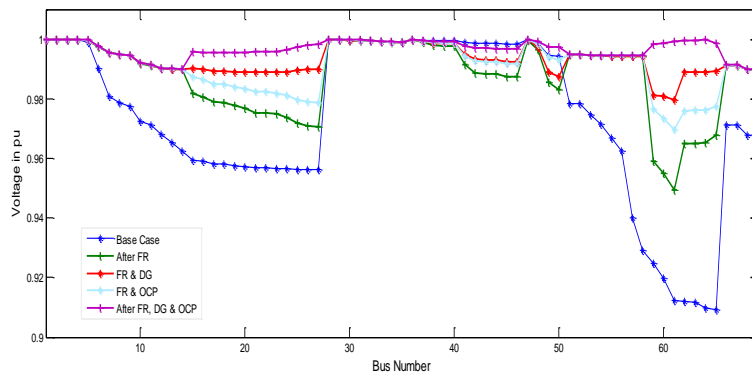


Figure 3. Comparison of bus voltage at nominal load for 69 bus system

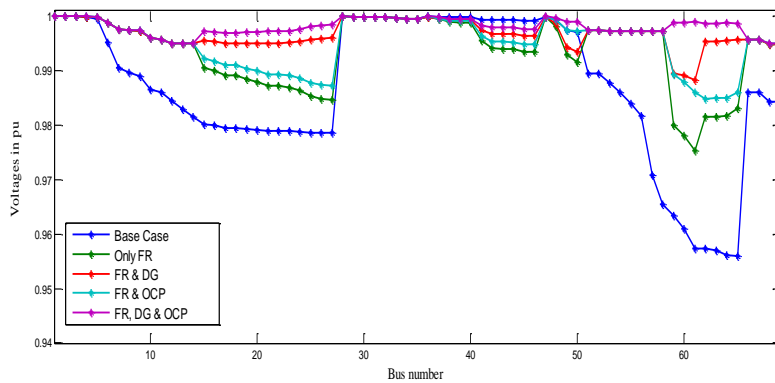


Figure 4. Comparison of bus voltage at light load for 69 bus system

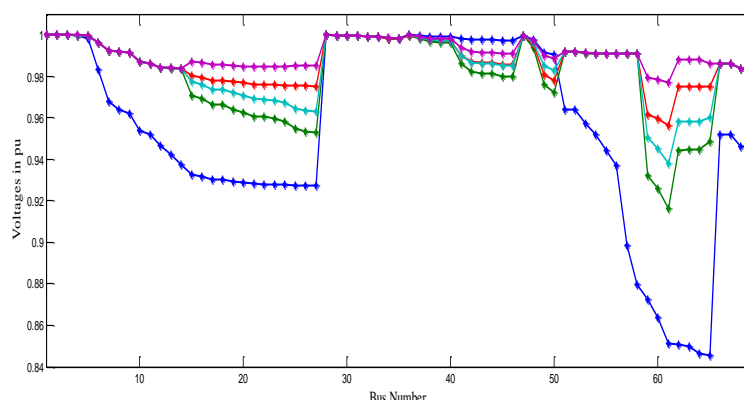


Figure 5. Comparison of bus voltage at heavy load for 69 bus system

5. Conclusion

In this paper new approach has been presented to minimize distribution power losses. Network reconfiguration problem has been solved by SPSO algorithm and allocation of DG units problem is solved by novel analytical technique. DG and capacitor units are used for allocation. A new mathematical expression, Power Voltage Sensitivity Constant (PVSC), has been formulated to determine size & site of DG units. The level of DG penetration is also considered in a range of 0–50% of total system load. A novel index, DGPI, is also anticipated which incorporates level of DG penetration and % reduction in real power losses. The above mentioned method is tested on standard 69 bus system. Six different cases and three different load level are presented here. The results are compared with latest proposed algorithm and found better in terms of DGPI value. In all loading condition, the value of DGPI is high as compared to other ones. The high value of DGPI means, the proposed approach gives maximum power loss reduction in a lesser amount of DG size. The voltage profile is also equal or higher than other methods. The proposed hybrid approach can be easily implemented on real distribution system.

References

- [1] Merlin, H Back. *Search for a Minimal-Loss Operating Spanning Tree Configuration in Urban Power Distribution Systems*. Proc. of 5th Power Systems Comp. Con., Cambridge, U. K., Sept. 1-5, 1975.
- [2] Civanlar, JJ Grainger, H Yin, Sh Lee. Distribution feeder reconfiguration for loss reduction. *IEEE Trans. Power Deliv.* 3, (3), pp. 1217–1223, 1988.
- [3] Lin Whei- Min, Chin Hong-Chan, A new approach for distribution feeder reconfiguration for loss reduction and service restoration. *IEEE Transactions on Power Delivery*, Vol. 13, No. 3, pp. 870-875, 1988.
- [4] D Shirmohammadi, HW Hong. Reconfiguration of electric distribution networks for resistive losses reduction. *IEEE Trans. Power Delivery*, vol. 4, pp. 1402–1498, Apr. 1989.
- [5] S.K. Goswami and S.K. Basu. New algorithm for the reconfiguration of distribution feeders for loss minimization. *IEEE Trans. Power Deliv.* 7, (3), pp. 1484–1491, 1992.
- [6] YH Song, GS Wang, AT John, PY Wang. Distribution network reconfiguration for loss reduction using fuzzy controlled evolutionary programming. *IEE Proceedings-Generation, Transmission and Distribution*, Vol. 144, Issue 4, pp. 345-350, 1997.
- [7] MW Siti, DV Nicolae, AA Jimoh, A Ukil. Reconfiguration and Load Balancing in the LV and MV Distribution Networks for Optimal Performance. *IEEE Trans. On Power Delivery*, Vol. 22, No. 4, Oct 2007.
- [8] KR Niazi, MR Farooqi, CM Arora, SL Surana. *Distribution Feeder Reconfiguration for Complex Power Loss Minimization*. Proc. of the 3rd IASME/WSEAS Int. Conf. on Energy, Environment, Ecosystems and Sustainable Development, Agios Nikolaos, Greece, July 24-26, 2007.
- [9] Chung-Fu Chang. Reconfiguration and Capacitor Placement for Loss Reduction of Distribution Systems by Ant Colony Search Algorithm. *IEEE Transactions on Power Systems*, 2008.
- [10] B Amanulla, Chakrabarti Saikat. Reconfiguration of Power Distribution Systems Considering Reliability and Power Loss. *IEEE transactions on power delivery*, vol. 27, no. 2, April 2012.

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- [11] YA Katsigiannis, PS. Georgilakis. Optimal Sizing of Small Isolated Hybrid Power Systems Using Tabu Search. *Journal of Optoelectronics and Advanced Materials*, Vol. 10, No. 5, May 2008, pp. 1241-1245.
- [12] Acharya N, Mahat P, Mithulanathan N. An analytical approach for DG allocation in primary distribution network. *International Journal of Electrical Power Energy System* 2006; 28: 69–78.
- [13] Gozel T, Hocaoglu MH. An analytical method for the sizing and siting of distributed generators in radial systems. *Electrical Power System Research* 2009; 79: 912–8.
- [14] Kim KH, Lee YJ, Rhee SB, Lee SK. Dispersed generator placement using fuzzy-GA in distribution systems. In: *Proceeding of IEEE power engineering society summer meeting, USA*, vol. 2; 2002. p. 1148–53.
- [15] Kim JO, Nam SW, Park SK, Singh C. Dispersed generation planning using improved Hereford Ranch algorithm. *Electrical Power System Research* 1998; 47(1): 47–55.
- [16] Kean A, Omalley M. Optimal allocation of embedded generation on distribution networks. *IEEE Trans Power Syst* 2006.
- [17] Zhang X, Karady GG, Ariaratnam ST. Optimal allocation of CHP-based distributed generation on urban energy distribution networks. *IEEE Trans Sustain Energy* 2014; 5(1): 246–53.
- [18] Injeti SK, Kumar NP. A novel approach to identify optimal access point and capacity of multiple DGs in small, medium and large scale radial distribution systems. *International Journal of Electric Power Energy System* 2013; 45: 142–51
- [19] S. Nawaz, Md. Imran, Avadhesh Sharma, Anjali Jain. Optimal Feeder Reconfiguration and DG Placement in Distribution Network. *International Journal of Applied Engineering Research*, Volume 11, Number 7 (2016) pp 4878-4885
- [20] Rajkumar Viral, DK Khatod. An analytical approach for sizing and siting of DGs in balanced radial distribution networks for loss minimization. *Electrical Power and Energy Systems* 67 (2015) 191–201
- [21] S Devi, M. Geethanjali. Application of Modified Bacterial Foraging Optimization algorithm for optimal placement and sizing of Distributed Generation. *Expert Systems with Applications* 41, 2772–2781, 2014
- [22] S Ghosh, KS Sherpa. An efficient method for load-flow solution of radial distribution networks. *International Journal Elect. Power Energy Syst. Eng.*, vol. 1, no. 2, pp. 108–115, 2008.
- [23] Attia El-Fergany. Study impact of various load models on DG placement and sizing using backtracking search algorithm. *Applied Soft Computing*. 30 (2015) 803–811
- [24] Tamer M. Khalil and Alexander V. Gorpnich. Selective particle swarm optimization, *International Journal of Multidisciplinary Sciences and Engineering (IJMSE)*, vol. 3, issue 4, pp. 1-4, April 2012.
- [25] JS Savier, D Das. Impact of network reconfiguration on loss allocation of radial distribution systems. *IEEE Trans. Power. Del.*, vol. 2, no. 4, pp. 2473-2480, Oct 2007
- [26] Neeraj Kanwar, Nikhil Gupta, KR Niazi, Anil Swarnkar. Improved meta-heuristic techniques for simultaneous capacitor and DG allocation in radial distribution networks. *Electrical Power and Energy Systems* 73, 653–664, (2015)