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Optimal placement and sizing of PV system and fuel cell on distribution system for loss minimization

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In current scenario optimal placement and sizing of distributed generation (DG) on the distribution system is drawing attention of electrical power utilities for minimization of real power loss. Power loss minimization has some in built advantages i.e. power flow reduction in feeder lines, reduces stress on feeder loading therefore increases reliability of the utility, fulfilled the load demand during peak load period and reduction in consumer bill, etc. In this paper particle swarm optimization with constriction factor approach (PSOCFA) for optimal placement and sizing of DGs (such as solar and fuel cell based), heuristic approach is applied for reconfiguration of distribution system with the purpose to minimize the total real power loss subjected to equality and inequality constraints in the distribution system is presented. The results obtained after placement of Photovoltaic (PV) system, Fuel cell (FC) and combination of both are shown by using PSOCFA algorithm applied on IEEE 33–bus radial distribution system. It shows significant reduction in power loss with the improvement in voltage profile and voltage stability index (VSI).

Keywords: *Distributed generation, particle swarm optimization with constriction factor approach, Photovoltaic system, fuel cell.*

1.0 INTRODUCTION

Now a days the big challenge on distribution system to meet increase in energy demand without violating service quality. To fulfil this demand needs addition of new substation or expanding capacity of existing substation but it requires extra expenditure. Due to power system deregulation and environmental concern disco planner engineers mainly seeks expansion planning through Distributed Generation (DG). DG is an electric power connected directly to distribution network or near the point of use[1]. DG output power ranges from less than kilowatt to 10 megawatts in size. DG units are mainly energized by wind, solar, biomass and fuel cell.

Distribution systems usually operated at low voltage are connected to the high voltage transmission systems and finally supply power to consumer at low voltage. The power losses in the distribution system lines is high because of low voltage and high current in this system, causes increase in the cost of power and poor voltage profile. The total power loss in the distribution system is composed of two parts: active power and reactive power loss. The active power loss is due to the flow of active component of current required by the load and the flow of reactive component of current required to compensate the reactive power requirement of system components and hence to control of the system voltage. The effect of active power loss is very important

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because it reduces the efficiency of power transfer and deteriorates the voltage profile. The task of power loss reduction and enhancement of energy efficiency is more important in distribution system from transmission system. It is reported that 13% of total power generated is wasted in the form of power losses at the distribution end [2]. The capacity of radial feeder is limited, so it is necessary to consider some alternatives source so that the future load demands can be supplied without violating power quality.

The energy transmitting efficiency from service to consumer reduces with increased power loss by improper configuration of distribution system. To minimize the power loss in the branches is by optimal network reconfiguration at planning and operational stages. Network reconfiguration means changing's ON/OFF status of the sectionalizing and tie switches. It transfers the loads from heavily loaded feeders to relatively less loaded feeders. So, the voltage profile improved in feeders and further reducing the system power loss.

The commonly used objectives for distribution system reconfiguration are the minimization of transmission loss and voltage deviations at the buses [3]-[9]. An essential criterion for system is maintaining radial nature and meeting all load demand requirements mainly for the easiness in relay coordination. Distribution reconfiguration is essentially a combinatorial optimization problem where the best possible combination of statuses (open or close) of the sectionalizing and tie-switches has to be found so that the objective function (such as the total active power loss) is minimized. In [3]-[5], branch exchange-based methods are employed to find the optimal network configuration, where an open switch is closed, and a closed switch is opened to maintain the radial configuration of the system. Simplified versions of power flow computation method that are suitable for radial networks are used to minimize the computational burden and speed-up the search process. A linear programming based distribution system reconfiguration method is proposed in [6], where, by using a modified simplex method, the optimal configurations of the switches, i.e., close or open status, are determined. The artificial intelligence based methodologies such as the use of fuzzy logic system, genetic algorithms, simulated annealing, ant colony systems, and other evolutionary techniques have increasingly been used for distribution system reconfiguration problem [7]-[9].

Recently due to the impacts of greenhouse gases on the global warming, clean energy is promoted in many countries. Solar power and Fuel cell is one of the cleanest and indigenous energy sources. However, due to the intermittent and stochastic characteristic of PV system resources, PV system power is not predictable. DG with an objective of minimizing real power loss and improving voltage profile, reliability, network upgrading, system planning, and reactive power planning in distribution system through PV system as an energy source are reported in [10]-[12]. The probabilistic approach for PV system power generation are reported in [13]-[14] for active power loss minimization and improvement in system reliability.

The mixed integer nonlinear programming (MINLP) to minimize the system's annual energy losses by optimally allocating different types of renewable DG units with probabilistic approach is formulated in [15]. Optimal placement and sizing of DG in the distribution networks to minimize power loss are suggested in [16-20]. The optimization techniques like genetic algorithm (GA) [16], artificial bee colony (ABC) algorithm [17], Combined Genetic algorithm (GA)/particle swarm optimization (PSO) [18], evolutionary programming (EP) [19] and MTLBO [20] are employed to arrive at the optimal solution.

This paper introduces optimal placement and sizing of PV system and fuel cell by PSOCFA based optimization technique for minimization of active power losses in 24 hours on distribution system without violating the constraints. The paper is organized follows. In section 2 power loss assessment of distribution system and VSI of each bus, Section 3 is composed modeling of load, PV and fuel cell, Section 4 represent mathematical formulation of problem, Section 5 briefly describes reconfiguration of distribution system, Section 6 explain PSO-CFA algorithm. Section 7 describes optimal placement and sizing of PV system and fuel cell. Finally relevant conclusions are discussed.

2.0 POWER LOSS ASSESSMENT OF DISTRIBUTION SYSTEM

Power loss for each configuration is calculated by using distribution system load flow algorithm [21]. It is derived from basic circuit theory. It is assumed that three-phase distribution system is balanced and represent by single line diagram (Figure 1).

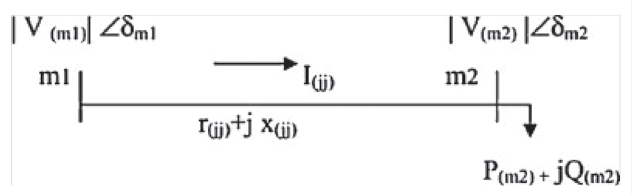

FIG. 1 SINGLE LINE DIAGRAM OF RADIAL DISTRIBUTION SYSTEM

Receiving end voltage for branch jj

$$V_{m2} = V_{m1} - I_{jj} Z_{jj} \quad \text{....(1)}$$

Where jj =1, 2, 3-----------N

Current through branch jj is equal to the sum of the load currents of all the nodes beyond branch jj plus the sum of the charging currents of all the nodes beyond branch jj.

$$I_{JJ} = \sum_{i=2}^{N} IL(i) + \sum_{i=2}^{N} IC(i) \quad \text{....(2)}$$

Identification of the nodes beyond all the branches is realized through an algorithm as explained in [22].

Load current at node i :

$$IL(i) = \frac{PL(i) - jQL(i)}{V(i)} \quad \text{....(3)}$$

Charging current at node i:

$$IC(i) = Y(i) \times V(i) \quad \text{....(4)}$$

Where Vm1 and Vm2 is voltage of node m1 and m2, δm1 and δm2 is phase angle of voltage Vm1 and Vm2, r(jj) and x(jj) is resistance and reactance of branch jj, N and NB is number of nodes and branches.

Active and Reactive for branch j :

$$LP(jj) = |I_{jj}|^2 r_{jj} \quad \text{....(5)}$$

$$LQ(jj) = |I_{jj}|^2 x_{(jj)} \quad \text{....(6)}$$

Active and reactive power loss for 24 hours:

$$P_L = \sum_{hr=1}^{24} \sum_{jj=1}^{NB} LP(jj), hr \quad \text{....(7)}$$

$$Q_L = \sum_{hr=1}^{24} \sum_{jj=1}^{NB} LQ(jj), hr \quad \text{....(8)}$$

In initial step, a flat voltage profile is considered. Iteration cycle will stop when difference in previous and new voltage is less than .0001 reached.

2.1 Voltage Stability Index

It is a parameter that finds the sensitivity of a node against voltage collapse [23].

$$VSI_{(m2)} = \left|V_{(m1)}\right|^4 - 4\left\{P_{(m2)} r_{(jj)} - Q_{(m2)} x_{(jj)}\right\}^2 + 4\left\{P_{(m2)} r_{(jj)} + Q_{(m2)} x_{(jj)}\right\}^2 \quad \text{....(9)}$$

Condition for stable operation of radial distribution system is VSI(m2) ≥0, where m2 =2, 3----N. The node where VSI(m2) is to be minimum i.e. is most sensitive node against voltage collapse.

3.0 MODELLING OF LOAD, PV AND FUEL CELL

3.1 Modelling of Load

The load on system varies with respect to time. The probability of load on each bus is modelled by using Normal Probability Density function [24].

$$F\left(S_i^D(hr)\right) = \frac{1}{\sqrt{2\pi\sigma_i^D(hr)}} \times \exp\left[-\frac{\left(S_i^D(hr) - \mu_i^D(hr)\right)^2}{2\sigma^2}\right] \quad ....(10)$$

Actual load on each bus for each hour is the product of load probability and load of base case (Figure 2).

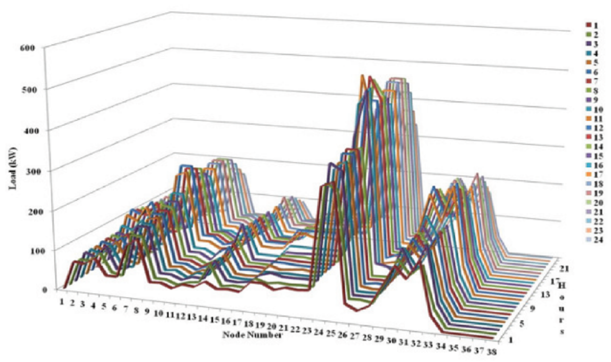

FIG. 2 HOURLY LOAD DATA OF 33 BUS SYSTEM WITH LOAD PROBABILITY

3.2 PV Modelling

For each hour in a day probabilistic nature of solar irradiance can be described by using Beta probability density function as [13]:

$$f_b(s) = \begin{cases} \frac{\Gamma(\alpha+\beta)}{\Gamma(\alpha)\Gamma(\beta)} s^{(\alpha-1)}(1-s)^{(\beta-1)} & 0 \le s \le 1, \alpha, \beta \ge 0 \\ 0 & otherwise \end{cases} \quad ....(11)$$

$$\beta = (1-\mu) \times \left(\frac{\mu(1-\mu)}{\sigma^2} - 1\right) \quad ....(12)$$

$$\alpha = \frac{\mu \times \beta}{1-\mu} \quad ....(13)$$

Where $f_b(s)$ is Beta distribution function of s, s is solar irradiance in kW/m2, and is the parameters of Beta distribution function, and is mean and standard deviation of s. Calculation of output power of PV module:

$$T_{cy} = T_A + s\left(\frac{N_{OT} - 20}{0.8}\right) \quad ....(14)$$

$$I_y = s\left[I_{sc} + K_i\left(T_{cy} - 25\right)\right] \quad ....(15)$$

$$V_y = V_{oc} - K_v \times T_{cy} \quad ....(16)$$

$$FF = \frac{V_{MPPT} \times I_{MPPT}}{V_{oc} \times I_{sc}} \quad ....(17)$$

$$P_o(s) = N \times FF \times V_y \times I_y \quad ....(18)$$

Where, Tcy and TA are the module temperature and ambient temperature. NOT, Isc and Voc are the nominal operating, short circuit current, and open circuit voltage of PV module. Kv and Ki are the voltage temperature coefficient and current temperature coefficient. FF is the fill factor. N is the number of PV modules used in the PV system. VMPPT and IMPPT are the voltage and current at maximum power point. Po(s) is the output power of PV system at solar irradiance s.

The expected output power at solar irradiance s (EP(s)) can be expressed as:

$$EP(s) = P_o(s) \times f_b(s) \quad ....(19)$$

The expected total output power (ETP) at a specified time interval can be calculated by

$$ETP = \int_0^1 P_O(s) \times f_b(s) ds \quad ....(20)$$

In this work step size of s is 0.05 kW/m2.

The output power of PV module is obtained by using module characteristics, mean and standard deviation of s (Figure 3, Tables 1-2).

TABLE 1

MODULE CHARACTERSTICS

Watt peak (W)	220
Open circuit voltage (V)	36.96
Short circuit current (A)	8.38
Voltage at maximum power (V)	28.36

Current at maximum power (A)	7.76
Current temperature coefficient (A/° C)	0.00545
Voltage temperature coefficient (V/° C)	0.1278
Nominal operating temperature(°C)	43

TABLE 2

MEAN AND STANDARD DEVIATION OF SOLAR IRRADIANCE

Hour	μ (kW/m^2)	σ (kW/m^2)	Hour	μ (kW/m^2)	σ (kW/m^2)
6	0.019	0.035	13	0.648	0.282
7	0.096	0.11	14	0.59	0.265
8	0.222	0.182	15	0.477	0.237
9	0.381	0.217	16	0.338	0.204
10	0.511	0.253	17	0.19	0.163
11	0.61	0.273	18	0.08	0.098
12	0.657	0.284	19	0.017	0.032

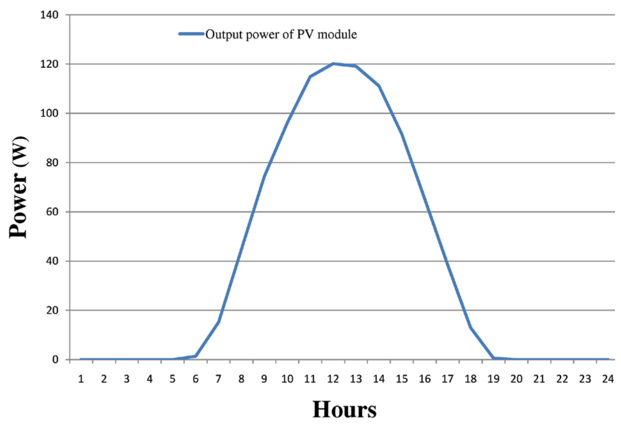

FIG. 3 OUTPUT POWER OF PV MODULE

3.3 Fuel cell Modelling

Fuel cell is considered as a constant power source without uncertainties.

4.0 PROBLEM FORMULATION

Critical factor for PV system and fuel cell is location and size on distribution system. Improper size and placement can be lead to increase in system power loss and cost. The optimum placement and sizing of PV system and fuel cell lead to optimum compensation in system power loss. The optimum size of PV system and fuel cell for bus i can be found by using this relation:

$$P_i = P_{Gi} - P_{Di} \qquad \text{....(21)}$$

Where Pi, PGi, PDi is power injected, generation and demand at node i.

The objective function is to be minimized active power loss:

$$P_L = \sum_{hr=1}^{24} \sum_{jj=1}^{NB} (|I(jj)|^2 R(jj), hr \qquad \text{....(22)}$$

The objective function is subjected of constraints as given below:

Power balance: The flow of power in all the nodes of the system must satisfy the below relation.

$$P_i - (P_{Gi} - P_{Di}) = 0 \qquad \text{....(23)}$$

Bus voltage: Voltage magnitude at each node must lie within permissible limit to maintain power quality.

$$|V_i^{min}| \leq |V_i| \leq |V_i^{max}| \qquad \text{....(24)}$$

Where V_i^{min} and V_i^{max} are the minimum and maximum values of the voltages at bus i (i.e. 0.90–1.05), respectively.

PV system and fuel cell capacity: The maximum power generated by PV system and fuel cell capacity should not exceed from 50% of total feeder load of the network [25].

$$NPV \times P_{(max,PV\ module)} \leq 0.5 \times \sum_{i=2}^{N} \sqrt{(P_i^L)^2 + (Q_i^L)^2} \qquad \text{....(25)}$$

$$P_{(FC,capacity)} \leq 0.5 \times \sum_{i=2}^{N} \sqrt{(P_i^L)^2 + (Q_i^L)^2} \qquad \text{....(26)}$$

$$NPV \times P_{(max,PV\ module)} + P_{(FC,capacity)} \leq 0.5 \times \sum_{i=2}^{N} \sqrt{(P_i^L)^2 + (Q_i^L)^2} \qquad \text{....(27)}$$

Where NPV is number of PV module, P (max, PV module), P (FC, capacity) is the maximum power generated by PV system and fuel cell capacity. and is active and reactive power of load for i bus.

5.0 RE-CONFIGURATION OF DISTRIBUTION SYSTEM

5.1 Solution methodology

Compute the voltage difference between across all tie switches. If the voltage difference across all tie switches is greater than ε (.001) [8], start switching operation otherwise discard switching operation. During reconfiguration each loop contain only one tie switch and radiality must be maintained.

5.2 Algorithm for system Reconfiguration

These are the following steps [26].

1. Read the system data.
2. Run the load flow, calculate system power loss and voltage at each node.
3. Compute the voltage difference across all open tie switches (i.e., $vd_{tie}(i)$, for i=1, 2, . . . , N_{tie}). Ntie represents the total number of tie switches.
4. Arrange the $vd_{tie}(i)$ in descending order, if 1st digit of vd_{tie} matrix is greater than the ε, go to step 5. Otherwise discard all switching operation.
5. Find the two nodes of the tie switch and check the node which has the minimum voltage, let it is Vk.
6. Close the tie switch from the loop and open the sectionalizing switch adjacent to minimum voltage node. Calculate active power loss.
7. Now close the current sectionalizing switch and open the next sectionalizing switch which is adjacent is to be minimum node voltage.
8. If difference in previous and current active power loss is less than zero then this sectionalizing switch is open in that loop. Otherwise swap the value of previous and current active power loss go to step7
9. If the number of iterations (n) is less than or equal to number of tie switches (Ntie), set n as n+1 and go to step 2 to repeat the program for the rest of the tie switches.
10. Run the load flow and the print the result.
11. Stop.

6.0 PARTICLE SWARM OPTIMIZATION ALGORITHM WITH CONSTRICTION FACTOR APPROACH

It is a Hybrid particle swarm optimization technique. It uses the mechanism of PSO and natural selection. PSO is a robust stochastic optimization technique based on the movement and intelligence of swarms. It uses a number of agents (particles) that constitute a swarm moving around in the search space looking for best solution. Each particle is treated as a point in a N dimensional space which adjusts its flying according to its own flying experience and as well as flying experience of other particles. On the contrary, PSO-CFA can jump the current searching points into the effective (attractive) area directly by the natural selection mechanism. Unlike other evolutionary computational methods, CFA of PSO ensures the convergence of search procedures based on the mathematical theory. CFA considers dynamic behaviour of one agent and the effect of the interaction among agents. Selection mechanism is also adopted in this technique like as genetic algorithm.

For PSOCFA [27,28], the velocity of the particle is manipulated by the constriction factor (CF) as given in. The CF guarantees the convergence of PSO algorithm and the system can search different regions efficiently.

$$V_i^{k+1} = CF\left(V_i^k + c1 \times r1(pbest_i - x_i^k) + c2 \times r2(gbest - x_i^k)\right) \quad \text{....(28)}$$

$$CF = \frac{2}{\left|2 - \varphi - \sqrt{\varphi^2 - 4\varphi}\right|}$$

Where, φ = c 1+c2

In CF, φ must be greater than 4.0 for guarantee stability. However, as increases, the CF decreases and diversification is reduced, yielding slower response. A low value of CF facilitates rapid convergence and little exploration whereas high values of CF give slow convergence and much exploration. The value of CF is 4.1. Normally c1 & c2 is 2.05.

Where, v_i^k is the velocity of agent i at iteration k, rand1 and rand2 are the random numbers between 0 and 1. x_i^k is the current position of agent i at iteration k, pbesti is the personal best of agent i gbest is the best of the group.

Position updating equation:

$$x_i^{k+1} = x_i^k + v_i^{k+1} \qquad ....(29)$$

During the simulation of PSOCFA, the best chosen maximum population size = 50, maximum iteration cycles = 100.

6.1 Implementation of PSOCFA algorithm for optimal sizing of PV system

Step 1: Initialize the maximum and minimum number of PV module. The number of PV modules ranges between minimum and maximum specified limits is described as:

$$NPV_i = NPV_{min} + rand \times (NPV_{max} - NPV_{min}) \qquad ....(30)$$

Where NPVmin and NPVmax are the minimum and maximum number of PV modules, rand = random number between 0 and 1.

In this case, number of PV modules is assumed as particles and the location of PV system is randomly placed at the node at which load is connected.

Step 2: Evaluate the objective function for each particle.

Step 3: Compare the objective function for each particles evaluate with the current particle's to obtain pbest.

Step 4: Compare objective function evaluate with the population's overall previous to obtain gbest.

Step 5: Update position and velocity of particle by above equations.

Step 6: Go to step 2 until criteria are satisfied.

Step7: Complete the optimal number of PV modules.

6.2 Optimal sizing of Fuel cell

Step 1: Initialize the maximum and minimum capacity of fuel cell. The capacity of fuel cell ranges between minimum and maximum specified limits is described as:

$$P_{FCi} = P_{FCmin} + rand \times (P_{FCmax} - P_{FCmin}) \qquad ....(31)$$

Where P_{FCmin} and P_{FCmax} are the minimum and maximum capacity of fuel cell, rand = random number between 0 and 1.

In this case, capacity of fuel cell is assumed as particles and the location of fuel cell is randomly placed at the node at which load is connected.

Step 2 to step 6 is followed

Step 7: Determine the optimal size of fuel cell.

6.3 Optimal sizing of PV system and Fuel cell

Step 1: Initialize the maximum and minimum number of PV module, maximum and minimum capacity of fuel cell.

The number of PV modules and capacity of fuel cell ranges between minimum and maximum specified limits is described as:

$$NPV_i = NPV_{min} + rand \times (NPV_{max} - NPV_{min}) \quad ....(32)$$

$$P_{FCi} = P_{FCmin} + rand \times (P_{FCmax} - P_{FCmin}) \quad ....(33)$$

Where NPV_{min} and NPV_{max} are the minimum and maximum number of PV modules, PFC_{min} and $PFC_{ma}x$ are the minimum and maximum capacity of fuel cell, rand = random number between 0 and 1.

For this case, the sum of maximum power generated by PV system and capacity of fuel cell must be not exceeded from 50% from total feeder load of the network.

In this case, number of PV modules and capacity of fuel cell are assumed as particles and the location of PV system and fuel cell is randomly placed at the node at which load is connected.

Step 2 to step 6 is followed

Step 7: Determine the optimal no. of PV modules and size of fuel cell.

7.0 OPTIMAL PLACEMENT AND SIZING OF PV SYSTEM AND FUEL CELL

7.1 Assumptions

1. Both are considered as negative loads.
2. Both inject only active power at unity power factor.
3. Individual maximum power generated should not exceeded 50% of the total feeder load of the network.
4. Sum of maximum power generated should not exceeded 50% of the total feeder load of the network.
5. Source node cannot be considered as the location for placing them.

7.2 Computational procedure for optimal PV System placement

Step 1: Set parameters of PSO-CFA, maximum iteration, maximum population, c1, c2, CFA and maximum and minimum number of PV modules.

Step 2: Put the PV system at node 2 and the number of modules varies from between minimum and maximum specified limit.

Step 3: Run the load flow and calculate voltage magnitude of buses. Check the constraint is satisfied or not. If satisfied calculate the objective function. Otherwise discard the result.

Step 4: Calculate the pbesti and gbest of the particle. Increase NOP by 1 and check NOP is less or equal to maximum population. Go to step 3 otherwise go step 5.

Step 5: Update the velocity and position of particle by updating equations .Increase the iteration by 1 and check iteration is less or equal to maximum iteration. Go to step 3 otherwise go to step 6.

Step 6: Calculate the objective function for every node except source node by above steps.

Step 7: Store the total system real power losses of 24 hours for every node and corresponding to its PV modules.

Step 8: Display that node and number of modules whose network loss is minimum for 24 hours.

7.3 Optimal Fuel cell placement

The fuel cell placement is same as the placement of PV system, but here fuel cell capacity varies in place of number of PV modules between minimum and maximum specified limit.

7.4 Optimal PV system and Fuel cell placement

The algorithm of single PV system and fuel cell optimal placement given in the above section can be extended for optimal placements of PV system and fuel cell simultaneously too with the objective to minimize the total real power losses of 24 hours in 33-bus IEEE test distribution network before and after reconfiguration subjected to the constraints. For PV system and fuel cell optimal placement, it is assumed that here the PV system and fuel cell cannot be located at same node (Figure 4).

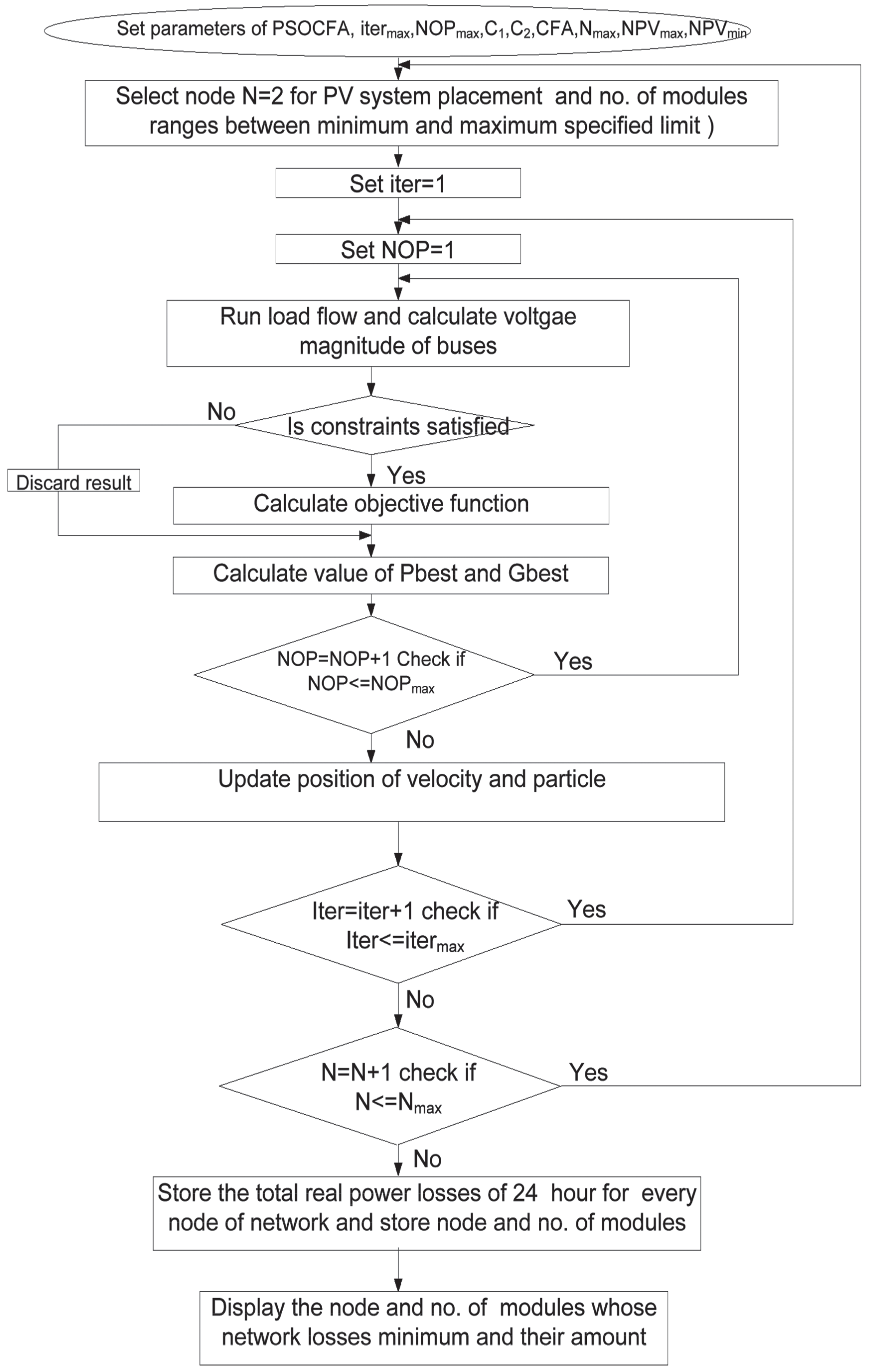

FIG. 4 FLOW CHART OF PV SYSTEM PLACEMENT

8.0 NUMERICAL RESULTS

In order to demonstrate the effectiveness of the presented method (optimal placement and sizing of PV system and fuel cell by using PSOCFA) is tested on IEEE 33-bus radial distribution system [29] before and after reconfiguration. In this system, there are 5 tie switches and 32 sectionalizing switches. For this system, substation voltage = 12.66 kV, base MVA = 100, total active power load = 3.715MW and total reactive power load =2.3 MVAr. The load of each hour of the day for each node is explained in section 3

8.1 The Following cases are considered under simulation study:

Case 1: Base case.

Case 2: Base case with PV system placement at optimal location.

Case 3: Base case with fuel cell placement at optimal location.

Case 4: Base case with PV system and fuel cell placement at optimal location.

Case 5: Base case with system reconfiguration.

Case 6: Base case with PV system placement after reconfiguration of distribution system

Case 7: Base case with Fuel cell placement after reconfiguration of distribution system.

Case 8: Base case with PV and fuel cell system placement after reconfiguration of distribution system.

TABLE 3

OPTIMAL RESULTS OF STANDARD AND RECONFIGURED 33 BUS RADIAL DISTRIBUTION NETWORK AFTER PV AND FUEL CELL SYSTEM PLACEMENT

Parameter's	**Case 1**	**Case 2**	**Case 3**	**Case 4**	**Case 5**	**Case 6**	**Case 7**	**Case 8**
Optimal node	------	8	6	14,29	------	30	30	8,30
Optimal PV module	-------	18300	------	7125	-------	12976	------	9669
Max. power generated by PV system in 12th hour (kW)	-------	2200	--------	856.21	-------	1559.3	------	1162.1
Fuel cell Size (kW)	-------	------	2200	1341.6	-------	------	1072.2	1032.9
Active power loss (kW/day)	4767.7	3753.0	2548.1	2451.2	3291.2	2805.2	2333.0	2044.2
% Reduction in active power loss	-------	21.281	46.55	48.58	30.96	41.16	51.06	57.12
Reactive power loss (KVAr/day)	3178.6	2517.2	2006.8	1689.1	2408.6	2136.2	1807.8	1544.2
% Reduction in reactive power loss	-----	20.80	37.86	46.86	24.22	32.7	43.12	51.41
Min. Voltage magnitude (p.u)	0.8985	0.9093	0.9320	0.9248	0.9275	0.938	0.9384	0.9429
Min. VSI	0.6527	0.6686	0.7557	0.731	0.7416	0.7554	0.7764	0.7942
Open Switches	33, 34, 35, 36, 37	33, 34, 35, 36, 37	33, 34, 35, 36, 37	33, 34, 35, 36, 37	7, 9, 14, 32, 37	7, 9, 14, 32, 37	7, 9, 14, 32, 37	7, 9, 14, 32, 37

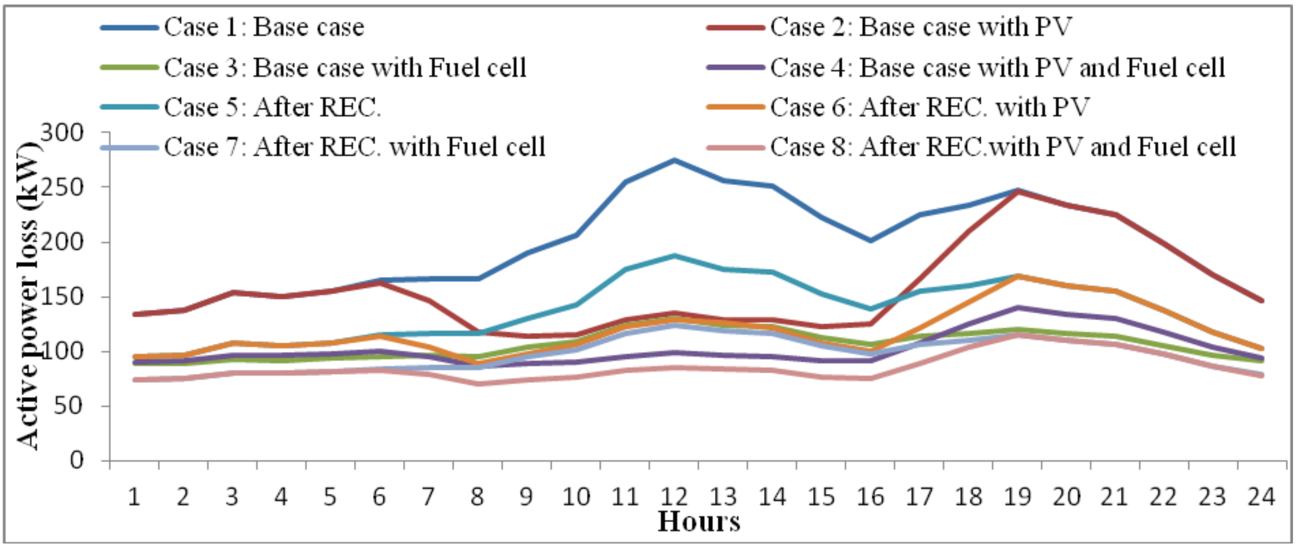

FIG. 5 HOURLY ACTIVE POWER FOR DIFFERENT CASES

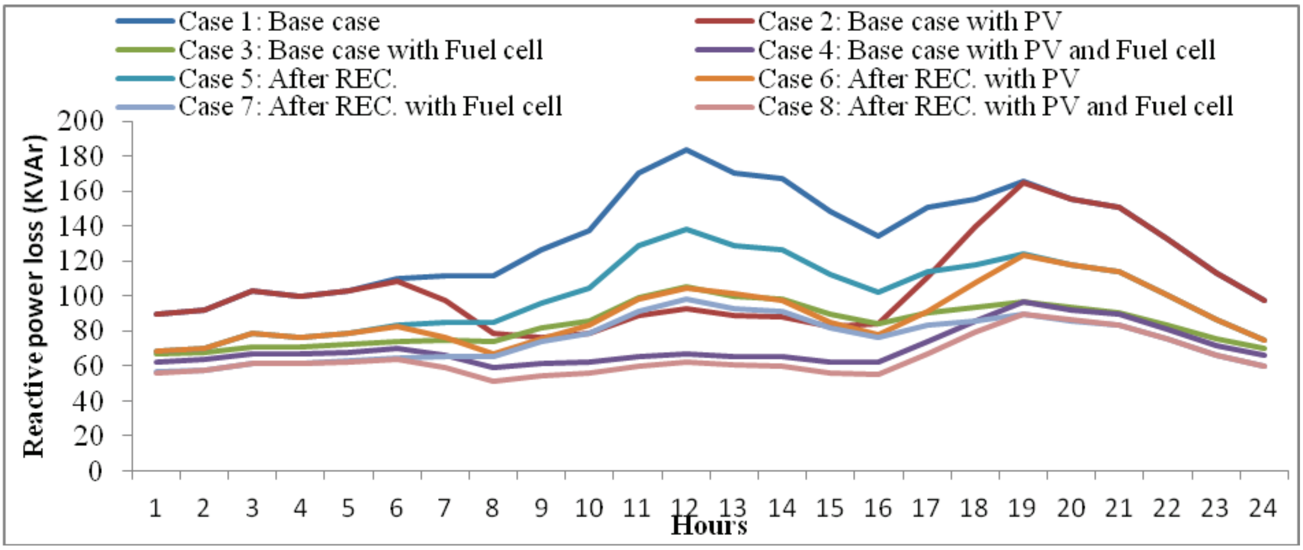

FIG. 6 HOURLY REACTIVE POWER FOR DIFFERENT CASES

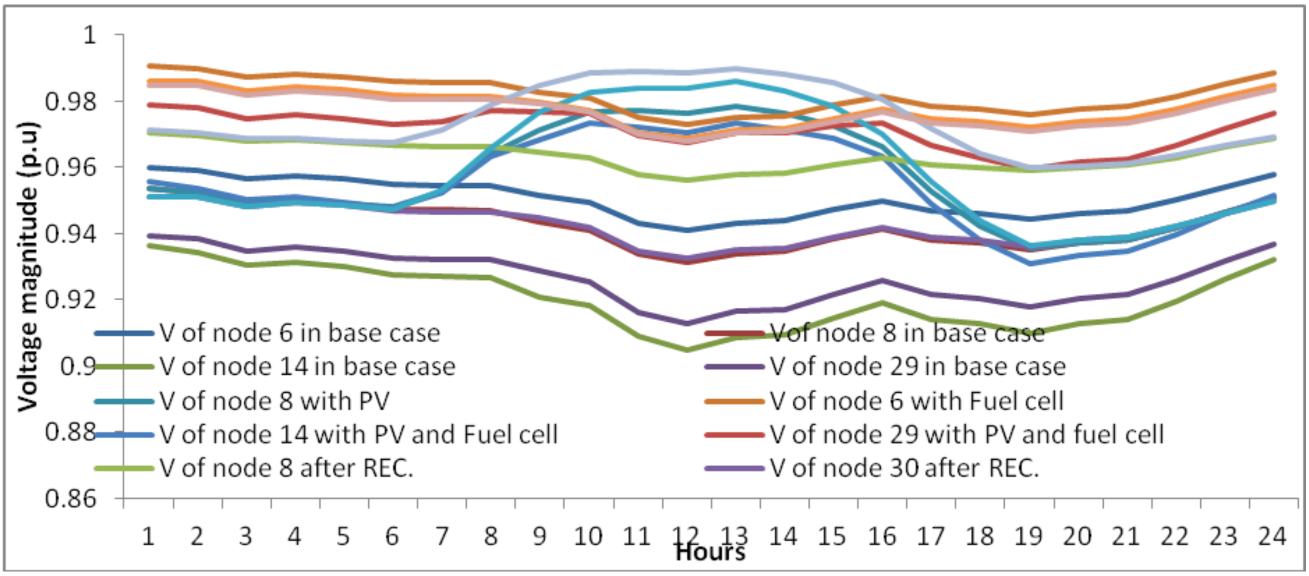

FIG. 7 VOLTAGE PROFILE OF OPTIMAL NODE'S FOR DIFFERENT CASES

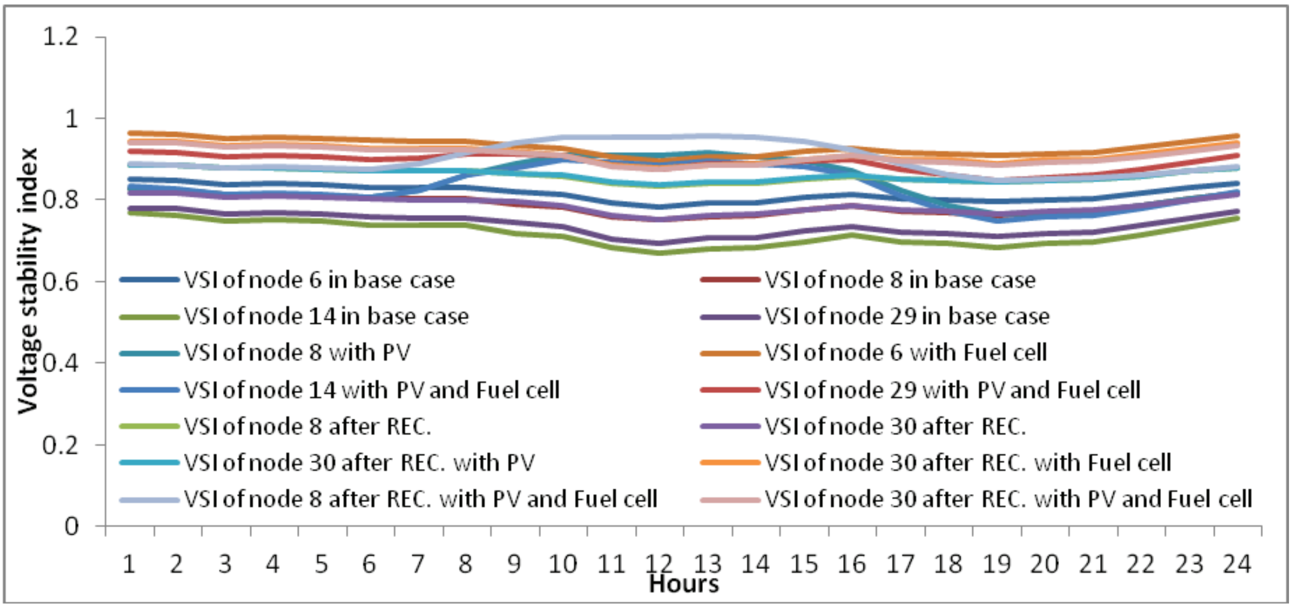

FIG. 8 VOLTAGE STABILITY INDEX OF OPTIMAL NODE'S FOR DIFFERENT CASES

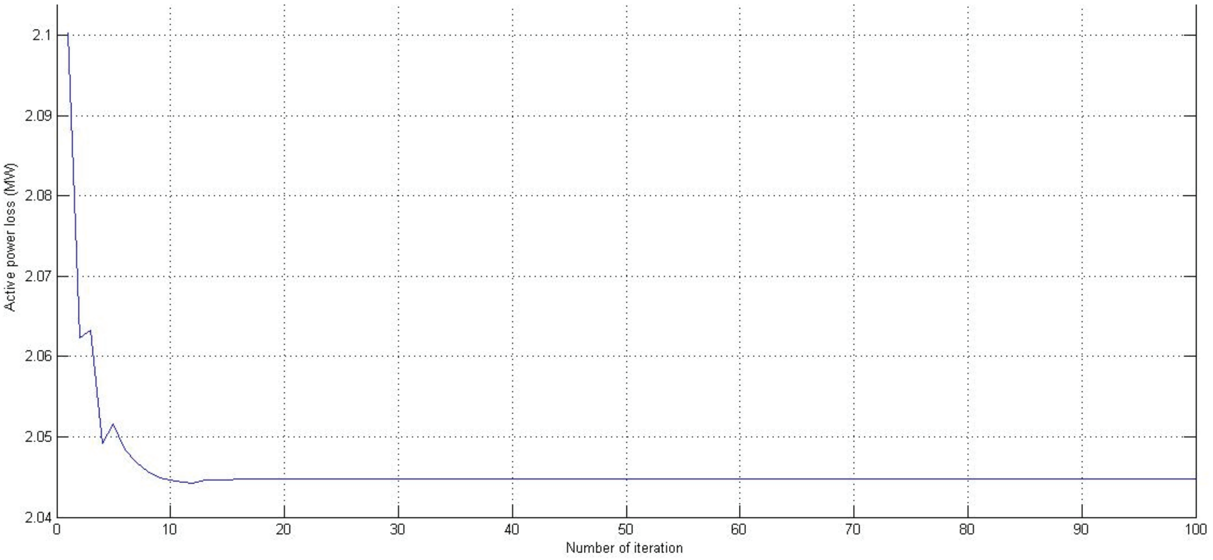

FIG. 9 CONVERGANCE CHARACTERSTIC OF CASE 8

In these 8 cases (Table 3, Figures 5-9) the case number 8 in which PV and fuel cell system placement in reconfigured IEEE 33 bus radial distribution system at optimal location is most effective. This case shows most reduction in active power and reactive power losses in 24 hours from other cases with improvement in profile of voltage and voltage stability index.

9.0 CONCLUSION

Optimal placement of DG (such as wind, solar, biomass, fuel cell) plays important role for maximizing total active power loss reduction in distribution system with active power compensation. PSOCFA optimization algorithm is used for optimal placement and sizing PV system and fuel cell in distribution system so the total active power loss of the system in 24 hours is minimized. Placement of both PV system and fuel cell in distribution system is more effective for active power loss minimization than single PV system and fuel cell placement. Placement of both PV system and fuel cell in reconfigured distribution system is more effective for active power loss minimization than without PV system and fuel cell of standard IEEE 33 bus radial distribution system. Placement of both PV system and fuel cell in reconfigured system gives more improvement in voltage and voltage stability index of each load bus and reduction in reactive power loss of the system in 24 hours from other cases.

REFERENCES

[1] Ackermann T, Andersson G, Soder L Distributed generation: a definition. Electric Power System Research; vol. 57 pp. 195–204, 2001.

[2] H L Willis, Power Distribution Planning Reference Book, New York: MercelDekkar, Inc second ed., 2004.

[3] S K Goswami and S K Basu, “A new algorithm for the reconfiguration of distribution feeders for loss minimization,” IEEE Trans. Power Delivery, vol. 7, pp. 1484-1491, 1992.

[4] M A Kashem, G B Jasmon, and V Ganapathy, “A new approach of distribution system reconfiguration for loss minimization,” Electric Power and Energy Systems vol. 22, pp. 269-276, 2000.

[5] A Merlin and H Back, “Search for a minimal-loss operating spanning tree configuration in an urban power distribution system,” in Proc. of the Fifth Power System Conference (PSCC), Cambridge, pp. 1-18, 1975.

[6] A Abur, “A modified linear programming method for distribution system reconfiguration,” Electric Power and Energy Systems, vol.18, pp. 469-474, 1996.

[7] M K Nara, A Shiose, and T Ishihara, “Implementation of genetic algorithm for distribution systems loss minimum reconfiguration,” IEEE Trans. Power Systems, vol.7, pp. 1044-1051, 1992.

[8] D Das, “Reconfiguration of distribution system using fuzzy multi-objective approach,”International Journal of Electrical Power & Energy Systems, vol. 28, pp. 331-338, 2006.

[9] K Prasad, R Ranjan, N C Sahoo, and A Chaturvedi, “Optimal reconfiguration of radial distribution systems using a fuzzy mutated genetic algorithm,” IEEE Trans. Power Delivery, vol. 20, pp. 1211-1213, 2005.

[10] R Rao, K Ravindra, K Satish, and S Narasimham, “Power loss minimization in distribution system using network reconfiguration in the presence of distributed generation,” IEEE Transactions on Power Systems, vol. 28, pp. 317-325, 2013.

[11] T Niknam, M Zare, and J Aghaei, “Scenario-based multi objective Volt/Var control in distribution networks including renewable energy sources,” IEEE Transactions on Power Delivery, vol. 27, pp. 2004-2019, 2012.

[12] Taher Niknam, Abdollah Kavousi Fard, Alireza Seifi, “Distribution feeder reconfiguration considering fuel cell/wind/photovoltaic power plants,” Renewable energy, vol. 37, pp. 213-225, 2012.

[13] Jen-Hao Teng, Shang-Wen Luan, Dong-Jing Lee, and Yong-Qing Huang, “Optimal charging/discharging scheduling of battery storage system for distribution systems interconnected with sizeable PV generation systems ,” IEEE Trans. Power Systems, vol. 28, pp. 1425-1433, 2013.

[14] Duong Quoc Hung, N Mithulananthan, R C Bansal, “Integration of PV and BES units in commercial distribution systems considering energy loss and voltage stability,” Applied energy, vol. 113, pp. 1162-1170, 2014.

[15] Y Atwa, E El-Saadany, M Salama, and R Seethapathy, “Optimal renewable resources mix for distribution system energy loss minimization,” IEEE Transactions on Power Systems, vol. 25, pp. 360-370, 2010.

[16] Mithulanathan N, Oo Than, Van Phu Lee, “Distributed generator placement in power distribution system using genetic algorithm to reduce losses, Thammasat,” Int J Sci Technol, vol. 9, pp. 55–62, 2004.

[17] Abu-Mouti FS, El-Hawary ME, “Optimal distributed generation allocation and sizing in distribution systems using artificial bee colony algorithm” IEEE Trans. Power Delivery, vol. 26, pp. 2090–2101, 2011.

[18] Moradi MH, Abedini M, “A combination of genetic algorithm and particle swarm optimization for optimal DG location and sizing in distribution systems,” Electric Power Energy System, vol. 34, pp. 66–74, 2012.

[19] Khatod DK, Pant Vinay, Sharma Jaydev, “Evolutionary programming based optimal placement of renewable distributed generators,” IEEE Trans. Power System, vol. 28, pp. 683-695, 2013.

[20] Garcia JAM, Mena AJG, “Optimal distributed generation location and size using a modified teaching learning based optimization algorithm,” Electric Power and Energy System, vol. 50, pp. 65–75, 2013.

[21] D Das, “Simple and efficient computer algorithm to solve radial distribution network,” Electric Power Components and Systems, vol. 31, pp. 95-107, 2003.

[22] S Ghosh, D Das, “Method for load-flow solution of radial distribution networks,” IEE Proceedings-Generation, Transmission and Distribution, vol. 146, pp. 641-648, 1999.

[23] S Sivanagaraju, N Visali, V Sankar, T Ramana, “Enhancing voltage stability of radial distribution systems by network reconfiguration,” Electric Power Components and Systems, vol. 33, pp. 539-550, 2005.

[24] K Zou, A P Agalgaonkar, K M Muttaqi, and S Perera, “Distribution system planning with incorporating DG reactive capability and system uncertainties,” IEEE Transactions on Sustainable Energy,, vol. 3, pp. 112-123, 2012.

[25] S Gopiya Naik , D K Khatod, M P Sharma, “Optimal allocation of combined DG and capacitor for real power loss minimization in distribution networks,” Electric Power and Energy Systems, vol. 53, pp. 967-973, 2013.

[26] R Srinivasa Rao, S V L Narasimham, “A new heuristic approach for optimal network reconfiguration in distribution system,” vol. 5, pp. 15-21, 2009.

[27] S Naka, T Genji, T Yura, Y Fukuyama, “A hybrid particle swarm optimization for distribution state estimation,” IEEE Trans. on Power Systems, vol. 18, pp. 60-68, 2003.

[28] J G Vlachogiannis , K Y Lee, “A comparative study on particle swarm optimization for optimal steady-state performance of power systems,” IEEE Trans. on Power Systems, vol. 21, pp. 1718-1728, 2006.

[29] J Z Zhu, “Optimal reconfiguration of electrical distribution network using the refined genetic algorithm,” Electric Power Systems Research, vol. 62, pp. 37-42, 2002.