Pathumwan Academic Journal, Vol. 8, No. 22, May - August 2018: 1 - 14

Optimal Distributed Generation Placement and Network Reconfiguration Using Hybrid Algorithm

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Abstract

Recent advances in electric utility sector show that it is beneficial to inject the power and store energy at the distribution levels. But the non-optimal placement of distributed generations may adversely affect the distribution system performance. Therefore, distributed generations should be installed optimally. In this paper, a hybrid method combining genetic algorithm (GA) and particle swarm optimization (PSO) is developed and applied to determine the optimal size and location of distributed generations along with best network topology to reduce power losses and improve voltage profiles. The simulation results show that simultaneous reconfiguration and distributed generation placement is superior to improve the network performance. The power loss reduction after installation of active power distributed generations together with network reconfiguration is 73.91% in the IEEE 33-bus distribution network compared to base case power loss. Moreover, voltage profiles are improved significantly in all scenarios as compared to the base case profile. In nutshell, a proposed hybrid algorithm is efficient to solve the optimal distributed generation placement problem along with network reconfiguration.

Keywords: Hybrid Algorithm, Distributed Generation, Network Reconfiguration, Optimal Location and Sizing

Nomenclature

VSI_i	Voltage stability index at bus i
I_i	Equivalent current injected at i[th] bus
S_{Li}	Total apparent load at bus i
P_{Li}	Total active load at bus i
Q_{Li}	Total reactive load at bus i
P_{Gi}	Total active power generation at bus i
Q_{Gi}	Total reactive power generation at bus i
V_i^{min}	Minimum voltage at bus i

Research Paper

Received 19 March 2018

Accepted 30 March 2018

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V_i^{max}	Maximum voltage at bus i
N_L	Number of main loops in the network
N_{br}	Total number of branches
N_{bus}	Total number of buses
ndg	Total number of DG installed
P_{DGi}	Active power generation of i^{th} DG
Q_{DGi}	Reactive power generation of i^{th} DG
P_{DGi}^{min} / P_{DGi}^{max}	Minimum/Maximum active power generation limit of i^{th}
Q_{DGi}^{min} / Q_{DGi}^{max}	Minimum/Maximum reactive power generation limit of i
pf_{DGi}	Power factor limit of i^{th} DG
P_{ss}	Power supplied by the substation
$P_{Loss}(i, i+1)$	Real power loss in the line connecting bus i and i+1

1. Introduction

1.1 Background

The increasing energy demand and continuous depletion in conventional energy resources reserve led the world to the age of huge energy crisis. At present, excessive rise in energy consumption from hydrocarbon-based fossil fuels has been one of the severe threats for the human life and environment. The distributed generation based on renewable energy sources can be viable solution to meet the growing energy demand in more flexible and modular way and to address the environmental concerns. As compared to cost of electricity generation from large-scale conventional power plants, the electricity generation cost from distributed generation is always quite high. If the load center and centralized generating stations are located very far from each other, due to high transmission cost, the energy from those centralized generating stations can becomes more expensive than that generated locally from distributed generations. Hence, that distributed generations provide economically viable solution to meet the energy demand of those areas located very far from those centralized generating stations as well as environmental benefits can be achieved through it.

1.2 Distributed Generations

Distributed Generation refers to the small-scale (normally 1 kW to 50 MW) electric power generators that are tied directly to the electric distribution network and generate electricity at proximity of clients [1]. Distributed generation or decentralized generation units are not planned and dispatchable by central network operator and attached to the low voltage distribution networks directly, but they can influence power flow, voltage profile, stability, reliability and power quality of the system significantly [2]. The most recent definition of distributed generation given by Ackermann is "DG is an electric generation source connected directly to the distribution network or consumer side of the meter" [3].

1.3 Necessity of Optimal Sitting and Sizing

The line loss reduction and voltage profile improvement can be achieved through providing active and reactive power support to the system at each and every bus, which is not feasible economically. So that, most suitable location and capacity of DG should be determined from which optimum benefit could be achieved [4]. The selection of location and size of DG in distribution system is very challenging and crucial job because strategically installed DG gives the benefits such as minimum system losses, voltage profile and stability improvement in the system, deferral of distribution and transmission system expansion to meet the increased load demand, improve voltage regulation, reliability, stability, system security etc. But random integration of DG may create many problems such as reverse power flow, protection coordination issues, voltage swell, frequency deviation, increased system losses, harmonics in the system etc. [5]. Therefore, to achieve maximum benefit from DG placement in distribution network wise selection of its location and unit size is essential.

1.4 Reconfiguration of Distribution Network

The distribution network reconfiguration (DNRC) is a process of altering the topological structure of the feeder by changing the open/close status of the sectionalizing and tie switches in the system [6]. The sectionalizing switches are normally closed, and tie switches are normally open in the system. DNRC is normally done by utility companies of the distribution system to achieve certain objectives. During DNRC a feasible radial configuration is obtained which optimize a certain objective [7]. Total power loss reduction, voltage profile enhancement, reliability improvement, restoring power to any outage partitions of a feeder, relieving overloaded lines are few advantages of the DNRC [8].

1.5 Review of Previous Works

A new method to solve the network reconfiguration problem in the presence of distributed generation (DG) with an objective of minimizing real power loss and improving voltage profile in distribution system was developed [9]. A Meta Heuristic Harmony Search Algorithm (HSA) was applied to simultaneously reconfigure and identify the optimal locations for installation of DG units in a distribution network. Mohamed Imran in [10] suggested a novel integration technique for optimal network reconfiguration and distributed generation (DG) placement in distribution system with an objective of power loss minimization and voltage stability enhancement using Fireworks Algorithm (FWA).

Nguyen et al. in [11] proposed a new methodology to optimize network topology and placement of distributed generation (DG) in distribution network with an objective of reduction real power loss and voltage stability enhancement. A meta-heuristic cuckoo search algorithm (CSA) inspired from the obligate brood parasitism of some cuckoo species which lay their eggs in the nests of other birds of other species for solving optimization problems was adapted to simultaneously reconfigure and identify the optimal location and size of DG units in a distribution network.

The remainder of this paper is organized in four sections. In Section 2, the objective function and constraints which are used in this paper are proposed. In Section 3, the methodology of the proposed method which is hybridization of GA and PSO is presented. In Section 4, the simulation results of the proposed method are discussed which are compared to different techniques. Finally, in Section 5, the conclusion of this paper is summarized.

2. Objective Function and Constraints

The complete optimization problem to solve the optimal reconfiguration along with finding the best location and size of DGs formulated can be summarized as follows.

Objective function to be minimized:

$$OF(X) = w1 * PLI + w2 * QLI + w3 * \Delta VSI \quad (1)$$

and $w_1 + w_2 + w_3 = 1$

2.1 Active Power Loss Index (PLI)

The active power loss index is defined as the ratio of total active power loss after DG placement and reconfiguration to the base case active power loss.

$$PLI = \frac{P_{loss}^{after}}{P_{loss}^{0}} \quad (2)$$

Where,

P_{loss}^{after} = total active power loss after DG placement and reconfiguration.

P_{loss}^{0} = base case active power loss.

2.2 Reactive Power Loss Index (QLI)

The reactive power loss index is defined as the ratio of total reactive power loss after DG placement and reconfiguration to the base case reactive power loss. Mathematically, it can be represented as:

$$QLI = \frac{Q_{loss}^{after}}{Q_{loss}^{0}} \quad (3)$$

Where,

Q_{loss}^{after} = total reactive power loss after DG placement and reconfiguration.

Q_{loss}^{0} = base case reactive power loss.

2.3 Voltage Stability Index (VSI)

Installation of DG directly affects the voltage profile of the distribution network. In order to extract maximum benefit from DG application and reconfiguration, at least one parameter related to the voltage should be included. In this paper, deviation in voltage stability index is considered. The voltage stability index is used to search the most sensitive bus to voltage collapse and considered as candidate location for DG installation, which reduce the size of search space for optimization and leads to fast convergence. The node having small value of VSI is more prone to voltage collapse. The voltage stability deviation index can be defined as:

$$\Delta VSI = max(1 - VSI_i) \quad \forall i = 2 \ldots . N_{bus} \tag{4}$$

In this paper we choose $w_1 = 0.8$, $w_2 = 0.1$ and $w_3 = 0.1$

The vector of control variables is denoted by X as follows:

$$X = \left[X_{Tie}, X_{RCS}, X_{Loc}, X_{PDG}, X_{QDG}\right]$$

$$X_{Tie} = \left[\overline{Tie_1}, \overline{Tie_2}, \ldots \ldots \ldots . \overline{Tie_{N_{Tie}}}\right]$$

$$X_{RCS} = \left[\overline{RCS_1}, \overline{RCS_2}, \ldots \ldots . \overline{RCS_{N_{RCS}}}\right]$$

$$X_{Loc} = \left[\overline{Loc_1}, \overline{Loc_2}, \ldots \ldots . \overline{Loc_{ndg}}\right] \tag{5}$$

$$X_{PDG} = \left[\overline{P_1}, \overline{P_2}, \ldots \ldots \ldots \ldots \ldots . \overline{P_{ndg}}\right]$$

$$X_{QDG} = \left[\overline{Q_1}, \overline{Q_2}, \ldots \ldots \ldots \ldots \ldots . \overline{Q_{ndg}}\right]$$

Constraints:

$$P_{Gi} - P_{Li} = \sum_{j=1}^{nbus} V_i V_j Y_{ij} \cos\left(\theta_{ij} + \delta_i - \delta_j\right)$$

$$\forall i = 1,2 \ldots \ldots nbus \tag{6}$$

$$Q_{Gi} - Q_{Li} = \sum_{j=1}^{nbus} V_i V_j Y_{ij} \sin\left(\theta_{ij} + \delta_i - \delta_j\right)$$

$$\forall i = 1,2 \ldots \ldots nbus \tag{7}$$

$$P_{ss} = \sum_{i=2}^{nbus} P_{Li} + \sum_{i=1}^{nbr} P_{Loss}(i, i+1) - \sum_{i=1}^{ndg} P_{DG,i} \tag{8}$$

$$V_i^{min} \le V_i \le V_i^{max} \quad \forall i \epsilon \{buses\ of\ the\ network\} \tag{9}$$

$$|I_i| \le I_i^{max} \quad \forall i \epsilon \{buses\ of\ the\ network\} \tag{10}$$

$$S_{ij} \le S_{ij}^{max} \tag{11}$$

$$N_L = N_{br} - N_{bus} + 1 \tag{12}$$

$$P_{DGi}^{min} \le P_{DGi} \le P_{DGi}^{max} \quad \forall i = 1,2, \ldots ndg \tag{13}$$

$$Q_{DGi}^{min} \leq Q_{DGi} \leq Q_{DGi}^{max} \quad \forall i = 1,2, \dots ndg \tag{14}$$

$$0.8 \leq pf_{DGi} \leq 1 \ \ \forall i = 1,2, \dots ndg \tag{15}$$

3. Methodology

3.1 GA and PSO Hybridization

The main feature of GA is that, it can search a vast area and come up with reliable results. Bad solutions do not affect GA's end solution negatively since they are discarded as the iterations progress. The strength of PSO as an optimization technique is its flexibility to absorb other parameters for improvement. A result of GA can be nominated to use in the initial stages for assessment purposes and then a PSO improved by incorporating crossover and mutation parameters is selected to be used later for exploitation purposes. Given these strengths for the two optimization techniques, the hybridization is deemed to give excellent results.

It is necessary to use different hybridization tools to combine the features of two different algorithms to get better results. Different selection methods and type of cross over and mutation used are as follows.

- Greedy selection method
- Roulette selection method
- Arithmetic crossover and mutation

3.2 Detail Flow Chart of Proposed Method

The flow chart of step-by-step procedure to implement the proposed Hybrid GA/PSO-TVAC algorithm to find optimal reconfiguration, placement and sizing of DGs in distribution network is described as shown in Fig.1.

4. Results and Discussion

To test and verify the suitability of the proposed hybrid optimization technique to solve the optimal placement, sizing of DG units and reconfiguration problem simultaneously, the suggested method has been implemented and programmed in MATLAB framework. It is applied to IEEE 33-bus test system as shown in Fig.2 to verify its applicability and robustness. The maximum number of DGs that can be installed in all types of test system is limited to three. The unity power factor DG (active power DG) capable of supplying real power and is considered with the unit size limits of 0 to 2 MW.

During application of algorithm in networks, seven scenarios were considered to examine and interpret the quality of suggested method.

Scenario 1: Base case (without reconfiguration and DGs).

Scenario 2: Only network reconfiguration.

Scenario 3: DGs placement and sizing in base case network.

Scenario 4: Optimal placement and sizing of DGs after reconfiguration.

Scenario 5: Network reconfiguration after DGs integration based on scenario 3.

Scenario 6: Simultaneous reconfiguration and optimal sizing of DGs.

Scenario 7: Simultaneous reconfiguration, optimal location and sizing of DGs.

Application on the IEEE 33-bus test distribution network

The performance of the suggested hybrid GA/PSO-TVAC method on 33-bus test distribution network in different scenarios is shown in the Table 1.

From Table 1, it can be perceived clearly that, the in the base case the active power loss in the network is 202.68 kW which is declined to 132.93kW, 74.21 kW, 66.60 kW, 63.13 kW, 57.287 kW and 52.87 kW for scenario 2 to scenario 7, respectively. The percentage active power loss reduction is 34.41%, 63.38%, 67.14%, 68.85%, 71.74% and 73.91% from scenario 2 to scenario 7, respectively.

Also, from Table 1, the minimum voltage magnitude of the system is amended noticeably in all the scenarios. In the base case, the minimum voltage magnitude is 0.9108 p.u. which has been improved to 0.9433, 0.9801, 0.9668, 0.9832, 0.9802, and 0.9791 p.u. from scenario 2 to scenario 7, respectively.

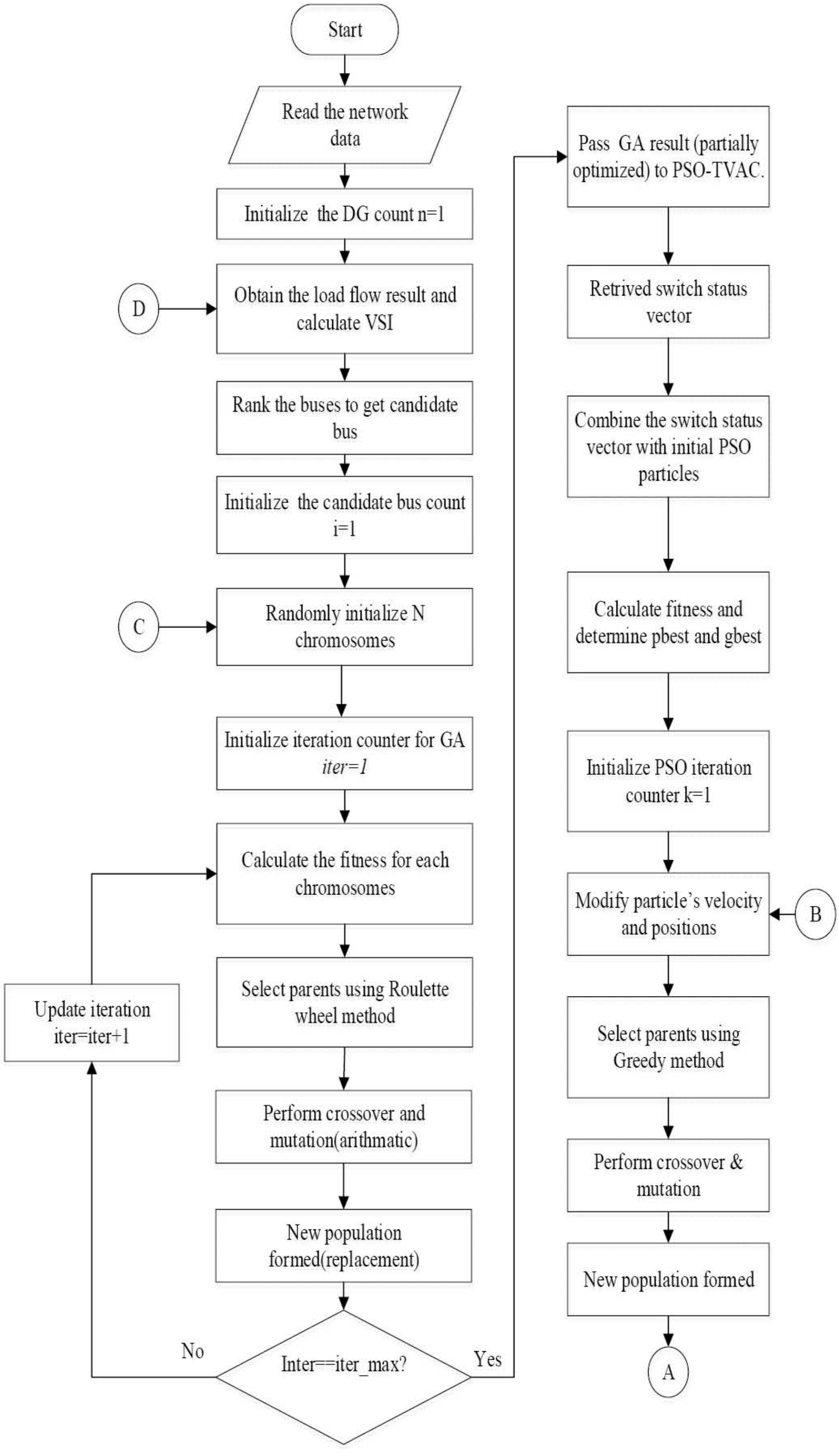
In addition, the VSI is also enhanced from 0.6880 to 0.7945, 0.9249, 0.8840, 0.9343, 0.9250, and 0.9189 by using scenarios 2, 3, 4, 5, 6 and 7, respectively. It is witnessed that the power loss abridged using scenario 7 is the highest, which reveals that the positions of DGs need to optimize concurrently with the reconfiguration and optimum size of DGs process.

The voltage profiles (which are shown in node voltages and VSI of nodes) of all seven scenarios are paralleled and publicized in Fig. 3 and Fig 4. From the figures, it can be observed that the voltage profile at all buses have been improved considerably after using reconfiguration and optimization of position and size of DGs.

For all scenarios, power loss in each line are presented in Fig. 5 and it can be seen from the figure that power loss in each line is radically reduced in each case as compared to the base case scenario.

The convergence characteristic of proposed algorithm can be described by the Fig. 6 which shows the fitness value at different iterations. It can be clearly seen from this convergence characteristic curve that it takes more time to find the best solution if more parameters are included in the optimization problem. It can be seen from Fig. 6 that the fitness value of scenario 7 is the lowest and it takes long time to converge compared to other scenarios because it is the most complex scenario among all.

To validate the acceptability of the proposed hybrid method, the performance of GA/PSO-TVAC has been compared with the performance of fireworks algorithm (FWA) and Cuckoo search algorithm (CSA) available in open literature as shown in Table 1. From the Table 1, it can be witnessed that in all considered scenarios, the proposed hybrid GA/PSO-TVAC has comparable performance of CSA and FWA in terms of power loss reduction, voltage profile improvement and voltage stability enhancement.


Start
Read the network data
Initialize the DG count n=1
Obtain the load flow result and calculate VSI
D
Rank the buses to get candidate bus
Initialize the candidate bus count i=1
Randomly initialize N chromosomes
C
Initialize iteration counter for GA iter=1
Calculate the fitness for each chromosomes
Update iteration iter=iter+1
Select parents using Roulette wheel method
Perform crossover and mutation(arithmatic)
New population formed(replacement)
No
Inter==iter_max?
Yes
Pass GA result (partially optimized) to PSO-TVAC.
Retrived switch status vector
Combine the switch status vector with initial PSO particles
Calculate fitness and determine pbest and gbest
Initialize PSO iteration counter k=1
Modify particle's velocity and positions
B
Select parents using Greedy method
Perform crossover & mutation
New population formed
A

(Cont.)

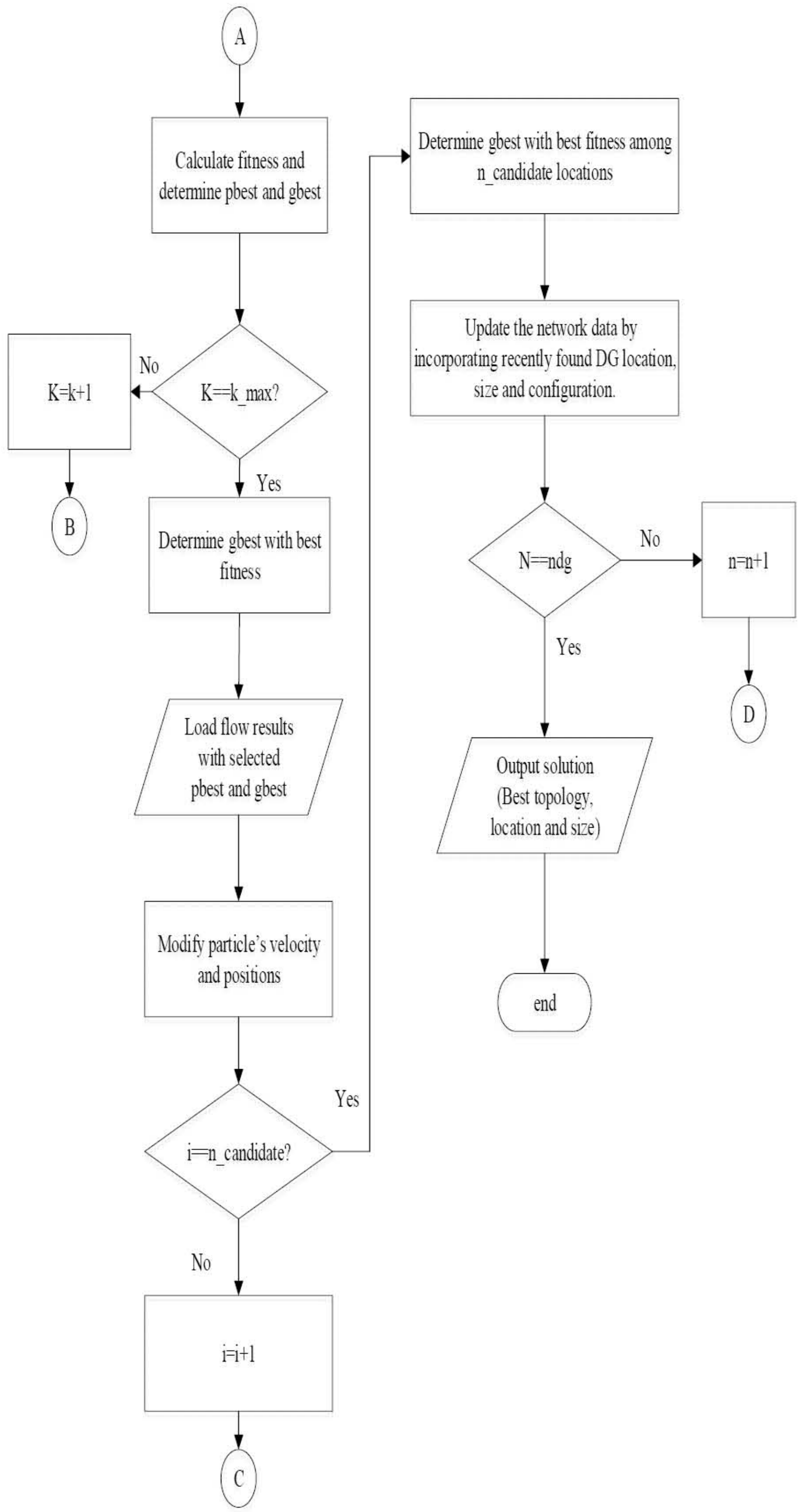


Fig. 1 Flow chart of hybrid GA/PSO-TVAC

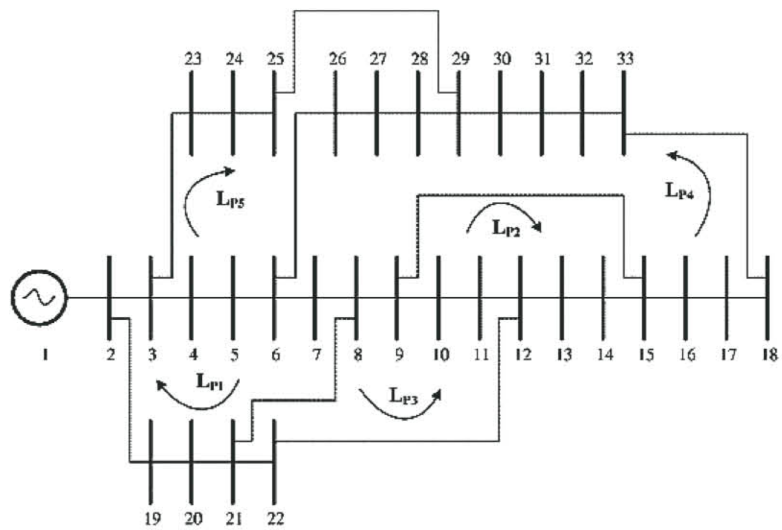


Fig. 2 IEEE 33-bus distribution network

Table 1 Performance analysis of GA/PSO-TVAC on IEEE 33-bus network for type I

Scenario	Item	Proposed Hybrid GA/PSO-TVAC	CS [10]	FWA [11]	HAS [12]
1	Switches opened	33 34 35 36 37	33 34 35 36 37	33 34 35 36 37	33 34 35 36 37
	Power loss (kW)	202.68	202.68	202.68	202.68
	Minimum voltage (p.u.)	0.9108	0.9108	0.9108	0.9108
2	Switches opened	7 9 14 28 37	7 9 14 28 32	7 14 9 32 28	7 14 9 32 37
	Power loss (kW)	132.93	139.98	139.98	138.06
	% Loss reduction	34.41	30.94	30.93	31.88
	Minimum voltage (p.u.)	0.9433(32)	0.9413	0.9413	0.9342
3	Switched opened	33 34 35 36 37	333 34 35 36 37	33 34 35 36 37	33 34 35 36 37
	Size of DG in MW (bus no.)	0.875(11)	0.7798(14)	0.5897(14)	0.1070(18)
		0.925(29)	1.1251(24)	0.1895(18)	0.5724(17)
		0.931(24)	1.3496(30)	1.0146(32)	1.0462(33)
	Power loss (kW)	74.213	74.26	88.68	96.76
	% Loss reduction	63.38	63.36	56.24	52.26
	Minimum voltage (p.u.)	0.9801(18)	0.9778	0.968	0.967
4	Switched opened	7 9 14 28 37	7 9 14 28 32	7 14 9 32 28	7 14 9 32 37
	Size of DG in MW (bus no.)	1.125(30)	1.7536(29)	0.5996(32)	0.2686(32)
		0.592(15)	0.5397(12)	0.3141(33)	0.1611(31)
		0.526(12)	0.5045(16)	0.1591(18)	0.6612(30)
	Power loss (kW)	66.60	58.79	83.91	97.13
	% Loss reduction	67.14	70.99	58.60	52.08
	Minimum voltage (p.u.)	0.9688(32)	0.9802	0.9612	0.9479
5	Switched opened	7 9 26 34 36	33 9 8 36 27	7 34 9 32 28	-
	Size of DG in MW (bus no.)	0.5897(14)	0.7798(14)	0.5807(14)	-
		1.7251(24)	1.1251(24)	0.1895(18)	-
		1.1436(31)	1.3496(30)	1.0146(32)	-
	Power loss (kW)	63.13	62.98	68.28	-
	% Loss reduction	68.85	68.93	66.31	-

	Minimum voltage (p.u.)	0.9832(18)	0.983	0.9712	-
6	Switched opened	7 10 13 27 32	7 10 13 32 27	7 14 11 32 28	7 14 10 32 28
	Size of DG in MW (bus no.)	1.554(29) 0.649(15) 0.486(21)	0.4263(32) 1.2024(29) 0.7127(18)	0.5367(32) 0.6158(29) 0.5315(18)	0.5258(32) 0.5586(31) 0.5840(33)
	Power loss (kW)	57.287	63.69	67.11	73.05
	% Loss reduction	71.74	68.58	66.89	63.95
	Minimum voltage (p.u.)	0.9802(13)	0.979	0.9713	0.97
7	Switched opened	33 35 11 31 26	33 35 11 31 28	-	-
	Size of DG in MW (bus no.)	0.8978 (17) 0.9656(7)	1.4381(25) 0.9646(7)	- -	- -
	Power loss (kW)	52.87	53.21	-	-
	% Loss reduction	73.91	73.75	-	-
	Minimum voltage (p.u.)	0.9791(31)	0.9318	-	-

From the above Fig. 7, it is clear that the proposed hybrid GA/PSO-TVAC method gives the better result than CSA and FWA method in case of 33-bus active distribution network and the robustness of the propose hybrid method is verified for small scale active distribution network.

In contrast with most of the previous researches, which only dealt with unity power factor DG, this research study also considers the type II DG capable of generating both active and reactive power with power factor that can varied from 0.8 to 1 lagging.

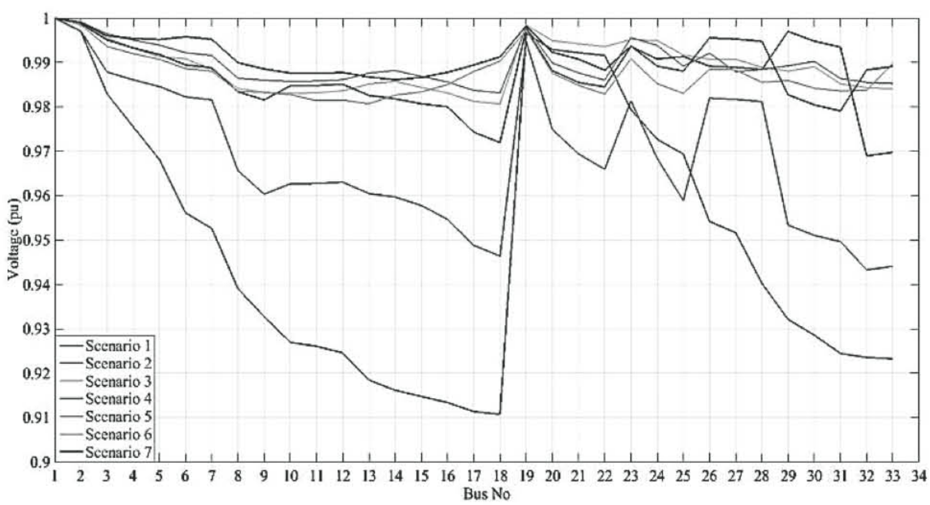


Fig.3 Comparison of node voltages on 33-bus network

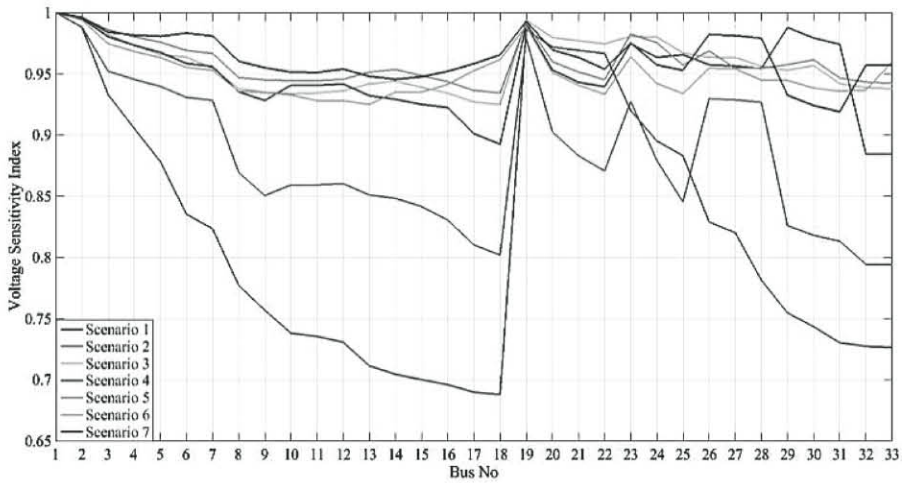


Fig.4 Comparison of voltage stability index of 33-bus network

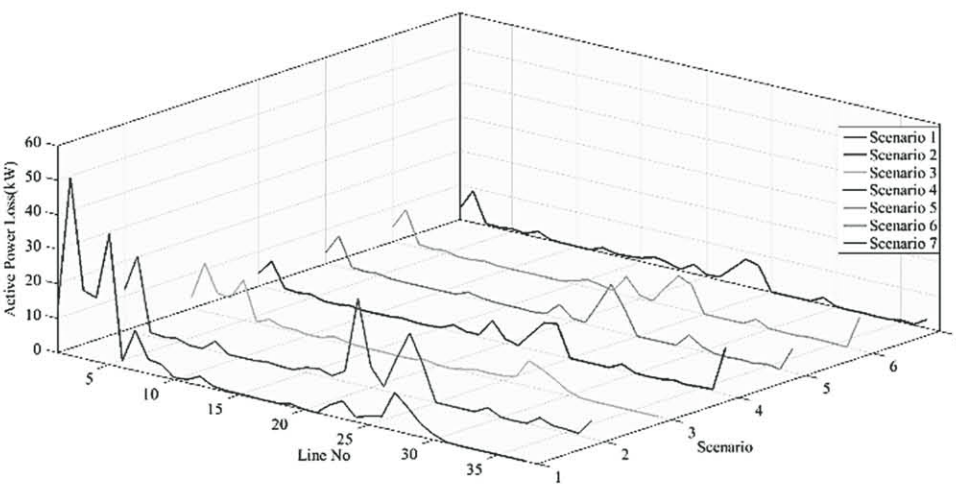


Fig.5 Comparison of power loss at each line of 33-bus network

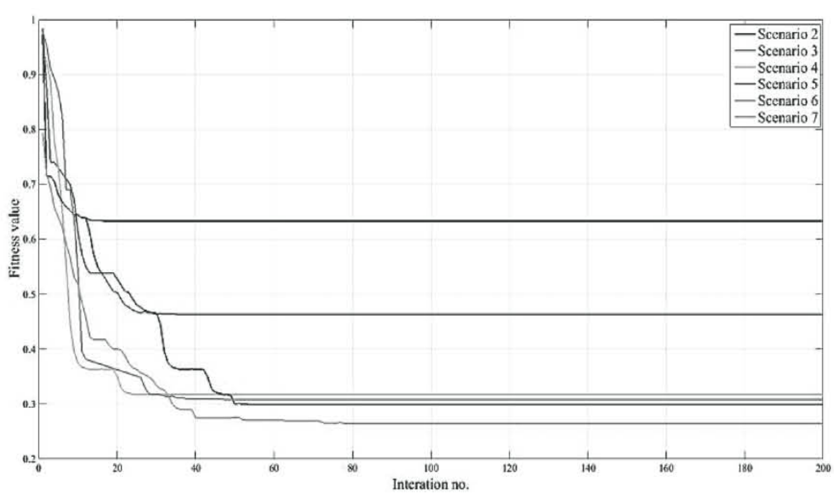


Fig.6 Comparison of GA/PSO-TVAC convergence for different scenarios in 33-bus network

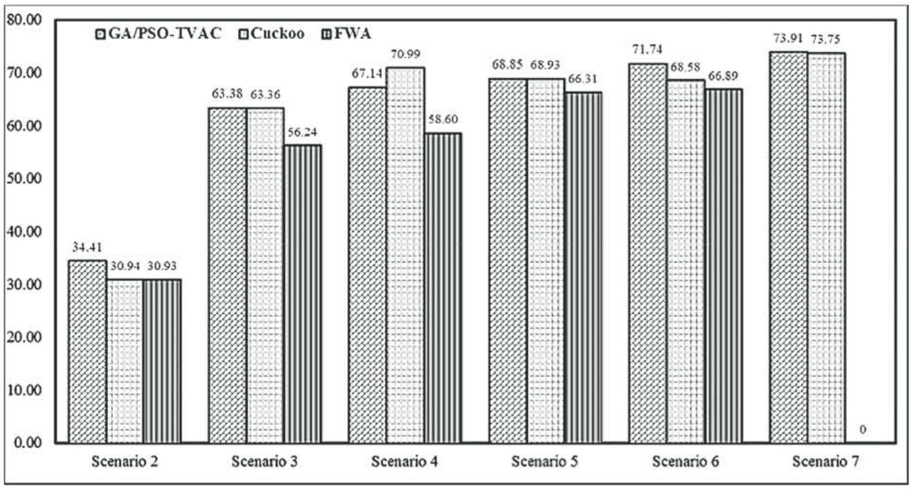


Fig.7 Comparison of percentage of power loss reduction by the proposed hybrid GA/PSO-TVAC and other classical methods for 33-bus network

5. Conclusion

A hybrid of GA and PSO-TVAC, which combines the features of GA and PSO, is suggested to solve the optimization problem. A better performance of proposed algorithm has been obtained by using the best solution of GA as an initial particle of PSO which assists to achieve faster convergence. A hybrid GA/PSO-TVAC has been implemented successfully for optimal placement and sizing of DGs with simultaneous reconfiguration of the network. The main objective is to reduce the active and reactive power loss along with enhancing voltage stability in the distribution network. To prove the superiority of the proposed method, simulations are carried out in different scenarios such as only the reconfiguration of the system, sole installation of DGs, optimal placement and sizing of DGs after network reconfiguration, reconfiguration after optimal placement of DGs, and optimal placement of DG and reconfiguration simultaneously. The performance of proposed method is evaluated in small scale 33-bus network. The performance in system shows that simultaneous reconfiguration and DG placement is superior to achieve the proposed objectives in reference to other scenarios considered. The performance of proposed method has been compared with the results from the literature obtained by applying FWA and CSA and it is concluded that the performance of the proposed hybrid method has beaten the performance of FWA and CSA in most of the cases.

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