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Power Loss Minimization and Reliability Enhancement in Active Distribution Networks Considering RES Uncertainty

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Abstract- Renewable energy sources (RES) utilization has been growing continuously and most probably to be included in distribution networks. The intermittent nature of RES electricity production is due to the dependency on external weather conditions that are changing seasonally. The uncertain power production causes negative impacts on voltage profile and results to increase the power losses. This paper proposes a novel technique based on hybrid optimization methods to determine the optimum power of the uncertain RE sources and the optimum network configuration to minimize the power losses and maintain the voltage profile under normal and shading conditions. The proposed hybrid algorithm utilizes a genetic algorithm (GA) combined with particle swarm optimization (PSO) to overcome the uncertainty and optimize the configuration of the networks. Considering different operational conditions of RES (i.e. normal and shading), the proposed model has tested on standard IEEE 33 and 66 bus systems and validated with other conventional methods to verify the correctness. Moreover, the performance of the proposed method is evaluated by comparing with other methods. The obtained results show a significant reduction of power losses, improvement in voltage profile, and hence increasing the overall distribution system stability.

Keywords Distributed Networks; Genetic Algorithm; Particle Swarm Optimization; Power flow; Network Reconfiguration

1. Introduction

Renewable energy sources become the second source of electricity globally after coal according to the latest report of the international electricity agency [1]. Therefore, most of the power networks include one or more of RES. However, RE sources have intermittent nature of electricity production due to the dependency on weather changes. For example, wind energy depends on wind speed, which changes seasonally. Similarly, electricity production of solar energy sources relies on solar irradiance and the temperature. This uncertain production causes to increase the power losses, poor voltage profile, and hence severe issues in network reliability and stability. Renewable energy and its intermittent nature consideration is the essential aspect while power planning and optimal power flow in distribution networks [2]. Recently, many researchers contributed to optimize the configuration of the radial power network to reduce the power losses and determining the optimum placement of the compensator capacitors for the same purpose. For example, in [3], the authors proposed a solution that focused on the optimization of the topology of the radial distribution systems to minimize the power losses and improve the voltage profile. A new algorithm for optimizing the reconfiguration of radial distribution systems based on particle swarm has been presented in [4] considering the historical local optimum configurations in generating new particles and presented an improvement over the traditional PSO optimization method, the proposed algorithm has tested via three different distribution systems to validate and verify the work. In addition, the power flow analysis has been utilized iteratively by testing all switches one by one to determine the optimum configuration for reducing the power losses [5], the proposed method was accurate in calculating the best configurations of the distributed system; however, it has a slower convergence performance and was not feasible for large distribution network due to the huge number of tested configurations and calculations. Moreover, in [6], the authors proposed a new method for optimizing the configuration of radial systems considering the reactive power compensators to reduce the power losses and enhanced the voltage profile, the authors used simultaneous reconfiguration and allocation technique of the reactive power compensators based on shuffled frog-leaping optimization algorithm in order to mitigate the losses, the optimization problem solution by using multi-objective function has presented and proved that their method realized improved results than that of a single objective-based method.

A novel algorithm based on genetic algorithm combined with minimum spanning tree (MST) algorithm to optimize the reconfiguration of radial power network in order to minimize the power losses by determining the optimum position and values of the capacitors to improve the power quality and reduce the power losses [7]. Besides, another method reported in [8] for reconfiguring of distribution networks and optimizing the capacitor insertion has utilized to maintain the voltage profile and reduce the power losses, the method was based on a simple branch exchange technique and employed a joint optimization algorithm with a genetic algorithm for optimizing the location and sizing of the capacitors and the sequence of the loop selection process, the authors also applied the simulated annealing algorithm to compare the results as regards to the convergence speed; the proposed technique has tested on the IEEE 77 bus distribution system and executed many tests for different load patterns. In [9], the authors modified the binary particle swarm technique to be selective particle swarm to determine the best configuration to reduce the power losses, the proposed methodology has tested on IEEE 33 and 69 bus systems and compared with other methods for validation and comparison.

Moreover, the authors in [10] used a genetic algorithm to solve the problem of power loss minimization by allocating compensator capacitors combined with reconfiguring the network. A new optimization method for determining the optimal size and location of the compensator capacitors has reported in [11], the outcome of the proposed methodology include reduction of power losses and improvement of the voltage profile; it executes two major tasks; firstly, searching the optimum location of the capacitor based on loss sensitivity factor and then using plant growth simulation algorithm to determine the optimal size of capacitors. The proposed technique has validated on IEEE 10, 34 and 85 bus systems. In [12], authors modified PSO algorithm to optimize the placement and sizing of the compensator capacitors and the network reconfiguration in order to reduce the power losses and improve the voltage profile. Furthermore, a new technique based on Ant colony has presented to solve the optimization problem with main objectives of power losses minimization and enhancing the voltage profile in radial power network system [13], the authors followed the combined the two means for power loss reduction, considering compensator capacitors and network reconfiguration. The obtained results proved that the optimal combination of compensator capacitors and network reconfiguration gives better results than using them separately. A novel optimization technique has proposed for optimizing the reconfiguration of distribution networks associated with determining the optimum placement of compensator capacitors in order to reduce the power losses and maintain the voltage profile [14].

The reconfiguration of a distribution network is an optimization problem with multiple objectives such as power loss, voltage profile and system reliability [15], [16]. The reconfiguration of distribution networks is addressed in [17] and the positive implications include power loss minimization and voltage profile improvement is investigated and hybrid algorithm namely IS-BPSO has proposed for problem solution. In [18] the optimal switching and network reconfiguration problem has solved by using the runner-root algorithm (RRA) and the main objectives of the stated problem include power loss, load balancing, switching operation and voltage profile. In [19] the authors proposed a new method namely HLF based on backward/forward sweep technique, which uses the network reconfiguration of capacitor compensated and the proposed model has implemented on IEEE 69-bus distribution network while optimizing power flow. Furthermore, to the optimization benefits of DGs integration in distribution networks are addressed and different methodologies are suggested to obtain enhanced system performance and stability [20-27].

The above survey concludes that essentially two approaches are used for power loss minimization and maintaining the voltage profile, which is based on either compensator capacitors or reconfiguration of distribution network sectionalizing switches. It also lists many methods and algorithms for solving the optimization problem include conventional method, artificial intelligence and heuristic search technique. A number of solution methods considered the two means of reducing the power losses separately, and some of them proposed the combination strategy. However, all techniques and algorithms do not consider the uncertainty in the output power of RES. The intermittent nature of such sources causes a serious problem of system reliability and it may change the results negatively associated with power losses and voltage profile. On the other hand, it is pertinent to mention that the partial shading conditions and RES output power uncertainty consideration are the essential factors while solving the stated problem. Therefore, there is still a knowledge gap that needs to be filled by looking for a new method that considers the uncertainty of renewable energy sources.

This paper presents a novel optimization method considering the uncertainty of RES to determine the optimum power production of the RES based on GA algorithm. In addition, the proposed method utilizes PSO to find out the optimum network configuration to obtain the power loss minimization and maintaining the voltage profile in distribution networks, that include renewable energy sources. This paper is organized as follow:

Section 2, presents the problem statement; section 3 explains the proposed solution and methodology. Results, discussion, and validation of the proposed methodology are summarized in section 4, the rest of paper section 5 concludes the work.

2. Problem Statement

Uncertain power production of RES is due to their intermittent nature. Therefore, considering RES penetration in distribution networks need to be optimized to reduce the power losses and maintain the voltage profile within an acceptable range. Therefore, there should be an optimization method to forecast the optimum output power level of RES and find out the optimum configuration of sectionalizing switches for power loss minimization and maintaining the voltage profile within permissible limits.

3. Proposed Solution

The proposed solution utilizes the hybrid optimization approach, a combination of genetic algorithm and particle swarm optimization techniques. “Fig.1” present the logic flow diagram of the proposed solution.

In the first stage, GA is of charge to forecast the optimum power of the RES based on uncertainty consideration. In addition, normal and shading conditions are considered.

In the second stage, the PSO applied to calculate the best configurations of sectionalized switches that to minimize the power losses, maintain the voltage profile, and satisfy all system constraints. Therefore, it realizes the system reliability and stability by optimizing power losses and voltage profile.

The genetic algorithm has applied to find the optimum power of the RES as follow:

In order to get the optimum power from the PV system, it is necessary to determine the optimum voltage and optimum current based on the equations below [28].

$$I_{sc} = I_{scs} \times (G / G_s) - \alpha_i (T - T_s) \tag{1}$$

$$V_{oc} = V_{ocs} + \alpha_v \times (T - T_s) - R_s \times (I_{sc} - I_{scs}) \tag{2}$$

where:

I_{scs}: Short-circuit current of the PV module at reference solar irradiance G_s (1000 w/m2)

V_{ocs}: Open-circuit voltage at the reference cell temperature T_s (25 ^{0}C)

I_{sc}: Short-circuit current of the PV module at the cell temperature T

V_{oc}: Open-circuit voltage at the cell temperature T

α_i: The temperature coefficient of current (A/^{0}C)

α_v: The temperature coefficient of voltage (V/^{0}C)

R_s: The series parasitic resistance of a solar array.

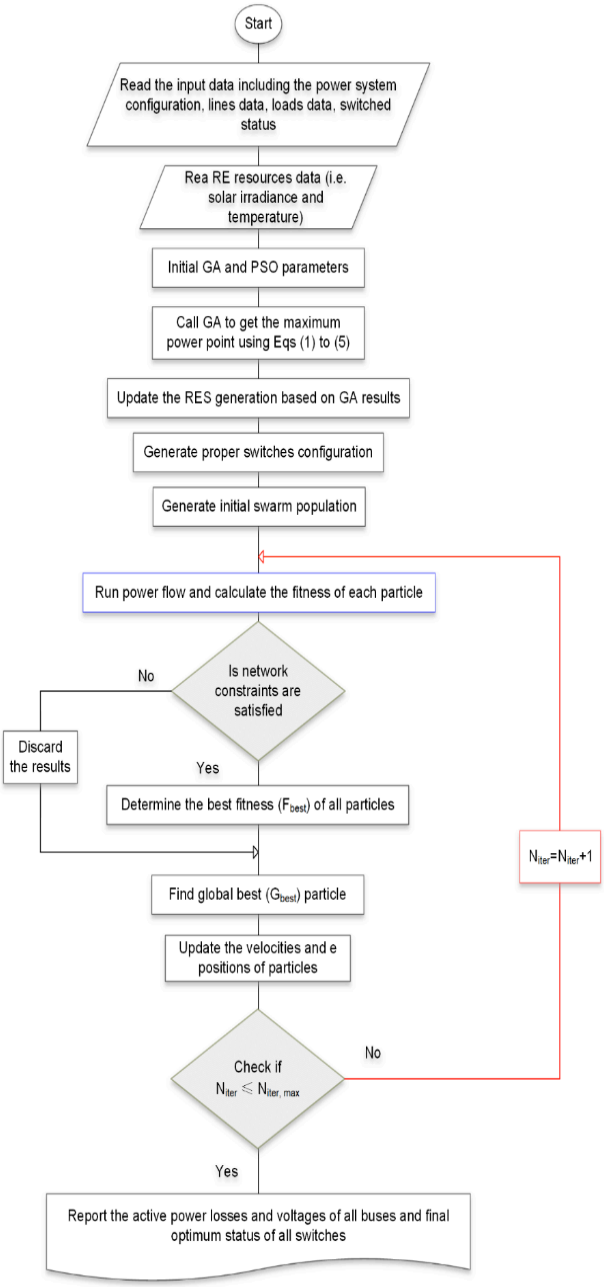

Fig. 1. Logic diagram of the proposed methodology

Furthermore, the optimal module current, voltage, and corresponding optimal power can be determined from Equation (3), (4) and (5), respectively as follows:

$$I_{optimum} = k_i \times I_{sc} \tag{3}$$

$$V_{optimum} = k_v \times V_{oc} \qquad (4)$$

$$Max\{P_{optimum}\} = V_{optimum} \times I_{optimum} \qquad (5)$$

where k_i and k_v are proportional factors, with typical values in the ranges of (0.75-0.85) and (0.9-0.92), respectively [14].

After determining the optimum power at a specific temperature and irradiance, the generation of PV is updated in the bus data. Then the PSO is started to looking for the global best values of switch configuration based on the fitness value, which represent the minimum power losses by solving power flow using Newton Raphson.

The objective function of the PSO is as follow:

$$Max\{1/sum(P_{losses}\} \qquad (6)$$

P_{losses} of branch k between buses i and j is: $P_{ij} + P_{ji}$

Sum (P_{losses}) show the total power loss. There are two radial power networks of interest to be tested in this research. In the first scenario, the IEEE 33 bus system has considered, the line diagram of the 33-bus system is depicted in "Fig.2" and the second scenario considering the IEEE 66 bus system which is shown in the "Fig.3". The solid lines show the busses and the normal lines show the switching track that may be connected or disconnected. In the first system, RE sources are connected at buses 9, 19, 25, 26, and 32. The second system considers the connection of RE sources at buses 15, 1 8, 19, 23, 25, 26, 32, and 35. These systems to be executed under the normal conditions, which means constant output power of RES and non-shading condition. In addition, it will be tested for shading condition and variant RES. The buses, branches and system data of IEEE 33 bus system can be found in ref [28].

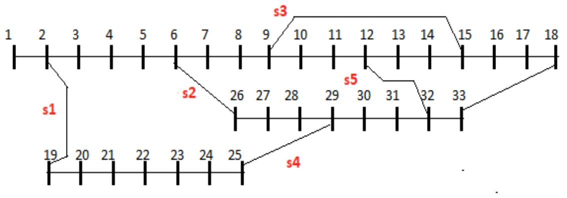

Fig. 2. IEEE 33-bus distribution power system

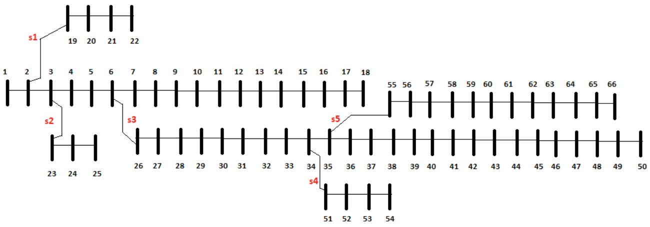

Fig. 3. IEEE 66-bus distribution power system

4. Simulation Results and Discussions

The proposed technique has tested on two standard systems, i.e. IEEE 33 and 66 bus systems. Furthermore, each scenario has two test cases: i.e., the normal case when there is no shading effect and shading case when there is a partial shading effect.

4.1. Scenario 1- Implementation on IEEE 33 bus system

The proposed methodology has implemented for minimizing power loss and voltage profile improvement in the IEEE 33-bus test system to verify its efficiency compared to other solution techniques reported in the literature. Two cases are analyzed as below considering normal and shading conditions

4.1.1. Test Case 1 for IEEE 33 bus system

In this test case, the proposed model has implemented on the IEEE 33 test system. The RE Source are connected at buses 9, 19, 25, 26 and 32 considering normal conditions and no shading effects. The objective of GA is to determine the optimum maximum power of the PV at a given operating condition of T and G. "Fig.4" depicts the convergence of the genetic algorithm which achieved the solution after 10 iterations only. Then the PSO started with the updated bus data based on the results of the GA optimization to determine the global best configuration of switches for the reduction the power losses. "Table 1." lists the results obtained by the proposed PSO; it shows clearly that, the power loss has significantly reduced by 33% with enhanced voltage profile shown in "Fig.5".

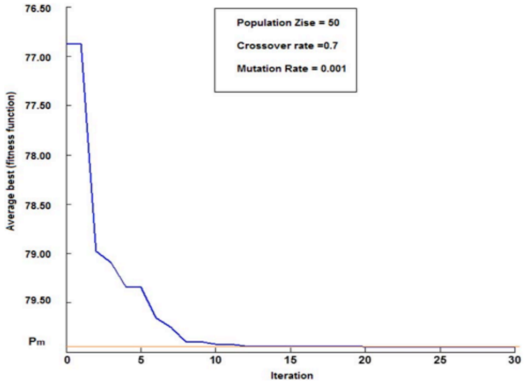

Fig. 4. Genetic algorithm convergence

On the other hand, the same test data has used by one of the conventional methods. The results of the conventional methods are depicted in "Fig.6" and "Table 2."respectively. It **shows** that the power loss has reduced by 24.4% only, as well as insignificant improvement occurred in the system voltage profile.

Table 1. Results obtained by the proposed method under normal conditions.

Description	Reconfiguration	
	Before	After
Tie switches	33, 34, 35, 36, 37	7, 10, 14, 32, 37
Power loss	208.3869 kW	139.5616 kW
Power loss Reduction	------	32.0277 %
Minimum voltage	0.91076 p.u.	0.94235 p.u.

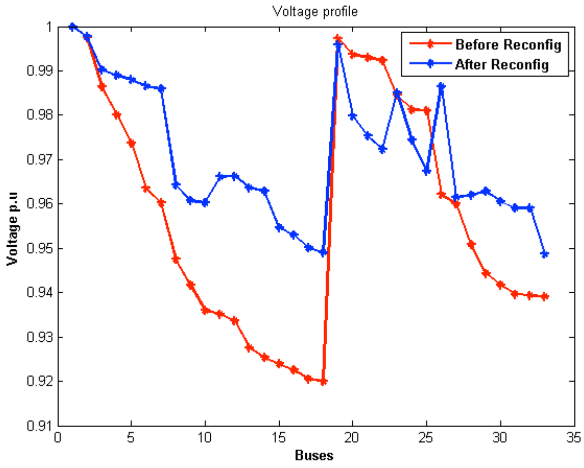

Fig. 5. Voltage profile of IEEE 33 bus system by the proposed technique at normal condition.

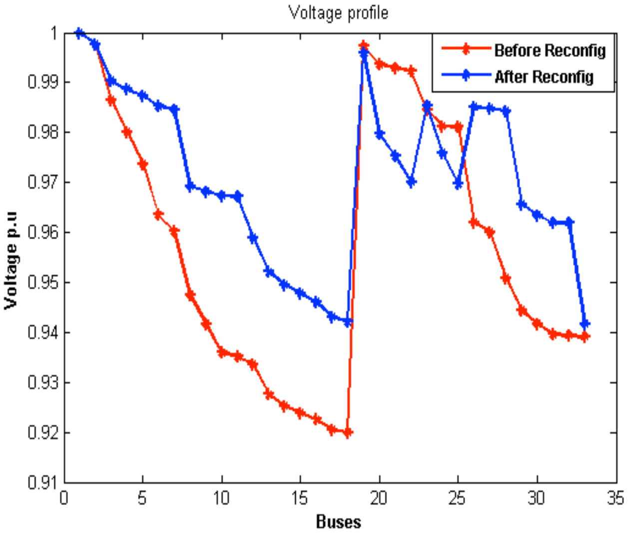

Fig. 6. Voltage profile of IEEE 33-bus system using conventional methods at normal condition

Table 2. Results obtained by conventional methods under normal conditions.

Description	Reconfiguration	
	Before	After
Tie switches	33, 34, 35, 36, 37	7, 21, 27, 32, 34
Power loss	208.4592 kW	157.5767 kW
Power loss Reduction	------	24.4088 %
Minimum voltage	0.91076 p.u.	0.92264 p.u.

4.1.2 Test Case 2 for IEEE 33 bus system:

In this test case, the IEEE 33 bus system data has used under consideration of shading conditions, as shown in "Table 3." The proposed methodology has implemented on IEEE 33 bus system. The results obtained, as shown in "Fig.7", present a significant improvement in the voltage profile. Moreover, "Table 4." lists the results obtained by the proposed model, which contain the power losses before and after configuration of the network, and "Table 5." presents the results obtained by other conventional methods.

Table 3. RES bus data at partial shading

Bus ID	Type	Pd	Qd	Base KV	Vmax	Vmin
9	1	0.01	12.66	12.66	1	0.9
19	1	0.01	12.66	12.66	1	0.9
25	1	0.01	12.66	12.66	1	0.9
26	1	0.01	12.66	12.66	1	0.9
32	1	0.01	12.66	12.66	1	0.9

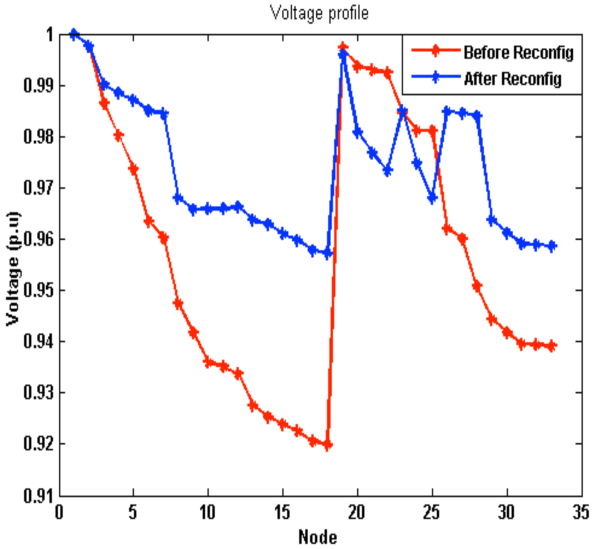

Fig. 7. Voltage profile of IEEE 33-bus system by the proposed technique at shading condition.

Table 4. Results obtained by the proposed method

Description	**Reconfiguration**	
	Before	**After**
Tie switches	33, 34, 35, 36, 37	7, 11, 14, 17, 28
Power loss	144.3863 kW	85.5715 kW
Power loss Reduction	------	40.7343 %
Minimum voltage	0.91995 p.u.	0.95368 p.u.

Table 5. Results obtained by the conventional method

Description	**Reconfiguration**	
	Before	**After**
Tie switches	33, 34, 35, 36, 37	---
Power loss	208.4592 kW	NaN kW
Power loss Reduction	144.3863	NaN %
Minimum voltage	0.91075 p.u.	NaN p.u.

It shows that the power loss has been reduced by 40%. However, the other methods are failed to manage this case. In addition, under testing the normal and shading operating conditions "Table 6." summaries the results achieved by the proposed and conventional methods.

for the proposed method and the conventional techniques, "Fig.8 and 9", charts the comparison of the reduction in power losses and improvement in voltage profile between the new method and the traditional methods.

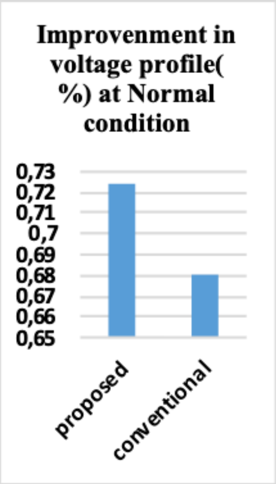

Fig. 8. Voltage improvement

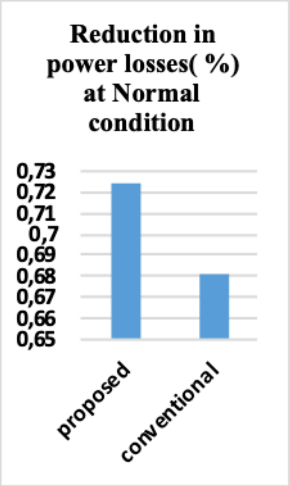

Fig. 9. Power loss reduction

Table 6. Results of the proposed and the conventional methods under different operating conditions

Description	**Power losses reduction %**		**Voltage profile improvement %**	
	Normal	**Shading**	**Normal**	**Shading**
Proposed Technique	32%	40%	4%	5%
Conventional Method [29]	24%	NaN %	2%	NaN %

4.2 Scenario 2- Implementation on IEEE 66 bus system:

The proposed methodology has implemented for minimizing power loss and voltage profile improvement in the IEEE 66-bus test system to verify its efficiency compared to other solution techniques reported in the literature. Furthermore, two cases are analyzed considering normal and shading conditions.

4.2.1 Test Case 1 for IEEE 66 bus system:

In this test case, the proposed methodology has implemented on IEEE 66 bus system under consideration of no shading conditions. The results obtained by the proposed model shown in "Fig.10" present the comparison of voltage profiles. Clearly, shows that the proposed methodology obtain better results of 0.7236 p.u. as compared to conventional methods obtaining 0.5803 p.u. In addition, the "Table 7." lists the test results, including the reduction in power losses before and after optimization.

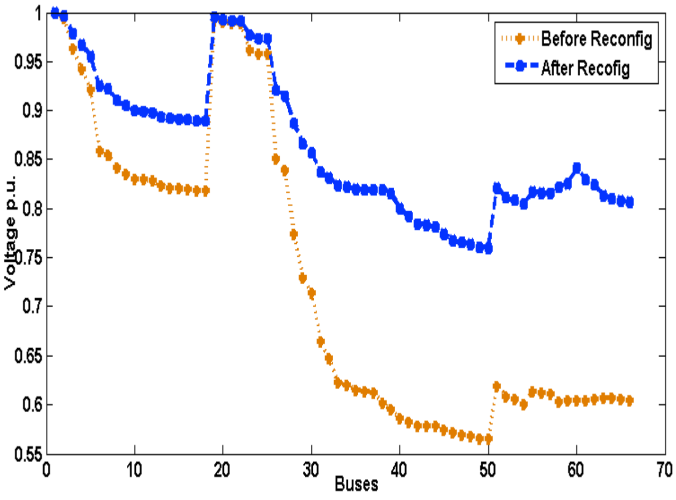

Fig. 10. Voltage profile of the proposed method for the 66-bus system under normal conditions

Table 7. Results of 66-bus system test under normal conditions

Description	Proposed	Conventional
Total real demand	7945.00	7945.00
Total reactive demand	5320.00	5320.00
Min voltage before configuration	0.58030	0.58030
Min voltage after configuration	0.72360	0.68100
Power losses reduction before %	12.500%	12.500%
Power losses reduction after %	25.800%	21.900%

4.2.2 Test Case 2 for IEEE 66 bus system:

In this test case, the proposed model has implemented on IEEE 66 bus system with the consideration of partial shading conditions. The obtained results by the proposed model is shown in “Fig.11”; it also presents the voltage profile comparison and effectiveness of the proposed model that obtained better results than conventional methods reported. In addition, “Table 8.” lists the test results, including the reduction in power losses before and after optimization.

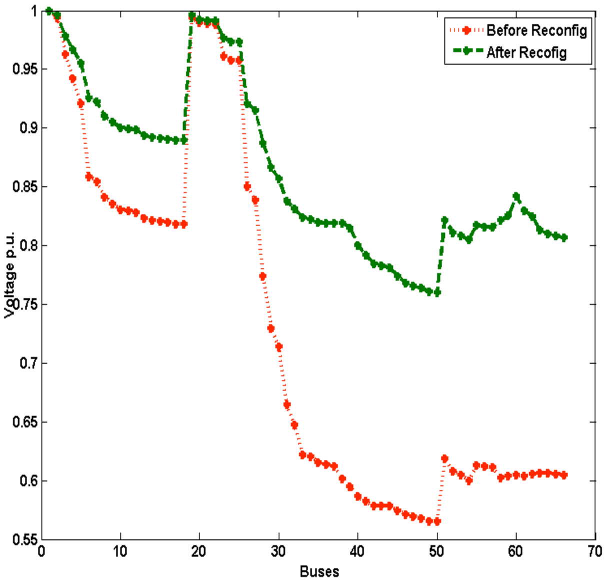

Fig. 11. Voltage profile of the proposed method for 66-bus test system under shading conditions

Table 8. Results of 66-bus system test under shading condition

Description	Proposed	Conventional
Total real demand	6885.00	NaN
Total reactive demand	4785.00	----
Min voltage before configuration	0.56510	----
Min voltage after configuration	0.75990	----
Power losses reduction before %	28.700%	----
Power losses reduction after %	1.3000%	----

4.3 Validation

In order to verify the correctness of the proposed method, the same configurations and parameters have been validated with other valid method presented in [30]. The results of the proposed method and the conventional method are verified, which prove the correctness of the proposed method.

5. Conclusions

Utilization of RES is growing rapidly and commonly included in distributed power systems. Due to the stochastic behavior of RES output power and its integration into the distribution system causes to negatively affect the network reliability. In this paper, a new hybrid optimization technique based on GA and PSO algorithm has proposed for minimizing power losses and maintaining voltage profile at different operating conditions of normal and shading cases. It utilizes the GA to forecast the optimum power produced by RES at corresponding operating conditions of temperature, Irradiance, and wind speed. Then it applied PSO to determine the optimum configuration for minimizing the power losses, maintaining the voltage profile at acceptable ranges, and hence increasing the efficiency, reliability, and system stability. The main contributions of this paper can be summarized as follow:

- Power loss minimization and reliability enhancement in active distribution networks considering RES out power uncertainty and its implications are addressed.
- A novel GA-PSO algorithm based meta-heuristic technique has proposed for the optimal placement of RES and reconfiguration of distribution networks.
- The developed model has implemented on standard IEEE 33 and 66-bus test system and the impact of partial shading and RES output power uncertainty is studied.
- The proposed approach provides better results in all considered cases and fast computation than other conventional methods, such as power loss reduction and voltage profile improvement.
- The superiority of the proposed model has evaluated by comparing with other existing methods.

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