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OPTIMAL REACTIVE POWER DISPATCH IN POWER SYSTEM COMPRISING RENEWABLE ENERGY SOURCES BY MEANS OF A MULTI-OBJECTIVE PARTICLE SWARM ALGORITHM

The electricity grid is developing fast today, with more renewable energy sources (RES) penetrating the industry. The traditional optimal reactive power dispatch (ORPD) is a complex and non-linear optimization problem and one of the sub-problems of the optimal distribution of the power flows in an energy system. The incorporation of RES further exacerbates this complex problem. In this paper, the ORPD problem solved as a single-objective as well as a multi-objective optimization problem in a power system comprising RES. This paper aims to minimize the active power loss and improve voltage profile by introducing renewable energy sources, such as wind and solar sources, in addition to the existing traditional sources. The optimization in a power system is achieved by adjusting control variables, such as generator voltages, tap ratios of a transformer, shunt capacitors, without violating technical constraints that are presented as equalities and inequalities. A multi-objective particle swarm optimization (MOPSO) algorithm is proposed to obtain the optimal values of the control variables of the power system. In the first stage, the modified PSO (MPSO) used to determine the optimal location of RES for IEEE 14 bus and IEEE 30 bus test systems. In the second stage, MPSO and genetic algorithm (GA) were used for individual optimization of objectives, and in the third stage, the objective functions are treated as competing objectives and optimized simultaneously in a single run. Finally, the best compromise solution was extracted from the optimal Pareto set and supplied to the decision-maker by fuzzy set theory. Also, the results of MOPSO are compared to MPSO, GA, and multi-objective GA.

Keywords: multi-objective optimization, particle swarm optimization, photovoltaic panels, renewable energy sources, wind energy, power loss, voltage deviation.

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ОПТИМАЛЬНОЕ РАСПРЕДЕЛЕНИЕ РЕАКТИВНОЙ МОЩНОСТИ В ЭНЕРГОСИСТЕМАХ С ВОЗОБНОВЛЯЕМЫМИ ИСТОЧНИКАМИ ЭНЕРГИИ С ИСПОЛЬЗОВАНИЕМ МНОГОЦЕЛЕВОГО АЛГОРИТМА РОЯ ЧАСТИЦ

Современные электроэнергетические системы (ЭЭС) весьма быстро развиваются в направлении использования возобновляемых источников энергии (ВИЭ). Задача поиска оптимального распределения реактивной мощности является сложной и нелинейной оптимизационной задачей, а также одной из подзадач оптимального распределения потоков мощности в ЭЭС. Введение в ЭЭС ВИЭ еще больше осложняет проблему. В данной статье проблема оптимального распределения реактивной мощности рассматривается и как одноцелевая, и как многоцелевая задача оптимизации. Статья направлена также на минимизацию потерь активной мощности и улучшение профиля напряжений узлов ЭЭС путем внедрения таких ВИЭ, как ветровые и солнечные источники. Оптимизация режима ЭЭС производится путем наилучшего выбора управляющих переменных, таких как напряжения генераторов, изменение коэффициентов трансформации трансформаторов, допускающих регулирование под нагрузкой, величин шунтирующих конденсаторов. Оптимизация выполняется без нарушения технических ограничений, которые представлены в работе в виде равенств и неравенств. Предложено использование алгоритма многоцелевой оптимизации роя частиц (MOPSO) для получения оптимальных значений управляющих переменных энергосистемы. На первом этапе модифицированный одноцелевой алгоритм роя частиц (MPSO) используется для определения оптимального местоположения ВИЭ для тестовых схем IEEE, содержащих 14 и 30 шин (узлов). На втором этапе MPSO и генетический алгоритм (GA) используется для раздельной оптимизации целей, а на третьем этапе целевые функции обрабатываются как конкурирующие цели и оптимизируются совместно с помощью MOPSO. Наконец, с помощью теории нечетких множеств из оптимального множества Парето было извлечено наилучшее компромиссное решение для предоставления лицу, принимающему решение. Также результаты работы MOPSO сравниваются с MPSO, GA и многоцелевым GA.

Ключевые слова: алгоритм многоцелевой оптимизации, алгоритм роя частиц, фотоэлектрические панели, возобновляемые источники энергии, энергия ветра, потери активной мощности, отклонение напряжения.

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Introduction. Renewable energy sources (RES) are now playing a major role in the performance of the integrated power system. They not only minimize harmful greenhouse gas emissions and fossil fuel reliance, but also reduce the cost of electricity production over the long term. There are two goals of economic operation on the power grid, one is active power control, and another is reactive power dispatch. By incorporating RES into the system, both goals can be improved [1, 2].

However, renewable distributed generation, i.e., wind and solar, are of an intermittent nature. Many challenges in the distribution system are introduced by this intermittent generation and load variance. These challenges include voltage drops and rises, power oscillations, problems in voltage stability, and increased power losses, so the ORPD study becomes necessary to incorporate both wind and solar energy in the power system [2, 3].

The ORPD problem is a sub-problem of optimal power flow which helps determine the optimal values to the control variables such as the generator voltage, tap changing transformer setting, and the optimal reactive power injected into the system, to minimize the active power loss and enhance voltage stability simultaneously [4, 5].

However, The ORPD problem is a complex and non-linear problem, and many traditional optimization methods have failed to solve it, such as the Newton method, linear programming, interior-point, and quadratic programming methods, because these techniques have low precision, high complexity, and failure to find the local and global optimum and thus result in unsafe convergence [6–8]. in order to overcome these disadvantages, many modern meta heuristic techniques have been applied: particle swarm optimization (PSO), evolutionary programming (EP), the genetic algorithm (GA) [4, 9–11].

Recently, the problem of ORPD has been presented as a multi-objective (MO) problem of optimization. The problem is not, however, viewed as a true problem with multiple goals. With a weighted sum of objectives, it was transformed into a single objective problem. Unfortunately, there is no logical basis for adequate weight determination and the objective function established in this way will lose importance because of mixing non-appropriate objectives [12, 13]. In addition, this requires multiple runs as many times as the number of desired Pareto-optimal solutions (POS). Therefore, traditional optimization approaches can at best find one solution in one simulation run which makes those methods inconvenient to solve multi-objective optimization problems [4, 14].

To avoid this difficulty, in this work, the concept of MOPSO for Multi-objective optimization was presented because of their ability to find a range of Pareto-optimal solutions in a single simulation run [4].

This paper aims to minimize power loss and voltage deviation by setting the control variable and integration of renewable energy sources in the network. Therefore, MOPSO is suggested to obtain the optimal control variable of the power system. As a test system, the IEEE 14 and IEEE 30 bus systems were used to demonstrate the applicability and efficacy of the proposed process.

Problem formulation

The problem can be mathematically formulated as a nonlinear constrained multi-objective optimization problem as follows [15]:

$$Minimize\ \ f = \left[\ F_{P_{loss}}, F_{VD}\ \right], \tag{1}$$

$$\text{Equality constraint } g\left(x,u\right) = 0, \tag{2}$$

$$\text{Inequality constrain } H\left(x,u\right) \leq 0, \tag{3}$$

where x is the dependent variables comprised of voltages of load bus V_{Li} (PQ bus), reactive power of generators Q_{Gi}, generator actual power at slack bus P_{G1}. It is possible to express x as follows:

$$x^T = \left[P_{G1}, V_{L1} \ldots. V_{NLB}, Q_{G1} \ldots. Q_{GNG}\right], \tag{4}$$

where u is the control variables comprised of generator bus voltages V_{Gi} (PV bus), tap ratios of transformer T_i, and reactive power injection Q_{Ci}. We can express u as follows:

$$u^T = \left[\ V_{G1} \ldots. V_{NG}, T_1 \ldots. T_{NT}, Q_{C1} \ldots Q_{CNC}\right], \tag{5}$$

A. Objective functions

In this work, the objective functions are the active power loss minimization and voltage profile improvement for power system optimized simultaneously in a single run.

1) Minimization of active power loss (P_{loss})

One of the main objective functions of the reactive power optimization is to minimize the active power losses in the transmission lines, which can be expressed as follows:

$$F_{P_{loss}} = \sum_{k=1}^{N_E} G_k \left[V_i^2 + V_j^2 - 2V_iV_j\,cos\left(\delta_i - \delta_j\right)\right], \tag{6}$$

where G_k is the conductance of the k^{th} line; NE is the transmission line number; V_i and V_j are the voltage at i and j bus.

2) Minimization of Voltage deviation (VD)

$$F_{VD} = \sum_{i=1}^{N_{LB}} \left| V_{Li} - 1 \right|, \tag{7}$$

where N_{LB} is the number of load buses and V_{Li} actual voltage magnitudes at bus i.

B. Problem Constrains

1) Equality constraints

The equality constraints are active and reactive power balance at each bus, which can be formulated by power flow equations as follows:

$$P_{Gi} - P_{Di} - V_i \sum_{j=1}^{N_B} V_j \left[G_{ij}\, cos\left(\delta_i - \delta_j\right) + B_{ij} \sin\left(\delta_i - \delta_j\right) \right] = 0, \tag{8}$$

$$Q_{Gi} - Q_{Di} - V_i \sum_{j=1}^{N_B} V_j \left[G_{ij} \sin\left(\delta_i - \delta_j\right) + B_{ij} \cos\left(\delta_i - \delta_j\right) \right] = 0, \tag{9}$$

where N_B is the number of buses; P_{Gi} and Q_{Gi} are the generator real and reactive power, respectively; P_{Di} and Q_{Di} are the load active and reactive power, respectively.

C. Inequality constraints

The inequality constraints represent the system operating constraints as follows.

1) Generation constraints:

$$V_{Gi}^{\min} \le V_{Gi} \le V_{Gi}^{\max}, \; i = 1, \dots, N_G, \tag{10}$$

$$Q_{Gi}^{\min} \le Q_{Gi} \le Q_{Gi}^{\max}, \; i = 1, \dots, N_G, \tag{11}$$

where N_G is total number of generators.

2) Transformer constraints:

$$T_i^{\min} \le T_i \le T_i^{\max}, \; i = 1, \dots, N_T, \tag{12}$$

where N_T is the number of transformers.

3) Switchable reactive power sources constraints

$$Q_{ci}^{\min} \le Q_{ci} \le Q_{ci}^{\max}, \; i = 1, \dots, N_C. \tag{13}$$

a. Security constraints:

$$V_{Li}^{\min} \le V_{Li} \le V_{Li}^{\max}, \; i = 1, \dots, N_{LB}, \tag{14}$$

$$S_{Li} \le S_{Li}^{\max}, \; i = 1, \dots, N_E, \tag{15}$$

where V_{Li} is the voltage of the PQ bus and S_{Li} is transmission line loading of i^{th} branch.

Best Compromise Solution (BCS)

Fuzzy set theory has been implemented to derive efficiently a candidate Pareto optimal solution for the decision makers. The fuzzy sets are defined by equations (16) called membership functions [4, 16].

$$\mu_{Fi} = \begin{cases} 1 & F_i \le F_i^{\min}; \\ \dfrac{F_i^{\max} - F_i}{F_i^{\max} - F_i^{\min}} & F_i^{\min} \le F_i \le F_i^{\max}; \\ 0 & F_i \ge F_i^{\max}, \end{cases} \tag{16}$$

where $F_i^{\max}$ and $F_i^{\min}$ are the maximum and minimum values of the i^{th} objective function, respectively.

In relation to all M non-dominated solutions, the efficiency of each M solution can be evaluated by normalization of its performance relative to sum of the performances of the M solutions as follows:

$$\mu^k = \frac{\sum_{i=1}^{Nob} \mu_{Fi}^k}{\sum_{k=1}^{M} \sum_{i=1}^{Nob} \mu_{Fi}^k}, \quad k = 1, \dots, M, \tag{17}$$

where N_{obj} is the number of objectives. The BCS is that having the maximum value of μ^k.

Wind Energy Modeling

The output power from a wind power unit is assigned in terms of the wind speed as expressed in (18) [3].

$$P_w(v_w) = \begin{cases} 0 & for\ v_w < v_{cin}\ and\ v_w > v_{cout}; \\ P_{wr}\left(\dfrac{v_w - v_{cin}}{v_{wr} - v_{cin}}\right) & for\ v_{cin} \le v_w \le v_{wr}; \\ P_{wr} & for\ v_{wr} \le v_w \le v_{cout}, \end{cases} \tag{18}$$

where P_{wr} is the rated power of the wind turbine, v_{wr} is the rated wind speed of the wind turbine, v_{cin} is the cut-in wind speed of the wind turbine, and v_{cout} is the cut-out wind speed. The numerical values of the speed considered are: v_{cin} = 3 m/s, v_{wr} = 16 m/s and v_{cout} = 25 m/s, same as the data of 3 MW turbine model Enercon E82-E4.

Photovoltaic energy modeling

In this paper, the power output of the solar photovoltaic (PV) arrays is determined by using the simplified method of estimating the output of the PV modules under different operating conditions. The PV module cannot generate a bulk amount of electrical power. Therefore, a large number of PV modules are connected in series and parallel to the design PV array. Series and parallel connection of PV modules boost up voltage and current to tailor PV array output [1, 17, 18]. If there are NS number of series and NP number of parallel PV modules, then the array power output is given by

$$P_A = N_S N_P P_{\max}. \tag{19}$$

The maximum power output of the PV module is given by [19].

$$P_{\max} = FF.V_{oc}.I_{sc}, \tag{20}$$

where FF is the fill factor of PV module, V_{oc} and I_{sc} are the open circuit voltage and short circuit current.

Simulation results

The algorithm is tested on IEEE 14-bus and IEEE 30-bus test systems for two different cases for each system. The system line and bus data as well as the system constraints are found in reference [4]. The number of control variables for the IEEE-14 system are 9, and the number of control variables for the IEEE 30 system are 12.

A. Calculate Power Output from renewable energy sources

Egypt possesses an abundance of land, sunny weather, and high wind speeds, making it a prime location for renewable energy projects. Egypt enjoys prominent wind resources in the Gulf of Suez, which is considered one of the best locations in the world with high and regular speeds. Therefore, in this paper, wind speed and solar radiation data from sites in Egypt were used to calculate the power generated in wind farms as well as solar power plants [20]. The locations for wind farms in this work are Gabal Al Zeit and Zafaran, while the locations for solar power plants are Benban and Kuraymat.

1) For IEEE 14 bus

The optimal locations of renewable energy sources for this system obtained by using MPSO are buses 4, 5, and 14. In bus 4, there is a wind farm and annual average wind speed from the location of Gabl Al Zeit in Egypt 8.8194 m/s in the year 2010 and this farm consists of 50 wind turbines. The power generation for each wind turbine in this location is calculated by equation (19) and the total power generation for this wind farm is 67.147 MW. In bus 5, there is a wind farm consisting of 25 wind turbines with annual average wind speed of 7.536 m/s from the location of Zafaran in Egypt in 2010. The power generation for each wind turbine in this location is calculated by equation (19) and the total power generation for this wind farm is 26.1715 MW.

In addition, in bus 14, there is a solar power plant with annual average radiation of 508.6 W/m^2 from the location of Benban in Egypt. The total power generation for this plant in this location is calculated by equation (20) and equals 11.377 MW.

2) For IEEE 30 bus

The optimal locations of renewable energy sources for this system obtained by using MPSO are buses 6, 7, 19 and 30. There is a wind farm in the location of Gabl Al Zeit in Egypt on bus 6 consisting of 60 wind turbines. The overall power output for this wind farm is 80.57 MW. In bus 7, there is a wind farm in the location of Zafaran in Egypt, which consists of 35 wind turbines with the total power generation of 31.41 MW. In bus 19, there is a solar power plant in the location of Benban in Egypt: the total power generation for it is calculated by equation (20) and equals 14.153 MW. Moreover, there was a solar power plant added to bus 30 in the location of Kuraymat in Egypt, with the annual average radiation from this location of 474.762 W/m^2. The total power generation for this plant in this location is calculated by equation (20) and is equal to 10.377 MW.

B. The results of IEEE 14-bus system

1) Case 1: Minimization of active P_{loss} *without RES for IEEE 14 bus*

Fig. 1 shows a reduction of P_{loss} after adjusting the control variables such as generator voltages, transformer tap-settings and capacitor banks by using MPSO and GA. The initial active P_{loss} was 13.3933 MW. After optimization with MPSO, the minimum P_{loss} is **12.488** MW, and after optimization with GA, the minimum P_{loss} by is **12.492** MW.

2) Case 2: Minimization of active P_{loss} *with RES for IEEE14 bus*

In this case, two wind farms were added on Bus 4 and 5, and a solar power plant was added on bus 14. The P_{loss} by MPSO and GA are **5.0054** MW and **5.0127** MW, respectively. The characteristics of convergence of MPSO and GA for P_{loss} are shown in Fig. 2.

3) Case 3: Minimization of VD without RES for IEEE14 bus

In this case, the voltage deviation was reduced by using MPSO and GA, and without the addition of RES. The base value for VD is 0.4036 pu and the value of VD by MPSO and GA are **0.0327** pu and

0.0332 pu, respectively. Fig. 3 shows a comparison between the base value voltage profile and that obtained by MPSO and GA. The convergence characteristics for VD are shown in Fig. 4.

4) Case 4: Minimization of VD with RES for IEEE14 bus

The value of VD after optimization by MPSO and GA are 0.02077 pu and 0.0212 pu, respectively. Fig. 5 shows a comparison between the base value voltage profile and voltage profile with the presence of RES obtained by MPSO and GA. The convergence characteristics for VD are shown in Fig. 6. Table 1 provides a comparison of the results for the individual optimization with and without RES obtained by MPSO and GA for case (1–4).

5) Case 5: Minimization of P_{loss} *and VD without RES for IEEE14 bus*

In this case, the active P_{loss} and the VD were minimized simultaneously by MOPSO and MOGA without the presence of the renewable energy sources in the grid. Fig. 7 shows Pareto-optimal front by MOPSO and MOGA without RES.

6) Case 6: Minimization of P_{loss} *and VD with RES for IEEE14 bus*

In this case, the active P_{loss} and the VD were minimized simultaneously with the presence of the renewable energy sources in the grid. Fig. 8 shows Pareto-optimal front with RES. Table 2 compares the BCS with the best value for each objective from MO optimization obtained by MOPSO and MOGA for cases (5, 6).

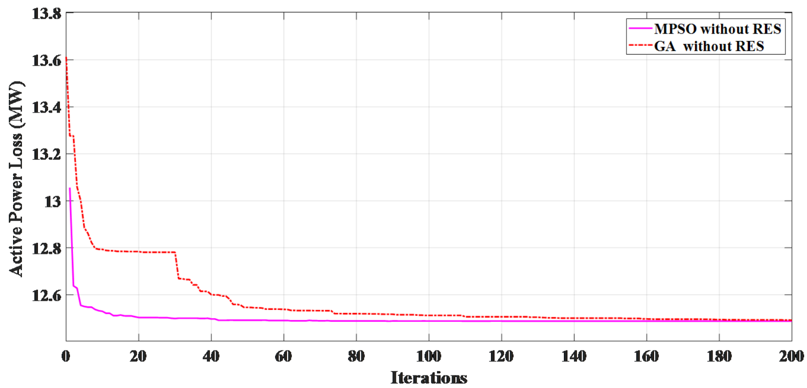

Fig. 1. Convergence of Ploss without RES for IEEE 14 bus for case 1

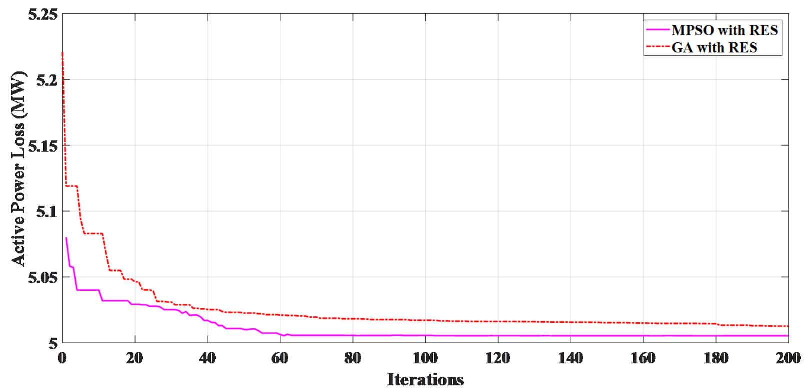

Fig. 2. Convergence of Ploss with RES for IEEE 14 bus for case 2

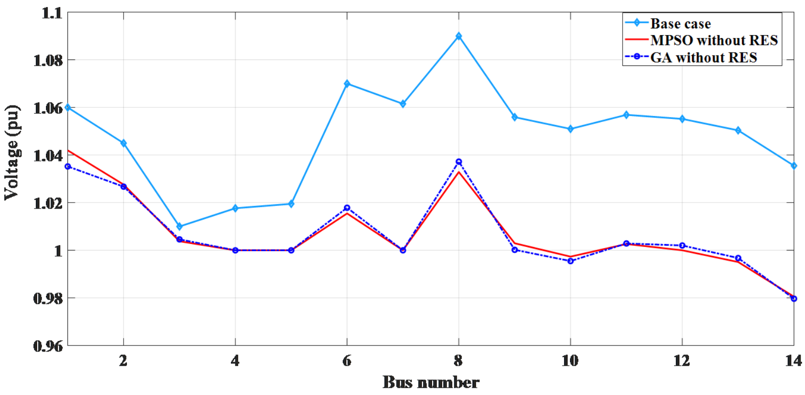

Fig. 3. Voltage profile without RES for IEEE 14 bus for case 3

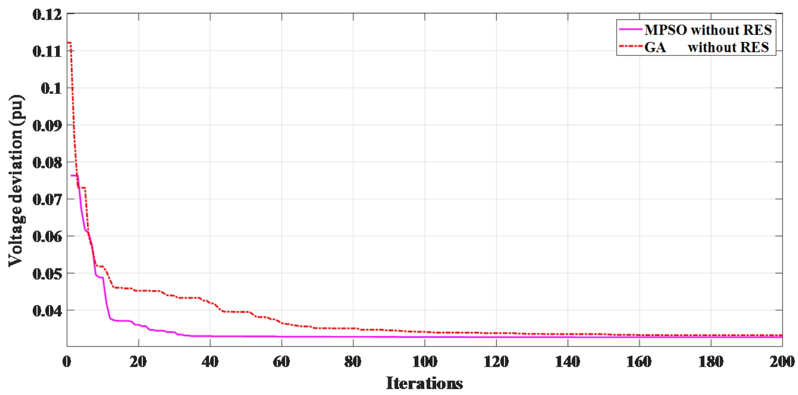

Fig. 4. Convergence of VD without RES for IEEE 14 bus for case 3

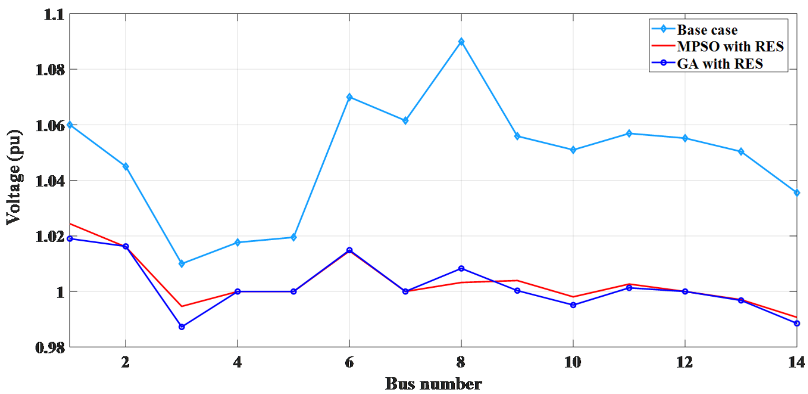

Fig. 5. Voltage profile with RES for IEEE 14 bus for case 4

C. The results of IEEE 30-bus system

1) Case 7: Minimization of active P_{loss} *without RES for IEEE 30 bus*

Fig. 9 shows a reduction of P_{loss} after adjusting the control variables such as generator voltages, transformer tap-settings and capacitor banks by using MPSO and GA. The initial P_{loss} was 17.557 MW and after optimization by using MPSO and GA the minimum P_{loss} are 16.348 MW and 16.399 MW, respectively.

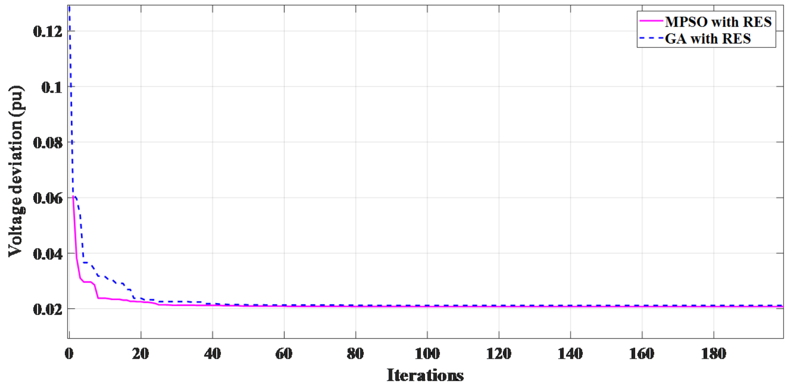

Fig. 6. Convergence of VD with RES for IEEE 14 bus for case 4

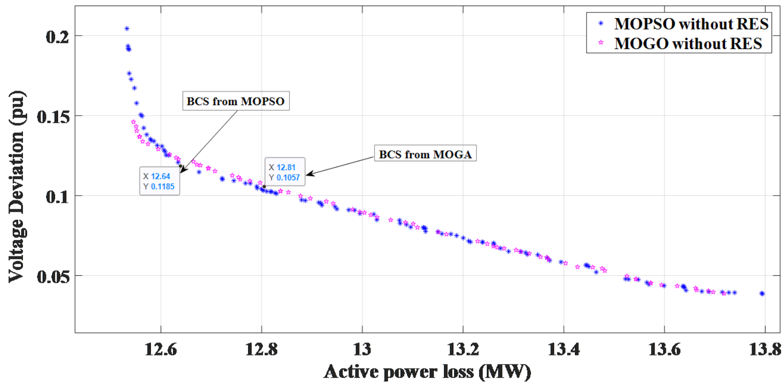

Fig. 7. POS set without RES for IEEE 14 bus for case 5

Table 1

Comparison results for the individual optimization with and without res for case (1–4) for IEEE 14 bud

Parameter	Base value	MPSO without RES		GA without RES		MPSO with RES		GA without RES	
		Best P_{loss}	Best VD	Best P_{loss}	Best VD	Best P_{loss}	Best VD	Best P_{loss}	Best VD
P_{loss} (MW)	13.393	**12.488**	14.03	**12.492**	14.23	**5.0054**	5.611	**5.0127**	5.659
VD (pu)	0.4036	0.4	**0.0327**	0.3957	**0.0332**	0.4017	**0.02077**	0.3425	**0.0212**

Table 2

A comparison of result for the MO optimization with and without res for cases (5, 6) for IEEE 14 bus

Parameter	MOPSO without RES		MOGA without RES		MOPSO with RES		MOGA with RES	
	P_{loss} (MW)	VD (pu)	P_{loss} (MW)	VD (pu)	P_{loss} (MW)	VD (pu)	P_{loss} (MW)	VD (pu)
BCS	12.6389	0.1185	12.805	0.1057	5.0465	0.1186	5.1591	0.0976
Best P_{loss}	**12.5325**	0.2045	**12.545**	0.1461	**5.0233**	0.2123	**5.0336**	0.1426
Best VD	13.794	**0.03857**	13.717	**0.03877**	5.5702	**0.0234**	5.5711	**0.0291**

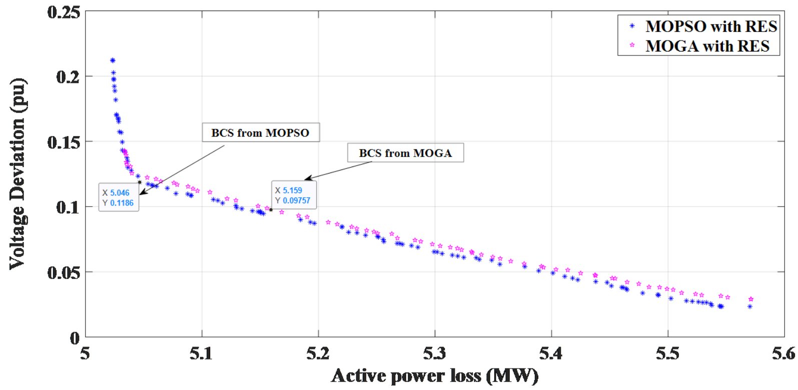

Fig. 8. POS set with RES for IEEE 14 bus for case 6

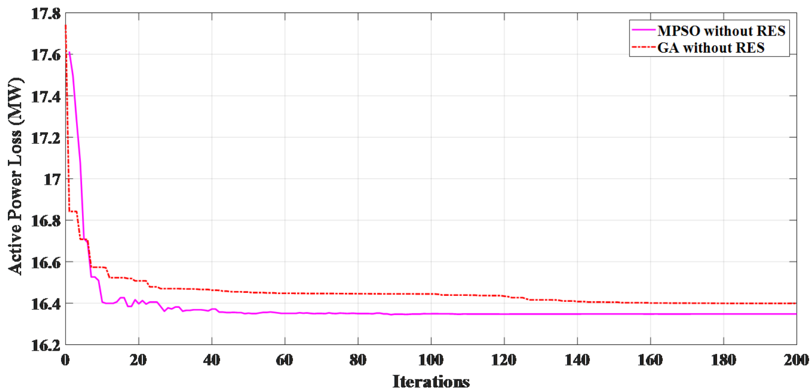

Fig. 9. Convergence of Ploss without for IEEE 30 bus for case 7

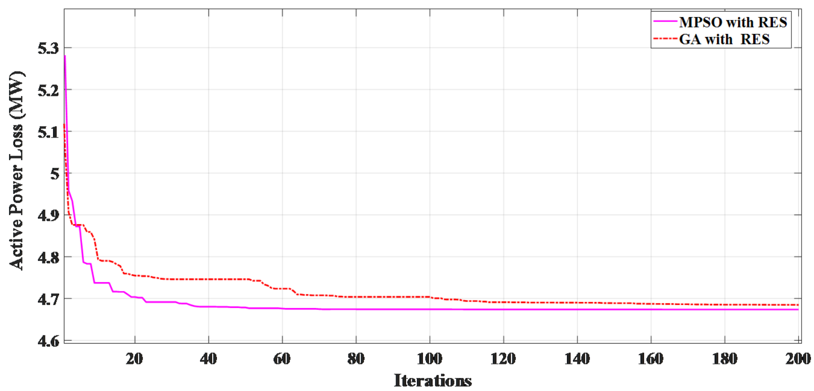

Fig. 10. Convergence of Ploss with RES for IEEE 30 bus for case 8

2) Case 8: Minimization of active P_{loss} *with RES for IEEE 30 bus*

In this case, two wind farms were added on Bus 6 and 7, and two solar power plants were added on bus 29 and 30. The P_{loss} by MPSO and GA are 4.6738 MW and 4.685 MW, respectively. The characteristics of convergence of MPSO and GA for P_{loss} are shown in Fig. 10.

3) Case 9: Minimization of VD without RES for IEEE 30 bus

Fig. 11 shows optimal voltage profile by using MPSO and GA. Voltage deviation after optimization by using MPSO is 0.1379 pu and by GA is 0.1508 pu. The initial voltage deviation was 0.6256 pu. The convergence characteristics for VD are shown in Fig. 12.

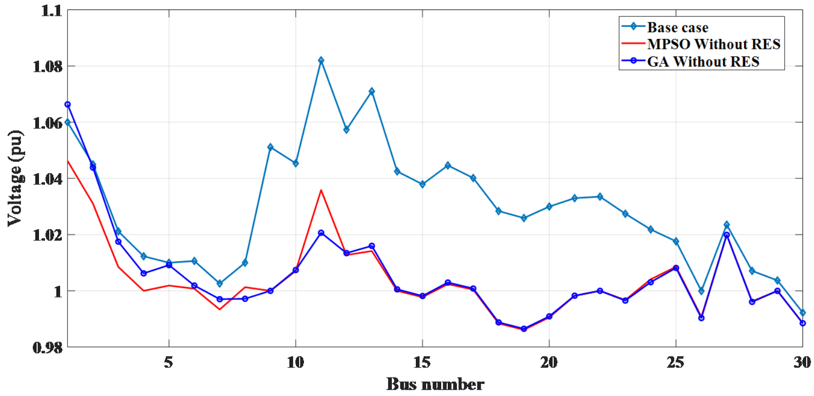

Fig. 11. Voltage profile without RES for IEEE 30 bus for case 9

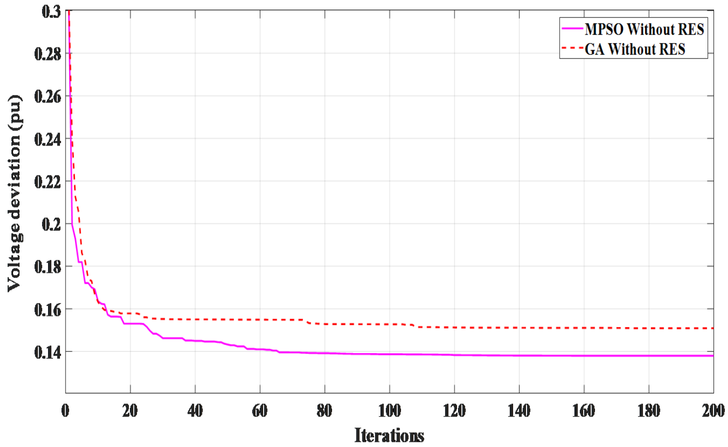

Fig. 12. Convergence of VD without RES for IEEE 30 bus for case 9

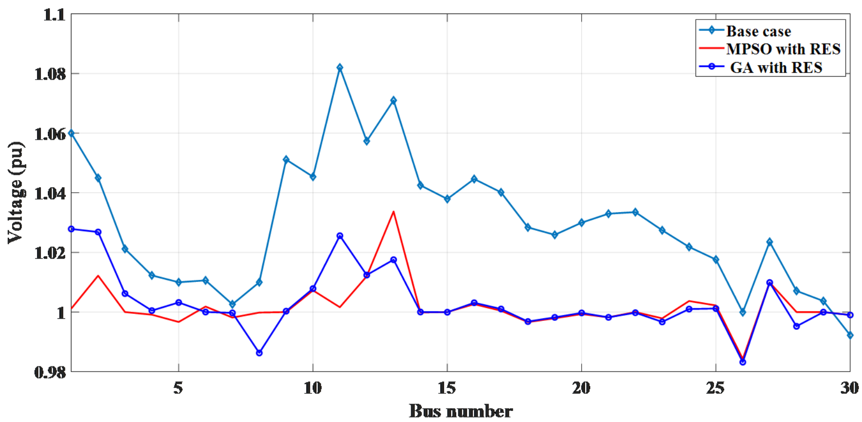

Fig. 13. Voltage profile with RES for IEEE 30 bus for case 10

4) Case 10: Minimization of VD with RES for IEEE 30 bus

The value of VD after optimization by MPSO and GA are 0.0697 pu and 0.0770 pu, respectively. Fig. 13 shows a comparison between the base value voltage profile and voltage profile with the presence of RES obtained by MPSO and GA. The convergence characteristics for VD are shown in

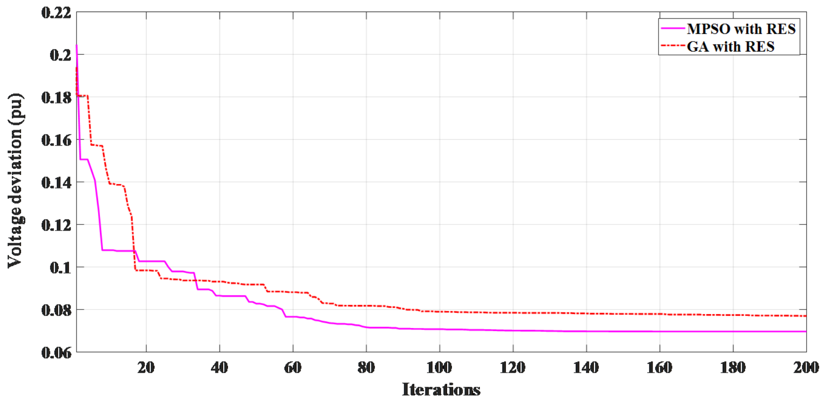

Fig. 14. Convergence of VD with RES for IEEE 30 bus for case 10

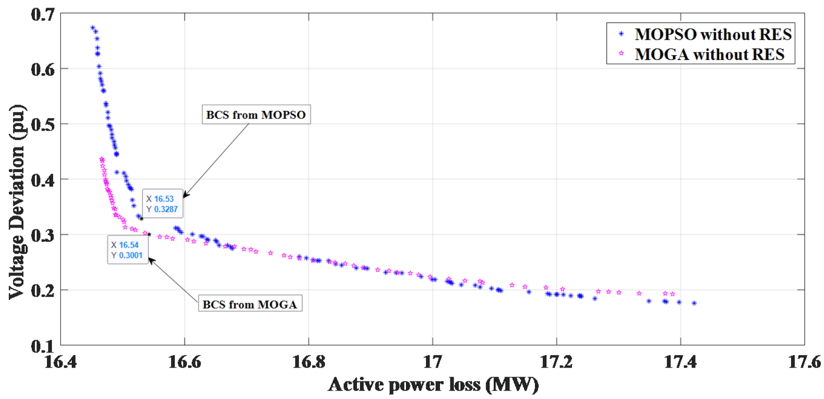

Fig. 15. Pareto front without RES for IEEE 30 bus for case 11

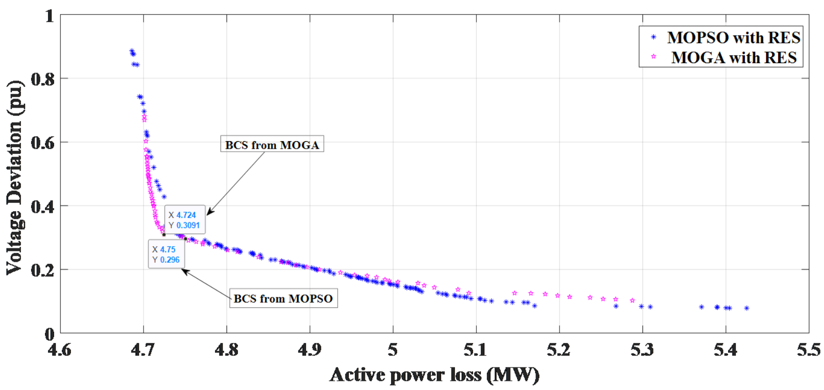

Fig. 16. Pareto front with RES for IEEE 30 bus for case 12

Fig. 14. Table 3 provides a comparison of the results for the individual optimization with and without RES obtained by MPSO and GA for case (7–10).

5) Case 11: Minimization of P_{loss} *and VD without RES for IEEE 30 bus*

In this case, the active P_{loss} and the VD were minimized at the same time by MOPSO and MOGA without the presence of the renewable energy sources in the grid. Fig. 15 shows Pareto-optimal front without RES.

6) Case 12: Minimization of P_{loss} *and VD with RES for IEEE 30 bus*

In this case, the active P_{loss} and the VD were minimized simultaneously by MOPSO and MOGA with the presence of the renewable energy sources in the grid. Fig. 16 shows Pareto-optimal front with RES. Table 4 compares the BCS with the best value for each objective from MO optimization obtained by MOPSO and MOGA for cases (11, 12).

Table 3

Comparison results for the individual optimization with and without res for IEEE 30 bus for case (7–10)

Parameter	**Base value**	**MPSO without RES**		**GA without RES**		**MPSO with RES**		**GA without RES**	
		Best P_{loss}	**Best VD**	**Best P_{loss}**	**Best VD**	**Best P_{loss}**	**Best VD**	**Best P_{loss}**	**Best VD**
P_{loss} (MW)	17.557	16.348	18.093	16.399	17.60	4.6738	5.638	4.685	5.4711
VD (pu)	0.6256	0.857	0.1379	0.825	0.1508	0.996	0.0697	0.984	0.0770

Table 4

A comparison of result for the MO optimization with and without res for cases (5, 6) for IEEE 14 bus

Parameter	**MOPSO without RES**		**MOGA without RES**		**MOPSO with RES**		**MOGA with RES**	
	P_{loss} (MW)	**VD (pu)**	**P_{loss} (MW)**	**VD (pu)**	**P_{loss} (MW)**	**VD (pu)**	**P_{loss} (MW)**	**VD (pu)**
BCS	16.5304	0.3287	16.5427	0.3001	4.7504	0.296	4.7245	0.3091
Best P_{loss}	**16.4518**	0.6736	16.4665	0.4359	**4.6859**	0.8862	**4.7009**	0.6806
Best VD	17.4218	**0.176**	17.3869	**0.1924**	5.4249	**0.0785**	5.2875	**0.1024**

Conclusion

In this work, we proposed a multi-objective particle swarm optimization (MOPSO) for solving the optimal reactive power dispatch (ORPD) problem. We incorporated renewable energy sources and considered the power loss and voltage profile improvement. The algorithm is tested on IEEE 14-bus and IEEE 30-bus test system for two different cases for each system. The MPSO for the optimal placement of renewable sources of test systems is used in the first stage. In the second stage, the active power loss and voltage deviation objectives are optimized individually with and without renewable energy sources in power systems by using MPSO and GA algorithms. In the third step, the objective functions are optimized simultaneously in a single run with and without renewable energy sources in power systems by using both MOPSO and MOGA algorithms. The results show that MOPSO could find high-quality solutions with more reliability and efficiency. The results also show that when the renewable energy sources are introduced into the networks with adjusting the control variables in the system with the algorithm, a decrease in active power loss and the deviation in voltage is much better than the absence of renewable energy sources.

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