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Optimal in Smart Grids Considering Interruptible Loads and Photo-voltaic Sources Using Genetic Optimization

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Abstract

The amount of the active power production by the photovoltaic systems depends on the radiation intensity and temperature. In this concept, the optimal use of photovoltaic systems is considered for controlling the voltage and correcting the power factor over day and night. Using this concept, it is possible to use photovoltaic systems in a more optimal way during the day and night. In this method, the photovoltaic systems capacity is not only used during the night to generate reactive power. Although studies have investigated the optimal locating of the distributed generation, DG is referred to as only the source of active power generation. In this paper, a new method for optimal placement of the photovoltaic systems, by considering their inverter nominal capacity to generate reactive power in addition to the active power in order to improve the voltage profile and reduce the system losses of the micro-grid, was employed. Two 33-bus and 6-bus networks were selected for investigating, and after implementing the method as well as applying the genetic algorithm optimization, it was determined that the optimal location of the photovoltaic systems by taking into account the active and reactive power production.

Keywords: DG, Genetic Algorithm Optimization, Optimal Location, Photovoltaic Systems.

1. INTRODUCTION

In current power systems, electrical losses are significant in the distribution of electrical energy, especially at lower voltage levels.

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Loss reduction can be achieved through the appropriate control of Distributed Generation (DG) resources in the distribution systems [1-3], or more generally, through the control of dispatch able resources (DG, load, storage), which can be effectively assessed by using tools such as OPF-like software. There are losses at all levels of the power system, i.e., production, transmission, and distribution, but about 70% of losses occur in the distribution system [1]. Moreover, the high emission of pollutant gases, climate change, overheating of the Earth's atmosphere, and the limitation of fossil fuels make the electricity industry more likely to consider the reducing of the pollutant emissions and controlling the use of the limited fossil fuels in its agenda, and seeks to produce the necessary capacities for using the renewable energy resources and increase the connection of the Distributed Generation (DG) to the network close to the consumers in the line with energy losses [2].

Generally, the operational modes of micro grids can be classified as islanded mode or grid-connected. In the islanded mode, a micro grid must be stable while it is disconnected from the main grid.

Furthermore, the role of DERs is critical [9]. Although the use of the distributed generation and renewable resources such as wind, solar, geothermal energies, etc. can reduce the mentioned concerns, the uncertainties arising from renewable energy power generation will result in a significant impact on the network reliability indices due to the unpredictable nature of these energies [3]. The smart grid, according to [4], is the maximum use of distributed generation in distribution feeders, as well as an increase in consumers' participation in network control and operation. Nevertheless, in a smart grid, DSO has the ability to select different options, such as the DG and the hybrid vehicles on the consumer side, to create a supply/demand balance. Thus, creating timely coordination and communication between DSO and consumers in smart grids require the existence of an appropriate and bi-directional communication platform as well as the use of advanced metering infrastructure. Demand response is a subset of Demand-side Management and the main elements of the smart grid. This program not only is capable of reducing the electricity consumption with the consumers' anticipation in response to incentive payments (at the time of the system's lower storage capacity, network reliability reduction, and during the peak hours), or by changing the electricity prices in the market (when the price in the wholesale electricity market is high), but also it can modify the electricity consumption patterns of subscribers [5]. Because of the high R/X ratio in radial distribution systems, power losses are more, which the volatility problem in these networks is likely more serious [6-7]. The voltage stability index introduced in [8] is obtained by balancing the distribution network in 2-buses and calculating the Jacobin matrix of the reduced system. Using the active and reactive power equations in the distribution lines, the voltage stability index of the equivalent two-bus voltage system was developed. The stability index analysis of an equivalent two-bus system with the presence of the distributed generation was conducted in [9]. Therefore, these indices are valid only when the equivalent one-line distribution network is available at the points-of-work. In addition to load calculations, the proposed methods require additional computational operations such as reducing the distribution network to the equivalent two-bus.

Moreover, the proposed methods do not allow the change in the pattern of the different bus systems that have the most significant impact on the voltage collapse point. The introduced stability index in [10] is based on the pseudo-second order equation depending on the start and the end voltage size of the equivalent line and the power of the end-line. In this way, the critical point is determined when the stability index is zero. Similarly, the developed bus stability index in [11] used the equations of the end-line bus voltage based on the Kirchhoff's voltage law in a section of the line.

In this paper, using the open DSS and MATLAB, we will consider the load flow of the two 33-bus and 6-bus circuits. In order to make the coding in load flow easier, we used the open DSS software instead of MATLAB software. But the load flow was conducted instantly, i.e., it was carried out at a specific time, and in this study, we needed 24 hours for conducting load flow in MATLAB software. In other words, the coding was conducted in open DSS, and then we entered it into MATLAB software that was carried out for 24 hours, in which the voltage outputs and losses were obtained. The voltage and losses were obtained for two output sections that in the first section the load flow without voltage and losses were obtained and in the second section load flow was obtained using solar. Finally, these two outputs were compared and examined.

2. FORMULATING THE TARGET PROBLEM

In the proposed method, the objective function includes losses, which are essentially equal to the losses, and the goal is to minimize these losses; while doing this, radially constraints in the network, should be considered. The introduced relationship in the proposed method is as follows:

$$\min imiz \sum_{b=1}^{N} R_b . i_b^2 \tag{1}$$

$$\mathrm{A}, \mathrm{i} = \mathrm{I} \tag{2}$$

$$\mathrm{i} \le \mathrm{i}_{\mathrm{max}} \tag{3}$$

$$\mathrm{V}_{\mathrm{min}} \le \mathrm{V} \le \mathrm{V}_{\mathrm{max}} \tag{4}$$

$$\mathrm{M} = \mathrm{N} - \mathrm{N}_{\mathrm{f}} \tag{5}$$

R_b is the b branch strength, i_b is the mixed flow of the b branch, I is the vector flow, i_{max} is the maximum flow of the branches, I is the node current vector, A is the crossing matrix, V is the voltage node, V_{min} is the minimum voltage of the node, V_{max} is the maximum voltage of the node, M is the number of the radial network branches, N is the number of the nodes, and N_f is the number of the sources. In the above relations, (1) represents the objective function of the proposed method andthe aim of which is to reduce the total number of active losses in power systems [12].

3. THE EXAMINED NETWORKS

To demonstrate the efficiency of the proposed method, the test was performed on the 2 networks of standard 33 and 6-buses. The 33 and 6-bus micro-grids are presented in Figures (1) and (2) [13].

4. THE IEEE 33-BUS NETWORK

In this network, the bus number 1 is the reference bus that connects to the upstream

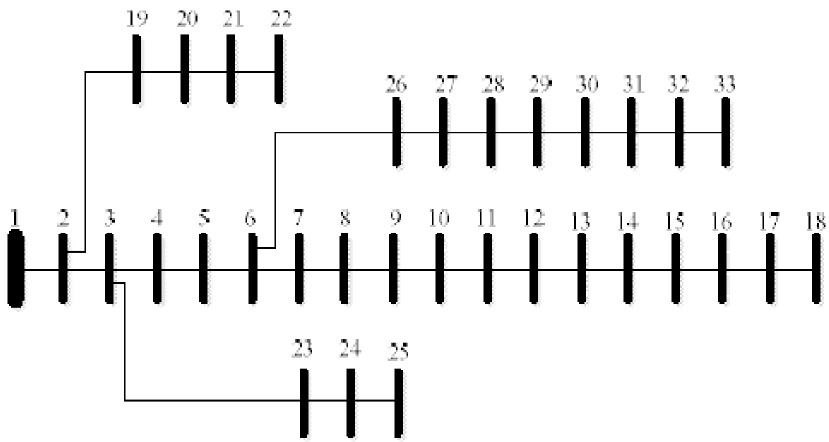

Fig. 1. The studied 33-bus micro-grid.

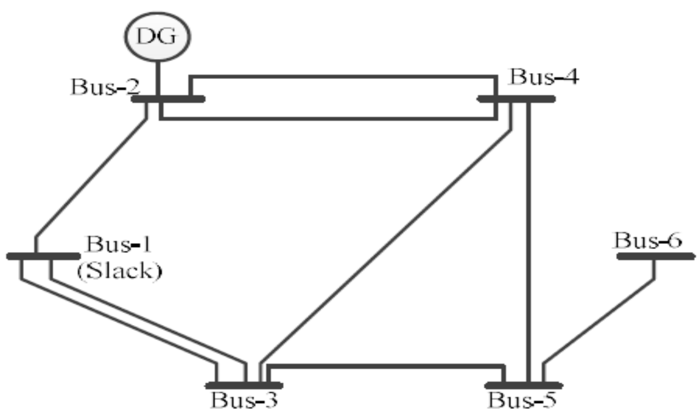

Fig. 2. The studied 6-bus micro-grid.

network. The peak load on the buses of this system is presented in Table 1. The purpose of this study is to optimally utilize the inverter capacity of the photovoltaic system. Thus, a 24-hour load profile is needed for implementing this method. The 24-hour used load profile in this study is obtained by multiplying the peak load of the 33-bus micro-grid by a typical daily load which is as a percentage of peak loads.

Figure 3 shows the percentage of used 24-hour load in this system.

5. THE RESULTS OF THE SIMULATED IEEE 33-BUS MICRO-GRID

In order to optimally locate the photovoltaic systems in the micro-grid, a photovoltaic system with a nominal capacity of 100 kVA inverter was considered. It should be mentioned that during 11 to 1 p.m, the solar radiation is in its maximum levels and as a result, PV has the maximum active power production, i.e., the total capacity of the

Table 1. ***The Load Peak of the Studied System.***

Bus number	Q(KVAr)	P(KW)	Bus number	Q (KVAr)	P (KW)
1	0	0	19	40	90
2	60	100	20	40	90
3	40	90	21	40	90
4	80	120	22	40	90
5	30	60	23	50	90
6	20	60	24	200	420
7	100	200	25	200	420
8	100	200	26	25	60
9	20	60	27	25	60
10	20	60	28	20	60
11	30	45	29	70	120
12	35	60	30	600	200
13	35	60	31	70	150
14	80	120	32	100	210
15	10	60	33	40	60

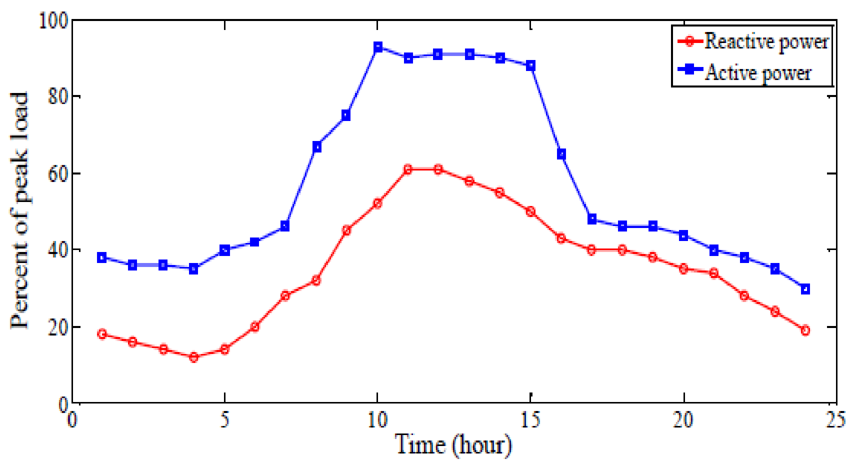

Fig. 3. The 24-hour network load as a percentage of the peak load.

inverters of the photovoltaic system will be used to generate the active power. Moreover, at 1 to 6 a.m, due to the lack of sunlight, PV has its maximum reactive power production, i.e., the total inverter capacity of the photovoltaic system will be used to generate the reactive power. In Table 2, the convergence process of algorithms by implementing this method using the generic algorithm is given in Figures 4 and 5.

Having been implemented both of the algorithms and their convergence, it was determined that the obtained results of both algorithms are very close, and in both algorithms the optimal placement of the proposed PV, by considering the reactive and active power, was the 32-bus. This is while location of this PV, by considering only the active power production, showed 32-busas

Table 2. ***The Amount of Active and Reactive Power Production by Photovoltaic System during the Day and Night.***

Hour	Q (kVAr)	P(kw)	Hour	Q(kVAr)	P(kw)
1	100	0	13	52.7	85
2	100	0	14	80	60
3	100	0	15	99.3	12
4	100	0	16	99.87	5
5	100	0	17	100	0
6	100	0	18	100	0
7	99.8	5	19	100	0
8	99.3	12	20	100	0
9	80	60	21	100	0
10	52.7	85	22	100	0
11	0	100	23	100	0
12	0	100	24	100	0

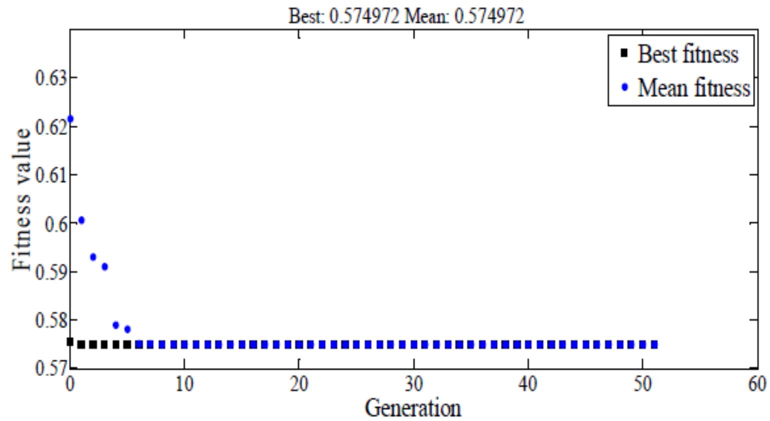

Fig. 4. The convergence process of the genetic algorithm, 33-bus micro-grid.

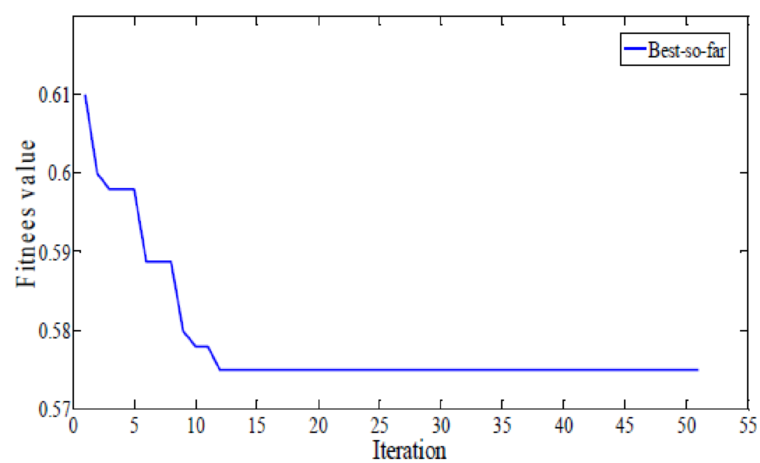

Fig. 5. The convergence process of the PSO algorithm, 33-bus micro-grid.

Table 3. ***The Obtained Placement Results and the amount of System Losses based on Kv.***

numbers PV	PV by P	PV by PandQ
1	Selected bus :18	Selected bus: 32
	The amount of losses: 1757/46	The amount of losses: 1696/6
2	Selected buses: 30 & 17	Selected buses: 32 & 13
	The amount of losses: 1692/8	The amount of losses: 1580/7
3	Selected buses: 17, 18, & 33	Selected buses: 16, 31, & 32
	The amount of losses: 1626/6	The amount of losses: 1475/9

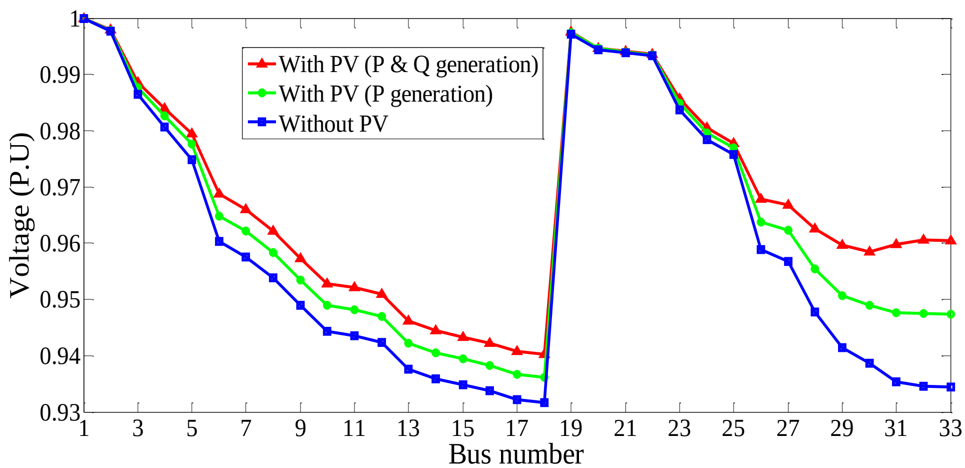

Fig. 6. The voltage profile without PV, with PV and active power production, and with PV and active and reactive power production at 9 o'clock in the morning.

optimal location. In addition, the total network losses in both considering modes of PV with active power production and considering PV with active and reactive power production were shown in Table 3, which as expected, by taking into account the reactive power production in addition to the active power significantly reduced the system losses. Then, this location was carried out for 2 and 3 similar PV systems by both considering active and reactive power production and by only active power production. The results of locating and total network losses are shown in Table 3.

To illustrate the effect of the proposed method for locating the voltage profile, 3 different times were taken into account during the day and night (at 9 AM, 12 noon, and 12 midnight). Figure 6 shows the system voltage profile at 9 a.m for condition without PV installation, with PV installation by considering the active power production capability as well as installation PV by considering active and reactive power production capabilities. The reason of the selection of this time is that the intensity of the solar radiation has not reached to its maximum amount at this time, and PV can produce both reactive and active power. In fact, at 9 o'clock in the morning, the amount of radiation from the sun is not high and the full inverter capacity of the photovoltaic system is not used for only producing active power; therefore, the extra inverter capacity will be used for producing reactive power. As shown in the following figure, by taking into account the potential of PV inverter to enerate active and reactive power, the system voltage profile improved more effectively.

Figure 7 shows the system voltage profile at 12 o'clock. This time was selected due to the presence of the maximum radiation and active power at 12 o'clock, and the total inverter capacity will be used for producing active power, in addition, the reactive power output will be zero consequently.

At 12 o'clock am, there is no sunlight, hence, all inverter capacity is allocated to reactive power production, and due to lack of radiation, the amount of active power output is zero. The voltage profile of the system buses at 12 o'clock is shown in the following figure. Since PV does not have reactive power production, therefore, if the reactive power is not considered at 12 o'clock am, the voltage profile will be coincided with the presence of PV and in the absence of PV. As shown in Figure 8, taking into account the reactive power produced by PV leads to improve the voltage profile.

6. IEEE 6-BUS MICRO-GRID

In this network, the reference bus is the bus number 1and is connected to the upstream network. Moreover, there is also considered a distributed generation (DG) source with a production of 100 kV in bus number 2. Since the aim of this study is to optimally locate by considering the inverter capacity of the photovoltaic system, it is therefore necessary to use 24-hour load profile for implementation. The 24-hour load profile used in this study is the result of multiplying the peak load of the 6-bus system, as shown in Table 4, by a typical daily load, as a presence of the peak load. The information on the lines of this micro-grid is also presented in Table 5.

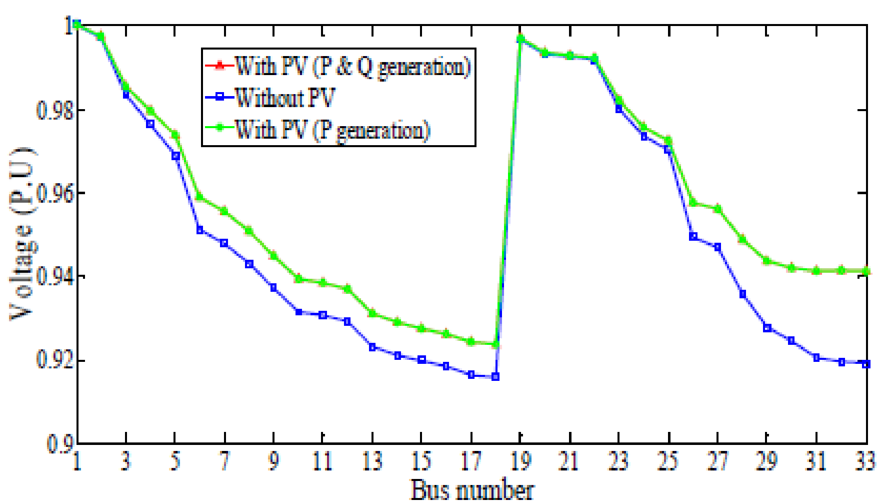

Fig. 7. The voltage profile of the system buses at 12 o'clock pm.

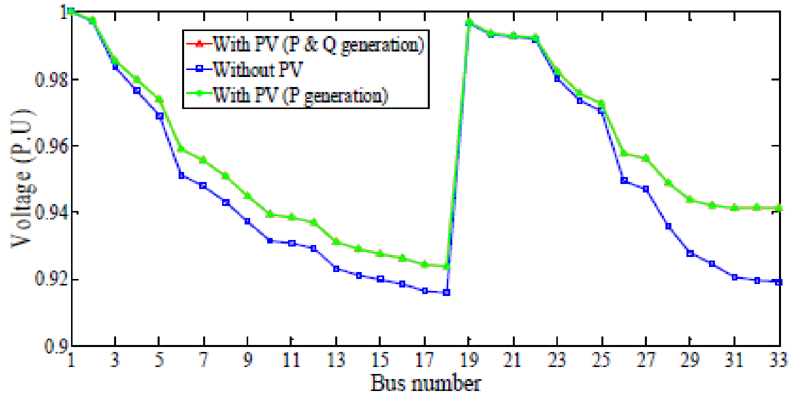

Fig. 8. The voltage profile of the system buses at 12 o'clock am.

Table 4. ***The Information of the 6-bus Micro-grid Load Peak.***

Bus	P (KW)	Q (KVAr)
1	0	0
2	200	65
3	850	279
4	400	131
5	200	65
6	200	65

Table 5. ***The Information of the Lines of the 6-bus Micro-grid.***

From bus	To bus	R (Ω)	X (Ω)	B
1	2	0.0912	0.48	0.0282
1	3	0.0342	0.18	0.0106
1	3	0.0342	0.18	0.0106
2	4	0.114	0.6	0.0352
2	4	0.114	0.6	0.0352
3	4	0.0228	0.12	0.0071
3	5	0.0228	0.12	0.0071
4	5	0.0228	0.12	0.0071
5	6	0.0228	0.12	0.0071

7. THE RESULTS OF THE SIMULATED IEEE 6-BUS MICRO-GRID

A photovoltaic system with a nominal inverter capacity of 600 kVA was considered for the optimal locating of the photovoltaic systems in the micro-grid. The active and reactive power production of this system during different hours of the day is given in Table 6. By implementing this method using genetic algorithm and PSO algorithm, the convergence process of the algorithms is presented in Figures 6 and 10.

After the implementation of both algorithms and their convergence, it was indicated that the results of both algorithms were very close together and, in both algorithms, the optimal location of the

Table 6. The Active and Reactive Power Production by the Photovoltaic System during the Day and Night.

Hour	*Q (KVAr)*	*P (KW)*	*Hour*	*Q (KVAr)*	*P (KW)*
1	*600*	*0*	*13*	*0*	*600*
2	*600*	*0*	*14*	*316.2*	*510*
3	*600*	*0*	*15*	*480*	*360*
4	*600*	*0*	*16*	*595.8*	*72*
5	*600*	*0*	*17*	*595.8*	*30*
6	*600*	*0*	*18*	*600*	*0*
7	*598.8*	*30*	*19*	*600*	*0*
8	*595.8*	*72*	*20*	*600*	*0*
9	*480*	*360*	*21*	*600*	*0*
10	*316.2*	*510*	*22*	*600*	*0*
11	*0*	*600*	*23*	*600*	*0*
12	*0*	*600*	*24*	*600*	*0*

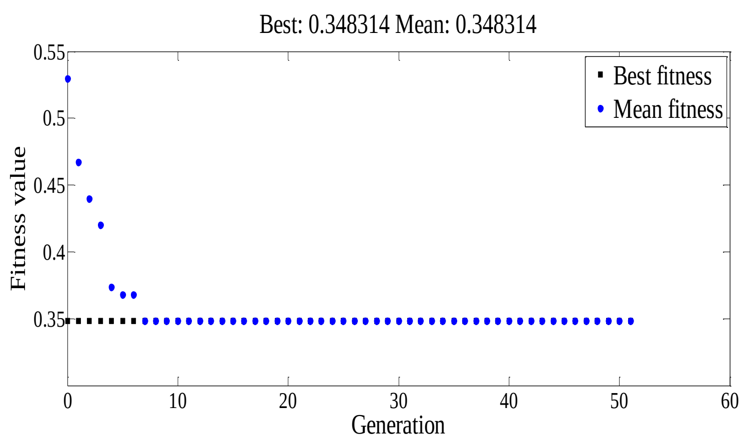

Fig. 9. The convergence process of the genetic algorithm in 6-bus micro-grid.

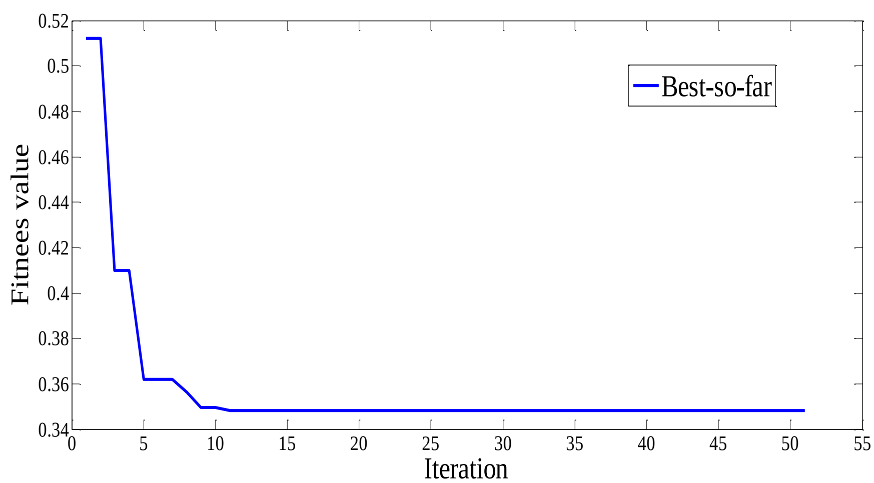

Fig. 10. The convergence process of the PSO algorithm in 6-bus micro-grid.

Table 7. ***The Results of Locating and System Losses in term of Kilowatts.***

PV by Q and P production	PV by P production
The selected bus: 5	The selected bus: 6
The amount of losses: 4770	The amount of losses: 4957

proposed PV by considering active and reactive power production is bus number 5. This is while changing the placement of this PV by considering only the active power production shows the bus number 6 as the optimal location. In other words, considering the reactive power leads to the displacement of an optimal PV location. Moreover, Table 7 shows the total network losses in both considering PV with active and reactive power production, which as expected, taking into account the reactive power production in addition to the active power significantly reduces the system losses.

In this section, three different times during the night and day (9 am, 12 pm, 12 am) were considered to show the effect of the proposed method on improving the voltage profile. The reason for selecting these hours for 33-bus system was explained, and here it is also the case. As shown in the following figures, considering the reactive power production by PV in addition to active power results in improving the network voltage profile. Figures 11, 12, and 13 illustrate this result.

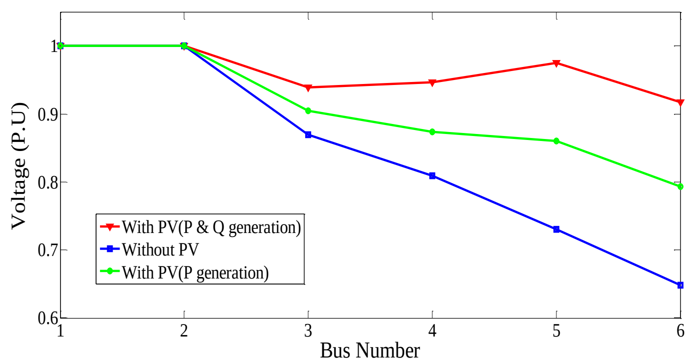

Fig. 11. The voltage profile without PV, with PV and active power production, and with PV and active and reactive power production at 9 o'clock.

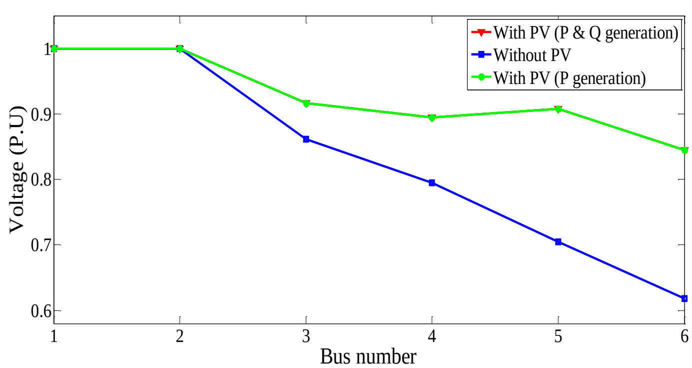

Fig.12. The voltage profile of the buses at 12 pm.

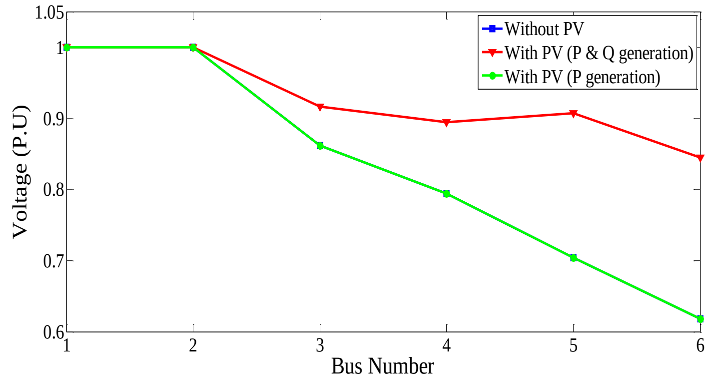

Fig. 13. The voltage profile of the buses at 12 am.

8. CONCLUSION

For constructing the micro-grids, it is possible to use fuel cell technologies, micro-turbines, geothermal energy, biomass, wind power converter systems, photovoltaic systems, etc. Using the photovoltaic systems have been more commonplace due to the unlimited energy of the sun. The amount of the active power production by the photovoltaic systems depends on the radiation intensity and temperature. The higher radiation, the more active power production. Given the amount of the radiation changes at different hours, the amount of the active power production of the photovoltaic systems also changes. Therefore, if the photovoltaic systems are only used to generate the active power, some parts of its inverter capacity remain unused during the day and night. By properly controlling the inverter of the photovoltaic systems, it can be possible to use all their inverter capacities to generate the active and reactive power during the day and night. In this concept, the optimal use of photovoltaic systems is considered for controlling the voltage and correcting the power factor over day and night. Using this concept, it is possible to use photovoltaic systems in a more optimal way during the day and night. In this method, the photovoltaic systems capacity is not only used during the night to generate reactive power, but also the remaining inverter capacity can be used during the daylight to generate reactive power. Although many studies have investigated the optimal locating of the distributed generation, DG is referred to as only the source of active power generation. In this paper, a new method for optimal placement of the photovoltaic systems, by considering their inverter nominal capacity to generate reactive power in addition to the active power in order to improve the voltage profile and reduce the system losses of the micro-grid, was employed. Two 33-bus and 6-bus networks were selected for investigating, and after implementing the method and applying the genetic algorithm optimization and PSO, it was determined that the optimal location of the photovoltaic systems by taking into account the active and reactive power production, in addition to changing the DG location, improves the voltage profile of the micro-grid buses. This also reduces the total system losses, compared with the situation in which the photovoltaic systems only produce the active power.

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