LOCALIZAÇÃO IDEAL DE UM SISTEMA FOTOVOLTAICO PARA MELHORAR O PERFIL DE TENSÃO, CONSIDERANDO AS LIMITAÇÕES DE POTÊNCIA ATIVA E REATIVA

OPTIMAL LOCATION OF A PHOTOVOLTAIC SYSTEM TO IMPROVE THE VOLTAGE PROFILE CONSIDERING THE ACTIVE AND REACTIVE POWER LIMITATIONS

جایابی بهینه سیستم فتوولتائیک به منظور بهبود پروفیل ولتاژ با در نظر گرفتن محدودیتهای توان اکتیو و راکتیو

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RESUMO

Este trabalho investigou a localização ótima de sistemas fotovoltaicos como uma das gerações distribuídas em micro-redes, no que diz respeito à potência ativa e reativa. As micro-redes fornecem a qualidade da energia de acordo com as necessidades dos clientes, os efeitos positivos das micro-redes no mercado de eletricidade e a respectiva economia. Por outro lado, seus efeitos na redução da poluição do ar levaram muitos pesquisadores e especialistas a perceber a questão das micro-redes. Assim, considerando a capacidade de geração de energia ativa e reativa para sistemas fotovoltaicos em 24 horas, eles podem ser usados de forma mais eficiente. Os algoritmos apresentados em micro-grade de 33 barramentos são aplicados no MATLAB, e os resultados foram investigados. Os resultados mostraram que a potência reativa gerada reduziria significativamente a potência ativa das perdas do sistema. Às 9h, considerando a capacidade do inversor fotovoltaico para gerar a energia ativa e reativa, o perfil de tensão do sistema melhorou mais efetivamente. Às 12 horas, existe a radiação máxima e a potência ativa gerada, e toda a capacidade do inversor é usada para gerar a energia ativa. A energia reativa fotovoltaica gerada levou à melhoria do perfil de tensão.

Palavras-chave: Algoritmo Genético, Perfil de Tensão, Micro-grade, localização ótima, sistema fotovoltaico.

ABSTRACT

This paper has investigated the optimal localization of photovoltaic systems as one of the distributed generations in micro-grids, with regard to active and reactive power. Micro-grids provide the power quality in accordance with customers' needs, positive effects of micro-grids on the electricity market and economic savings. On the other hand, their effects on reducing air pollution have caused many researchers and experts to notice the issue of micro-grids. So, considering the ability of active and reactive power generation for photovoltaic systems in 24 hours, they can be used more efficiently. The algorithms presented on 33 bus micro-grid are applied in MATLAB, and the results have been investigated. The results have shown that the generated reactive power would significantly reduce the active power of system losses. At 9 AM, considering the PV inverter capability for generating the active and reactive power, voltage profile of the system has improved more effectively. At 12 PM, there are existed the maximum radiation and active power generated, and the whole capacity of the inverter is used to generate the active power. The PV reactive power generated has led to the improvement of the voltage profile.

Keywords: Genetic Algorithm, Voltage Profile, Micro-grid, optimal localization, photovoltaic system.

چکیده

در این مقاله، جایابی بهینه سیستمهای فتوولتائیک به عنوان یکی از تولیدات پراکنده در ریزشبکهها با توجه به توان اکتیو و راکتیو مورد بررسی قرار گرفته است. ریزشبکهها کیفیت توان با توجه به نیاز مشتریان، اثرات مثبت آنها بر بازار

برق و صرفه جویی اقتصادی را تامین میکنند. از سوی دیگر، اثرات آنها بر کاهش آلودگی هوا موجب شده است که بسیاری از محققان و کارشناسان به مسئله ریزشکها توجه کنند. بنابراین، با توجه به قابلیت تولید توان اکتیو و راکتیو برای سیستم های فتوولتائیک در عرض 24 ساعت، می توان آنها را بیشتر مورد استفاده قرار داد. الگوریتمهای ارائه شده بر روی میکروگرید 33 باسه در محیط MATLAB اعمال گردیده و نتایج آن مورد بررسی قرار گرفته است. نتایج نشان میدهد که توان راکتیو تولید شده به طور قابل توجهی توان اکتیو تلفات سیستم را کاهش میدهد. در ساعت 9 صبح، با توجه به توان اینورتر PV برای تولید توان اکتیو و راکتیو، پروفیل ولتاژ سیستم به طور موثر بهبود یافته است. در ساعت 12 ظهر، حداکثر تابش و توان اکتیو تولید شده وجود دارد و ظرفیت کل اینورتر برای تولید توان اکتیو مورد استفاده میگیرد. توان راکتیو تولیدی PV باعث بهبود پروفیل ولتاژ شده است.

کلمات کلیدی:

الگوریتم ژنتیک، پروفیل ولتاژ، ریز شبکه، جایابی بهینه، سیستم فتوولتائیک

1. INTRODUCTION

In recent years, power industry restructuring and also its privatization has been proposed and applied in some countries. During this period, due to raising of the operational efficiency and encouraging the investors, the power industry is undergoing radical changes in terms of management and ownership; So that, to create an appropriately competitive environment, its different sectors including generation, transmission, and distribution have been independent. In the restructured environment of the power industry, it is not easy to convince the market players to invest in power generation, and transmission projects cost several billion dollars. These transformations in one side and factors such as environmental pollution, problems of constructing new transmission lines and technological progress in the economic field, construction of small-scale production units compared to large production units, on the other hand, have increased the use of small-scale production units as "distributed generations". Most distributed generation technologies are flexible in various aspects, such as size performance and expansion capability. Moreover, applying distributed generation causes a flexible reaction to initialize the electricity price. Various definitions have used for distributed generations, but its comprehensive and unlimited definition is "a source of electrical power that is directly connected to the distribution network and/or the consumer side. The nominal values of these generations vary, but their generation capacity is usually from a few kW to about 10MW. The units are located in substations and on distribution feeders near the bars [1]. Distributed generation of energy is not a new term. Since the beginning of human beings, there was a need for various types of energy to meets their needs.

Distributed generation is formed because the energy is actually produced near its consumption place. Distributed generations are used locally. Given that these generations are close to consumption centers, there is no need to transmit its electrical energy output in long distances. The more the consumer is closer to the generator, the cost of electrical energy will decrease.

Considering the competition and restructure in power systems it is expected that distributed generations have an increasing role in the future of these systems so that researches indicate that by 2015, more than 25% of electric power will be made by distributed generations [2]. Indian government considered the project of providing electricity to 100,000 villages using distributed generations [1-5]. The most obvious example is the use of sour gas with low inflammability in wells and in oil and gas fields that usually have no economic advantage and burns. Micro-turbines have the ability to burn this gas as fuel and provide the needed power and heat in that place [6].

To build micro-grids, users can use technologies including fuel cell, micro-turbines, geothermal energy, biomass, wind energy conversion systems, photovoltaic systems, etc. that in this regard, the use of photovoltaic systems is more common because of the unlimited energy of the sun. Many centuries ago, wind energy technology took its first steps by creating vertical axis windmills in Iran about 200 years before BC [7]. Then, the horizontal axis windmills were used in the Netherlands and Mediterranean basin between "1300" and "1875". In the 19th century and between "1850" and "1970", more than 6 million small wind machines were used to pump the water in the United States of America. The first wind turbine used to

generate electricity was installed in 1888 in Ohio, America with a capacity of 25 Kw [8]. In the period between 1935 until 1970, some efforts were made in Denmark, France, Germany, and Britain to build wind farms and it was shown that the use of large-scale winds farms could be cost-effective. Since then, wind turbines and wind farms technologies yielded unlimited growth and in the last 20 years the wind power, as the primary renewable energy, has attracted all countries of the world. Figure 2-4 shows the total capacity of wind power plants installed from 1996 to 2010 which with an exponential growth from about 6 GW in 1996 has increased to 194 GW in 2010 [8]. At the beginning of the 1980s, wind turbines with a capacity of 50 to 100 KW were built in California, America.

A sharp rise in the price of metals such as copper in recent years has made this technology an appropriate economic alternative for consumption networks in remote areas. Also, this technology has created the high tendency of consumers to consume, which in turn has provided the area for its rapid development [9]. The voltage increase that every P-N link creates is about half-volt and is not dependent on the size of the photovoltaic cell. Instead, the amount of current flows depends on the exposure level and sunlight amount. The more the cell surface, the incoming light is more and thus more flows will be generated [10].

In order to protect photovoltaic cells against weather and other environmental variables, are placed in a capsule like a frame. Modules are available in various shapes and sizes. Some of them are made in rectangular form with sizes from 5 to 200 Watts. Often, the terms "panel" and "module" are used interchangeably while, more precisely, a panel is a set of modules connected in series or parallel way to achieve a specific voltage. Similarly, arrays are a set of panels connected to each other [11].

Inverts are an essential part of FACTS devices that can generate reactive to improve the voltage profile and power factor correction of the system. The active power amount generated by photovoltaic systems depends on the radiation intensity and temperature. Active power generation increases with increased radiation. Given that the amount of radiation varies at different times of a day, the active power generation of photovoltaic systems will also change. Therefore, if we use photovoltaic systems just for generating the active power,

some part of its invert's capacity remains unused during day and night.

With proper control of inverter of photovoltaic systems, we can use their invert's full capacity to generate the active and reactive power during the day and night. In this new concept, the optimal use of photovoltaic systems is considered as STATCOM for voltage control and power factor correction during day and night [12]. In [13], a good controller for the performance of the photovoltaic system as STATCOM during the night and using its inverter's nominal capacity has been proposed. With this concept, photovoltaic systems can be utilized for 24 hours in a more efficient way. In this way, in addition to using the photovoltaic systems' capacity for reactive power generations during day and night, the remaining capacity of the inverter can be used to generate the reactive power during the day. Optimal placement of photovoltaic systems based on this new application will have more effect on the improvement of system voltage profile as well as reduction of losses [14].

Inverter of photovoltaic systems has the ability to generate reactive power in addition to active power generation [15]. By injecting reactive power generation, voltage profile and also system's power factor can improve. Inverters have a certain capacity, so their maximum current flow is limited and specified. With proper and independent control, this capacity can be used for active current generation and/or reactive current.

The inverter of photovoltaic systems is able to generate the reactive power in addition to the active power that in this paper we have tried to address the photovoltaic system placement in micro-grids with regard to the reactive power generations.

In many projects and papers, distributed generations' placement has been discussed and investigated but in all of these researches the DG is mentioned as the only source of active power generations which this paper shows that optimal placement of photovoltaic systems in a micro grid network, regarding its inverter's nominal capacity, causes the optimal relocation of DG placement and also more favorable results in reducing losses and improving voltage profile.

To implement the mentioned method, we use programming in MATLAB; this method is implemented on the 33-bus micro grids. Also, to distribute the load on the examined networks that are among the distribution networks the leading

and backward load distribution are used. For optimal placement, also, the two genetic optimization and particle algorithms (PSO) are used which are of the most evolved optimizer algorithms.

2. STATEMENT OF THE PROBLEM

Today's modern world is slowly in need for electricity energy with high quality and reliability. The increased need of availability and high reliability, requiring to use of the new energy resources as generators, old transmission, and distribution networks, all of them run the present challenges in order to increase the reliability, security, and quality of power. Therefore, researchers and experts, in order to achieve more efficient ways to provide electricity power, have introduced new technologies such as micro grid networks. The presence of micro grids in distribution networks provides many advantages for customers. Micro grids have the ability to provide power quality in accordance with customers' needs. In such circumstances, it is clear that it is important to have an optimal strategy for the location of distributed generation units in micro grids, and not considering it will waste time and financial resources. The reference [16] offers a removed sequential algorithm to placement and determines the capacity of DGs, [1] carries out a new innovative approach based on cost-benefit analysis to determine the capacity and optimal placement of DG. The reference [2] offers the method of genetic algorithm optimization for the development of DG resources in distribution. Placement of distributed generations' resources that photovoltaic systems are one of them have been studied in many types of research [17-20]. The reference [21] presented rational and logical issues to construct the micro grids. The effects of DG on the reliability and efficiency with the presence of time-varying loads in [22] have been studied. The reference [23-24] investigated the reliability of a micro grid network with optimal placement of distributed generations in it. In all studies conducted in the past, the resources of distributed power generation (DG) are mentioned as a source of active power generation. But this paper tries to, by a new approach, addresses the optimal placement of photovoltaic systems which known as one the of the DG resources in micro grids, considering the reactive power generation in addition to the active power.

3. RESEARCH METHODOLOGY

This study was done to reduce system losses and also improve the voltage profile of the system. Therefore, the objective function of this issue has 2 functions that will be addressed below.

The total amount of losses in distribution networks in 24 hours can be obtained from Equation 1.

$$f_p = P_{loss} = \sum_{t=1}^{t=24} \sum_{j=1}^{N-1} I_j^2 * R_j \quad (\text{Eq. 1})$$

$$f_{p\text{norm}} = P_{loss\text{norm}} = \frac{\sum_{t=1}^{t=24} \sum_{j=1}^{N-1} I_j^2 * R_j}{P_{loss}^{\max} * t} \quad (\text{Eq. 2})$$

In Equation 2.

$P_{loss}^{\max}$: Maximum losses of the system

I_j : Feeder flow in the i^{th} component

N : Number of buses in the system

$N - 1$: Number of feeders

$f_{p\text{norm}}$: Objective function normalized to reduce the losses

t : Time

The second component of the objective function that is for voltage profile improvement is as in Equation 3.

$$f_v = \sum_{t=1}^{24} \sum_{i=1}^{N=33} (V_{nom} - V_{it})^2 \quad (\text{Eq. 3})$$

$$f_{v\text{norm}} = \frac{\sum_{t=1}^{24} \sum_{i=1}^{N=33} (V_{nom} - V_{it})^2}{V_{nom} * t} \quad (\text{Eq. 4})$$

In Equation 4.

$f_{v\text{norm}}$: Objective function normalized for voltage profile improvement

V_{nom} : Nominal voltage of system (1 per-unit)

V_{it} : Voltage of i -th bus at t -time

The general objective function which includes two components of the reduction of

system losses and voltage profile improvement is as Equations 5 and 6:

$$f = w_1 f_{p \text{ norm}} + w_2 f_{v \text{ norm}} \quad (\text{Eq. 5})$$

$$w_1 + w_2 = 1 \quad (\text{Eq. 6})$$

In the above equations:

f : General objective function of the problem

w_1, w_2 : Weight coefficients

Weight coefficients in the above relationship

for w_1, w_2 are considered 0.4 and 0.6, respectively.

The relationship between active and reactive power and also their limitations are represented in Equations 7, 8, and 9.

$$S = \sqrt{P^2 + Q^2} \quad (\text{Eq. 7})$$

$$P_{\min} \leq P_{pv} \leq P_{\max} \quad (\text{Eq. 8})$$

$$Q_{\min} \leq Q_{pv} \leq Q_{\max} \quad (\text{Eq. 9})$$

In Equations 7, 8, and 9:

$P_{\min}$ and $P_{\max}$: Minimum and maximum of active power generations.

$Q_{\min}$ and $Q_{\max}$: Minimum and maximum of reactive power generations.

Minimum reactive power generation is zero which occurs during the night when the radiation is zero, and minimum reactive power generation occurs at noon when the radiation is maximum.

Due to the high ratio of (R/X) in distribution networks, using load distribution methods such as Newton-Raphson and a fast distinct method in distribution method may cause non-convergence. So, using the method of leading-backward load distribution that has a good convergence speed, is more appropriate for a distributed network. It involves two steps of leading and backward which are repeated within a loop until reaching the desired convergence [1-2].

4. LOAD DISTRIBUTION MODEL

The first step in this method is numbering the branches or lines of the network, that, to achieve this, there is a need to layer the network. Layering the network starts by the leading move from bus reference to the terminal buses. We consider the lines between each bus or node with the next node as a layer and this trend continues until layering the whole network. After layering the network, numbering the branches is started from the reference node. The number of branches are from 1 to Nb, and the number of lower layers is larger than the higher layers' number. In distribution networks, the following equation represents the relationship between the branches and nodes' numbers, as in Equation 10.

$$N_b = N - 1 \quad (\text{Eq. 10})$$

In Equation 10:

N_b : Branches number

N : Nodes number

Phases (stages) of leading- backward method algorithm is as follows.

4.1. Backward Stage

At this stage, by moving from terminal buses to the reference bus, the load distribution in the system is obtained from Equation 11:

$$S_n = S_i + \sum_{m \in M} S_m + Loss_n \quad (\text{Eq. 11})$$

In Equation 11:

S_n : load distribution in n^{th} branch

i : Last node of the n^{th} branch

S_i : Load power connected to the i^{th} node

M : Total branches connected to the n^{th} branch in j^{th} node

S_m : Power of m^{th} branch

$Loss_n$: Losses of n^{th} branch

4.2. Leading Stage

By moving from the branches connected to the reference bus towards the terminal branches, branch flow in the first bus of the n^{th} branch (j) and voltage in the second bus of the n^{th} branch (i)

are calculated based on the Equation 12, and Equation 13. Losses of branches are calculated by Equation 14.

$$J_n = \left(\frac{S_n}{V^j} \right)^* \quad (\text{Eq. 12})$$

$$V^i = V^j - Z_n \times J_n \quad (\text{Eq. 13})$$

$$Loss_n = (V^j - V^i) \times J_n^* \quad (\text{Eq. 14})$$

4.3. Calculate The Voltage Changes

Voltage changes of the buses at each iteration is obtained by the following equation:

$$\Delta V^{i(k)} = |V^{i(k)}| - |V^{i(k-1)}| \quad (\text{Eq. 15})$$

In which, k is the number of iteration.

This process continues until achieving the desired convergence.

Figure 1. Studied 33-bus micro grid

Peak load on the buses of this system is shown in Table 1. The aim of this study is the optimal use of inverter capacity of photovoltaic systems. So, in order to implement this method, a 24-hour load profile is needed. The 24-hour load profile studied in this study is obtained by multiplying the peak load of the 12-bus system micro-grid in a common load that is a percentage of peak load.

Figure 2. 24-hour load of the network as a percentage of peak load

(Figure. 2) shows the 24-hour load used in this system. For the optimal location of photovoltaic systems in the micro grid, a photovoltaic system with 100 kVA nominal capacity of the inverter is considered. It must be explained that between 11 to 13 PM, the radiation is maximum and thus pv has the maximum active power generation. In other words, the entire inverter capacity of the photovoltaic system is used for active power generation, and also between 1 to 6 AM due to the lack of radiation, pv has the maximum reactive power generation. In other words, the entire inverter capacity of the photovoltaic system is used for reactive power generation.

The amount of active and reactive power generation of the system at different hours of a day is presented in Table 2. By implementing this method through a genetic algorithm and also peso algorithm, the process of algorithms' convergence is shown in Figure 3 and Figure 4.

Figure 3. The convergence process of a genetic algorithm, 33-bus micro-grid.

Figure 4. The convergence process of pso algorithm, 33-bus micro-grid.

After the implementation of both algorithms and their convergence, it becomes clear that the results of both algorithms are very close and in both algorithms, the optimal placement location shows the desired pv by considering its active and reactive power generation in bus No.32, while placement of this pv considering just the active power generation shows the bus No.18 as the optimal location. Also, (Table. 3) shows the whole losses of network in both cases by considering pv with only active power generation and pv with active and reactive power generation which as expected, taking into account the reactive power generation in addition to active power will significantly reduce the system losses, then, the placement for the same 2 and 3 PV system in the case of active and reactive power generation and in the case of active power generation only. The results obtained from placement and the whole network losses are summarized in Table 3.

To demonstrate the effect of the proposed method for placement on voltage profile, 3 different times during the day (9am, 12 at noon and 12 pm) are considered. (Figure. 5) shows that voltage profile of the system at 9 am for modes without installing PV, by installing PV considering the active power generation ability and also by installing PV considering the active and reactive power generation ability. This time was chosen for the reason that at this time, the radiation is not reached to maximum and PV can generate both active and reactive power. In fact, at 9 am the radiation was not high, and the entire inverter capacity of the photovoltaic system is not used to generate only the active power, so the inverter capacity surplus is allocated to the reactive power generation. As indicated in (Figure. 5), by considering the ability of PV inverter to

generate the active and reactive power, voltage profile of the system has improved more efficiently.

Figure 5. Voltage profile without PV, with PV and active power generation and with PV and active and reactive power generation at 9 am.

(Figure. 6) shows that voltage profile of the system for 12 noon. This time was chosen for the reason that at "12" we have the maximum radiation and active power generation and the entire inverter capacity is used for active power generation, so the amount of reactive power generation is zero.

Figure 6. Voltage profile of system buses at 12 noon.

At "12" at night, when there is no radiation, the entire inverter capacity is allocated to the reactive power generation, and because there is no radiation the amount of active power generation reaches zero (Figure. 7). Voltage profile of buses at 12 o'clock at night is shown in (Figure. 7). Since PV is not able to generate the active power at night, so if not considering the reactive power at 12 o'clock at night, the voltage

profile will overlap in the presence of PV and without PV. As seen in the figure below, considering the active power generation of pv has improved the voltage profile.

Figure 7. Voltage profile of system buses at 12 o'clock at night.

5. CONCLUSION

In this paper, the simulation of a 33-bus micro grid of distributed generation units was investigated. Many articles have worked on the optimal placement of distributed generations, but in all of them, DG is mentioned as the only resource of active power generation. In this paper, a new method was used for the optimal placement of photovoltaic system considering the nominal capacity of the inverter to generate the reactive power in addition to the active power in order to improve the voltage profile and reduce the losses of the micro grid system. Also, a 33-bus network was selected to investigate and after implementing the method and using the genetic optimization and PSO algorithms, it was found that the optimal placement of photovoltaic system by considering the active and reactive power generation, improves the voltage profile of buses of micro grid as well as reducing the total system loss, in addition, to change the placement of DG location compared to the case that the photovoltaic system generates only the active power. Finally, the following results were obtained:

- 1) To take into account, the reactive power generation will significantly reduce the active power of system loss.
- 2) At 9 am, considering the ability of PV inverter in generating the active and

reactive power, the voltage profile of the system has improved more efficiently.

- 3) At 12 o'clock at noon, we have the maximum radiation, and active power generation and the entire inverter capacity is used to generate the active power.
- 4) To take into account, the reactive power generation of pv will improve the voltage profile.

6. REFERENCES

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Table 1. Information System's Peak Load

Q(KVAr)	P(KW)	Bus Number
0	0	1
60	100	2
40	90	3
80	120	4
30	60	5
20	60	6
100	200	7
100	200	8
20	60	9
20	60	10
30	45	11
35	60	12
35	60	13
80	120	14
10	60	15
20	60	16
20	60	17
40	90	18
40	90	19
40	90	20
40	90	21
40	90	22
50	90	23
200	420	24
200	420	25
25	60	26
25	60	27
20	60	28
70	120	29
600	200	30
70	150	31
100	210	32
40	60	33

Table 2. The Amount of Active and Reactive Power Generation by the Photovoltaic System During a Day-Long.

Q(kVAr)	P(kw)	Hour
100	0	1
100	0	2
100	0	3
100	0	4
100	0	5
100	0	6
99/8	5	7
99/3	12	8
80	60	9
52/7	85	10
0	100	11
0	100	12
52/7	85	13
80	60	14
99/3	12	15
99/87	5	16
100	0	17
100	0	18
100	0	19
100	0	20
100	0	21
100	0	22
100	0	23
100	0	24

Table 3. Results of Placement and System Losses in kw.

PV with P and Q geneartion	PV with P generation	PV Number
Selected bus: 32	Selected bus: 18	1
Loss: 1696/6	Loss: 1757/46	
Selected bus: 13 and 32	Selected bus: 17 and 30	2
Loss: 1580/7	Loss: 1692/8	
Selected bus: 16, 31, 32	Selected bus: 17, 18, 33	3
Loss: 1475/9	Loss: 1626/6	