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Optimal and Economic load Distribution by Adjusting all Types of Controllable Variables With the Aim of Reducing Production Costs and Minimizing losses

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Abstract

Smart Grids are the result of the activation of consumers in the power system and their role in the planning and operation of the power system. The communication, control and measurement infrastructure asa smart communication bridge establishes two-way communication between consumers and the power network and provides the basis for the effective implementation of the load response program as well as direct load control. The purpose of solving the problem of economic load distribution in the power system is to plan the output of production units in such a way as to provide the required load demand with the lowest possible cost. In addition, it satisfies the constraints of equality or inequality of all units. In this research, PSO optimization method is taken into consideration by considering voltage deviation, voltage loss and system load capacity as part of the objective function.

Keywords: economic load flow, voltage deviation, system load limit, voltage losses, PSO algorithm

1- Introduction

Engineers and researchers often face problems in various sciences whose complexity is increasing day by day. These issues are usually expressed in an optimization problem. For a problem, it may have different solutions, and to compare them and choose the optimal solution, a function called the objective function is defined. This function depends on the nature of the problem and its proper selection is one of the most important optimization steps. Sometimes it is considered in multi-objective optimization simultaneously; Such optimization problems, which include multiple objective functions, are called multi-objective problems.

The goal of optimization is to find the best acceptable solution according to the constraints and needs of the problem. The progress of computers over the years has led to the development of optimized problem solving methods, so that many instructions have been compiled during this period. Methods for solving optimization problems can generally be divided into the following two categories, classic methods such as dynamic programming methods,New methods such as heuristic and meta-heuristic methods.

In the studies related to planning and operation, the uncertainties of the power system are analyzed using probabilistic methods. In fact, deterministic load distribution uses certain deterministic values such as the power produced by generators and the required power of loads in order to evaluate and measure the system position and load distribution. Therefore, deterministic load spreading ignores all the uncertainties of the system, such as generator shutdown rates, network structural changes due to changes in the power demand of loads. But in today's modern systems, due to the uncontrollable nature of the primary sources, many power fluctuations have been introduced into the power system and grid. In order to consider uncertainty, there are different mathematical methods for unrealistic analysis; Probability methods, fuzzy systems can be mentioned among others. There are three general methods in probabilistic load distribution evaluation: analytical methods, approximate methods and Monte Carlo simulation method. In the analytical method, load distribution equations are linearized to make it possible to use them in probability functions, as in references [1], where analytical methods are used for probabilistic load distribution analysis. In approximate methods, there is no need to linearize load distribution equations. In this method, the number of evaluated points is reduced to minimize the computational load and storage. The third method, which is the Monte Carlo simulation method, is based on the repetition process and is based on two important characteristics, which include the generation of random numbers and random sampling. In this method, for the non-deterministic variables of the problem, a number of values are generated randomly, according to the probability distribution functions of these variables. The main advantage of this method is the simplicity of its implementation and implementation. For example, references [2] are articles that have been reviewed based on the use of the Monte Carlo method in possible studies of load distribution in power systems. In general, it can be pointed out that in most of the articles, such as [3] and [4], which aim to analyze and investigate the planning and performance of microgrids based on the non-deterministic and intermittent behavior of renewable energy sources (Figure 1), solving optimization problems through Random methods are used.Reference [5] has investigated systematic planning in electricity and gas transmission networks by considering uncertainty. Reference [6] deals with the planning of energy hubs in multi-energy systems in the transmission network with reliable reliability. An integrated and multi-regional longterm planning model in multiple energy systems is presented in [7], which considers the value of gas supply from production to energy consumption through gas pipelines. An integrated multi-directional course of expansion of production and transmission networks and natural gas network in the Great Sea is presented in [8]. In reference [9], a non-linear programming model mixed with integers considering reliability and uncertainty is presented.In reference [10] of the point estimation method, to determine and check the uncertainty of wind and solar power in the objective function (Figure 2), which is the optimization of the cost function, while power losses are ignored.

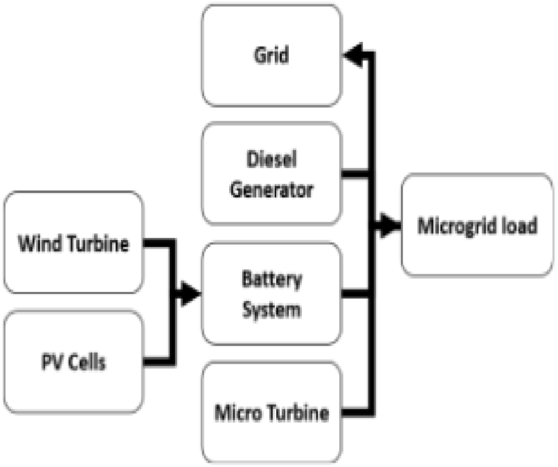

Fig.1. Layout of microgrid structure under study

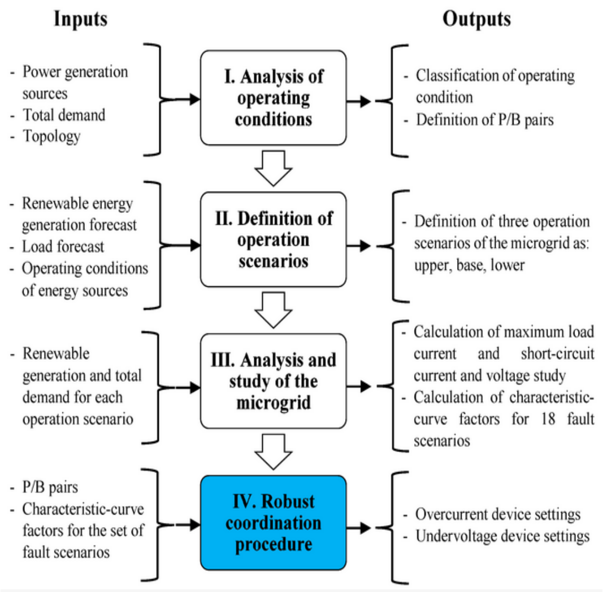

Fig.2. Four-stage procedure for the DPAU

In reference [11], the PSO algorithm has been applied to a sample microgrid that includes traditional distributed generation units, renewable energy sources such as wind and solar power, and batteries, in order to optimize the objective function. In reference [12], in order to show that the presence of renewable energy sources such as wind turbines and photovoltaic systems, along with other traditional sources of power generation in the microgrid, improves the reliability index. The power of renewable energy sources has been obtained through Monte Carlo sampling (Figure 8), Weibull and beta distribution functions, and also the results show that the power produced by wind and sun improves the uncertainty of these powers and the random deficits of the system.In reference [13], the problem of optimal load distribution related to several microgrids in the presence of load-related uncertainties and using probabilistic models related to the powers produced by small-scale renewable sources have been investigated. The power required by the load, solar radiation, and ambient temperature, which are among the factors affecting the power produced by the photovoltaic system, are modeled based on normal distribution functions and the power produced by wind generators by the Weibull function. In reference [14], a standard system of 30 tires consisting of energy storage and renewable energy sources is studied and by modeling a multi-objective problem through heuristic and meta-heuristic algorithms, it is claimed that the proposed method to minimize the cost of fuel and pollution as well as improving the line voltage profile is suitable (Figure 3) In this reference, the power produced by the wind power plant is modeled through the point estimation method based on the Weibull distribution function.

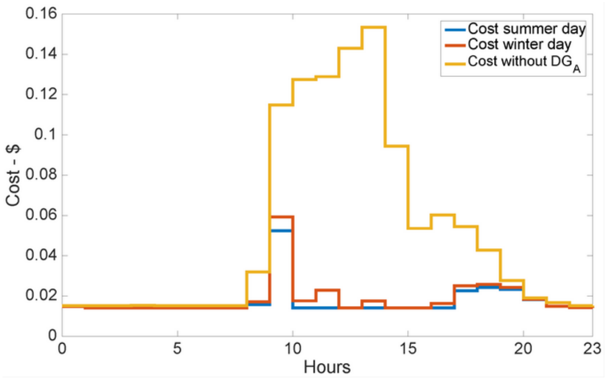

Fig.3. Energy cost of power with and without Distributed Generation (DG) on a summer day and a winter day

In a smart microgrid, the flows injected by the distributed energy resources (DER) and by the common connection point can be adapted to minimize the energy cost. Design and quality constraints usually cause the problem to grow rapidly with the number of network nodes. In this research, we provide a solution for the optimization problem, which significantly reduces the complexity according to the existing techniques.

In power systems, it is very important to produce optimal power and reduce the costs of operation and construction of power plants. In recent years, extensive studies have been conducted on optimization and cost reduction in power systems. In these systems, it was first assumed that in an interconnected power system, the active production power of all generators would be a constant value, but due to many operational problems, it was appropriate to produce and optimize this value with a coherent planning. How much active power each unit of the power system produces, as much as it takes the active power used by the system and the total cost of producing this power is reduced, is known as the issue of spreading an economy. By using economic load distribution, it is possible to calculate the amount of power plant production with the lowest cost by referring to mathematical relations. In power systems where mathematical calculations are not used for optimal power production, it was assumed that for the minimum energy production, the energy produced in times of low network load, from the most efficient power plant, consumes the required energy of the network, and with the increase of the network load . Power generation by this power plant continues until the efficiency of the power plant reaches.

According to the the economic and environmental issues and increasing the capacity of different parts of the power system, network development with traditional methods is not the answer. On the other hand, the current power system is not able to meet the load growth. Therefore, detailed economic and technical planning is needed in this field. In old programming, they often model one type of energy. Due to the possibility of replacing natural gas and electric energy and converting different energy carriers, there is a close connection between these two networks. In general, the integration and planning of the simultaneous development of electricity and gas distribution networks in terms of lower investment costs, more benefits for subscribers, facilitating market competition, guaranteeing energy security, reducing pollutants, market profits, etc, is of special importance.The purpose of optimal load distribution is actually the adjustment of all types of controllable variables, such as the voltage of generators, tap transformers, parallel capacitors and inductors, and other control variables in such a way as to meet a set of physical and operational constraints, production costs and losses. are minimized and other objective functions are satisfied.

2- Modeling the network optimization problem

In this research, DC microgrid modeling has been done on the network with wind and solar productions with local voltage controllers on the buses of distributed productions. An economic load distribution problem is presented to minimize the operation costs in the DC microgrid in the presence of renewable sources with voltage controller in real pricing conditions, where the operation costs include the cost of distributed generation and grid electricity. Also, by considering load distribution equations, it is possible to calculate losses and consider it as one of the system costs.The optimization problem modeling includes two parts: cost modeling and network power equation modeling. The optimization variables used in this research are: input or output power of the storage system, power received or sent to the network, bus voltage. Economical load distribution determines the most efficient, low cost and reliable operation of a power system by the proper distribution of energy generation resources to supply the system load. The primary goal is to minimize the total cost of production by considering the limitations of production resources.

A. Cost modeling and network power equation modeling

The problem of economic load distribution determines the amount of load for power plants in order to reduce costs. Its formulation is also presented as an optimization problem to minimize the total fuel cost of the total power plants that supply loads and losses. The limitations of the load distribution problem are also divided into three general parts, network load distribution equations, voltage controller on buses, and voltage and power limits of sources. The equation that is the energy conservation principle in the problem of electricity planning and optimal load distribution is expressed according to the following relation:

$$P_{renewable} + P_{utility} + P_{ESS} - P_{load} - P_{loss} = 0 \tag{1}$$

According to the above ratio, the total power produced by all units in the circuit must be equal to the total consumption of the system. The amount of network losses is shown in (2):

$$P_{loss} = \frac{1}{2} \times \sum_i \sum_j Y_{ij(DC)} \left(V_{i(DC)} - V_{j(DC)}\right)^2 \tag{2}$$

The presence of local voltage controllers on the distributed production bus is one of the issues that will be addressed. The equation related to the voltage controller in distributed production buses, which is considered as a constraint, is expressed in (3):

$$C_{total} = C_{utility} + C_{ESS} + C_{loss} \quad (3)$$

$C_{utility}$is the cost of network electricity, which is calculated in (4):

$$C_{utility} = \begin{cases} \frac{\lambda_{buy} P_{utility}}{\Delta T} & P_{utility} \geq 0 \\ \frac{\lambda_{sell} P_{utility}}{\Delta T} & P_{utility} \leq 0 \end{cases} \quad (4)$$

In this formula, λ_{buy} is the electricity purchase price, $\lambda_{sell}$is the electricity sale price, and ΔT is the number of optimization periods in one hour. To model the cost related to losses in the system, it is related to equation (5). In fact, losses are made according to load distribution calculations, which will be examined more precisely.

$$C_{loss} = \frac{\lambda_{buy} P_{loss}}{\Delta T} \quad (5)$$

P_{loss} is the transmitted power loss.

B. System load limit

The voltage stability in the power system is affected by the distribution system, therefore, this is also included in the load capacity index of the system. The main influence of the distribution network on the voltage stability of the upstream network is determined by the transmission lines. For ease of calculations, the upstream network can be simulated by means of Tonnon's equivalent circuit. The basis for calculating this index is using the theorem of maximum power transmission.Therefore, the voltage stability boundary theorem occurs when z_L/z_0=1. At this moment, the maximum power is equal to:

$$S_{cr} = \frac{E_{th}^2}{2Z_0\sqrt{[1+cos(\phi_0-\phi_{Leq})]}} \quad (6)$$

The index is defined:

$$VSM_s = \frac{S_{cr}-S_{Leq}}{S_{cr}} \quad (7)$$

The load limit of the system is the maximum load that can be placed on the system while the load distribution equations maintain their solvability. One of the characteristics of the load limit index is its ability to introduce the security margin of the system in the form of tangible physical quantities, and it can create a clear engineering understanding of the system's operating status for the user. This index can express the operating status of the system and its security margin in the form of an increaseable system load.According to these features, this index has been chosen as a selective index to evaluate the degree of security of power systems from the point of view of static voltage stability.

In Figure 4, a load characterized by impedance $Z_L < \varphi$is fed through a transmission line by a voltage source with amplitude V_s We know that parallel admittance can be ignored in distribution lines. Therefore, regardless of the parallel admittance of the transmission line, the passing current is equal to the load current, and considering the representation specified in the figure 8 can be written:

$$\frac{V_s-V_1}{R+jX} = \frac{P_1-jQ_1}{V_L^*} \quad (8)$$

Where R and X represent the resistance and reactance of the transmission line and V_L

specifies the complex conjugate at the load node.We assume that the source voltage, V_s is the reference voltage, and we assume that its angle is zero. Also, we assume the angle of the load node to be zero, so from the above equation we will have (9)And then (10):

$$\frac{V_S\angle 0 - V_L\angle -\delta}{R+jX} = \frac{P_L - jQ_L}{V_L\angle\delta} \tag{9}$$

$$\frac{V_S V_L\angle\delta - V_L^2}{R+jX} = P_L - jQ_L \Rightarrow V_s V_L\angle\delta - V_L^2$$

$$= (P_L - jQ_L)(R + jX) \tag{10}$$

By separating the real and imaginary parts, we will have (11):

$$V_s \cos\delta = \frac{1}{V_L}(V_L^2 + RP_L + XQ_L)$$

$$V_s \sin\delta = \frac{1}{V_L}(XP_L - RQ_L) \tag{11}$$

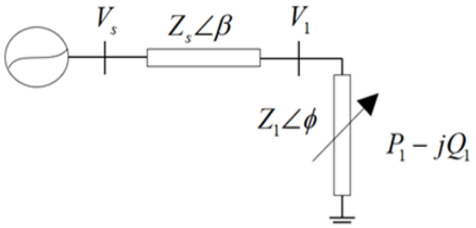

Fig.4. A system consisting of a single line

Using the above two relations:

$$(V_s \cos\delta)^2 + (V_s \sin\delta)^2 = V_s^2 \tag{12}$$

$$V_s^2 = \frac{1}{V_L^2}(V_L^2 + RP_L + XQ_L)^2 + \frac{1}{V_L^2}(XP_L - RQ_L)^2 \tag{13}$$

After simplifying the (13), the following final relations is obtained:

$$V_L^4 - [V_s^2 - 2(RP_L + XQ_L)]V_L^2 + (R^2 + X^2)(P_L^2 + Q_L^2) = 0 \tag{14}$$

The above relation has four possible solutions. Despite this, under the normal working conditions of the system (that is, within the voltage stability range), this equation has two acceptable solutions, that is, a solution that is real and positive.

C. PSO particle algorithm

Particle swarm optimization (PSO) is a population-based optimization technique inspired by the social behavior of birds, fish breeding, or insect swarms. It is a heuristic search algorithm used to find the optimal solution for a given problem. The algorithm starts by initializing a population of particles, where each particle represents a possible solution to the problem. Guided by its own experience and the experience of the crowd, each particle moves through the search space and tries to find the optimal solution.

The PSO algorithm is a heuristic search algorithm that repeatedly adjusts the position and velocity of a population of particles to find the optimal solution for a given problem. The algorithm is guided by the experience of each particle and the swarm as a whole. It is a popular optimization algorithm due to its simplicity, efficiency and effectiveness in solving a wide variety of problems.

The Particle Swarm Optimization (PSO) algorithm usually includes the following steps; Initialization,Assessment, Global best update, Speed and position updates andtermination.Steps 2 to 5 are repeated for a fixed number of iterations or until a stopping criterion is met.In each iteration, the velocity of a particle is updated based on the current velocity, personal best position, and global best position. A particle's position is updated based on its current position and updated velocity. The world best position is updated if a particle has a personal best position better than the current world best position.

The PSO algorithm seeks to optimize a fitness function by adjusting the position of particles in the swarm. By repeating these steps, PSO seeks to find the optimal solution in the problem domain.Suppose we have P particles and denote the position of each particle in each iteration t as X_i(t). In addition to the position, the velocity of each particle is also expressed by V_i(t) and in the general case for the next iteration, the position of each particle is updated as follows:

$$X_i(t+1) = X_i(t) + V_i(t+1) \qquad (15)$$

or as:

$$x_i(t+1) = x_i(t) + v_x^i(t+1) \qquad (16)$$

$$y_i(t+1) = y_i(t) + v_y^i(t+1) \qquad (17)$$

The speeds are also updated simultaneously as follows:

$$V_i(t+1) = wV_i(t) + c_1 r_1\big(Pbest_i - x_i(t)\big) + c_2 r_2(gbest - X_i(t)) \qquad (18)$$

where r_1 and $r_2$are random numbers between zero and one and constants w ,c_1 and$c_2$are the parameters of the particle algorithm. $Pbest_i$is the position with the best value ever extracted by all particles in the ensemble.

3- Optimization results

In this research, in order to test the proposed method, a DC microgrid including 38 buses has been used (Figure 5). Dispersed production sources are widely distributed on the level of microgrids. These sources include wind turbine, solar cell and energy storage system which is connected to bus number 17 and on the other hand, two fossil production sources are also connected to bus number 37 on the other side of the microgrid.

Various scenarios have been evaluated under optimization and stability and loss indicators have been compared. Information on load, impedance and admittance values of the lines is provided according to Tables 1 and 2.

A. The first study scenario

In this case, it is assumed that initially all production sources do not play a role in power exchange in the microgrid and are inactive in some way. In this case, the voltage profile before and after optimization will be as shown in Figure 5. This figure shows that if all production resources fail and do not contribute to the amount of power exchanged with the network, then after optimizing the economic costs, the amount of network losses and also the amount of voltage deviation compared to before the optimization It has dropped significantly, which shows the improper functioning of the distribution system.Table 3 shows the values obtained before and after optimization for this mode.

B. The second study scenario

In this case, it is assumed that only the wind power plant is active in the network and other production sources have no role in generating network power. The analysis of optimal load distribution possibilities for the microgrid considering the total wind power has been evaluated. In the general conditions of the first study, to minimize the cost without taking into account the losses and taking into account the losses and simultaneously minimizing the cost and pollution without taking into account the losses and taking into account the losses, the cost of the wind generator is considered and the expression $cost_j$ in (19) is expressed:

$$Cos\,t_j = \sum_{j=1}^{n_g} C_j\left(P_{gi}\right) + C_{w\,in\,d} \qquad (19)$$

$$= \sum_{j=1}^{n_g} \left(a_j + b_j . P_{gj} + c_j P_{gj}^2\right) + C_{op.wind} * P_{wind}$$

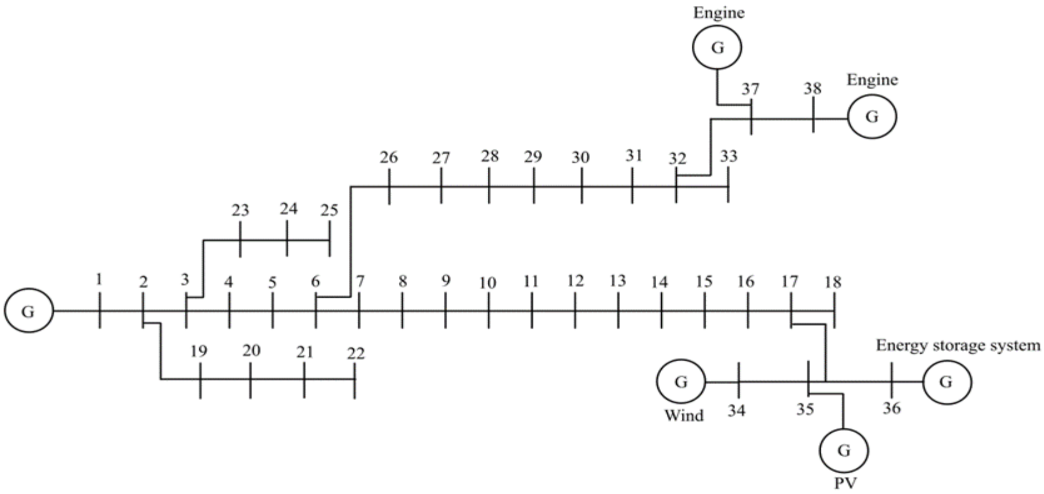

Fig.5. Single line diagram of the desired microgrid

Table 1. Load information

Load 2	P=100 Kw, Q=60 Kvar	Load 11	P=45 Kw, Q=30 Kvar	Load 20	P=90 Kw, Q=40 Kvar	Load 29	P=120 Kw, Q=70 Kvar
Load 3	P=90 Kw, Q=40 Kvar	Load 12	P=60 Kw, Q=35 Kvar	Load 21	P=90 Kw, Q=40 Kvar	Load 30	P=200 Kw, Q=600 Kvar
Load 4	P=120 Kw, Q=80 Kvar	Load 13	P=60 Kw, Q=35 Kvar	Load 22	P=90 Kw, Q=40 Kvar	Load 31	P=150 Kw, Q=70 Kvar
Load 5	P=60 Kw, Q=30 Kvar	Load 14	P=120 Kw, Q=80 Kvar	Load 23	P=90 Kw, Q=50 Kvar	Load 32	P=210 Kw, Q=100 Kvar
Load 6	P=60 Kw, Q=20 Kvar	Load 15	P=60 Kw, Q=10 Kvar	Load 24	P=420 Kw, Q=200 Kvar	Load 33	P=60 Kw, Q=40 Kvar
Load 7	P=200 Kw, Q=100 Kvar	Load 16	P=60 Kw, Q=20 Kvar	Load 25	P=420 Kw, Q=200 Kvar	Load 34	P=20 Kw, Q=5 Kvar
Load 8	P=200 Kw, Q=100 Kvar	Load 17	P=60 Kw, Q=20 Kvar	Load 26	P=60 Kw, Q=25 Kvar	Load 35	P=10 Kw, Q=10 Kvar
Load 9	P=60 Kw, Q=20 Kvar	Load 18	P=90 Kw, Q=40 Kvar	Load 27	P=60 Kw, Q=25 Kvar	Load 36	P=10 Kw, Q=20 Kvar
Load 10	P=60 Kw, Q=20 Kvar	Load 19	P=90 Kw, Q=40 Kvar	Load 28	P=60 Kw, Q=20 Kvar	Load 37	P=10 Kw, Q=5 Kvar

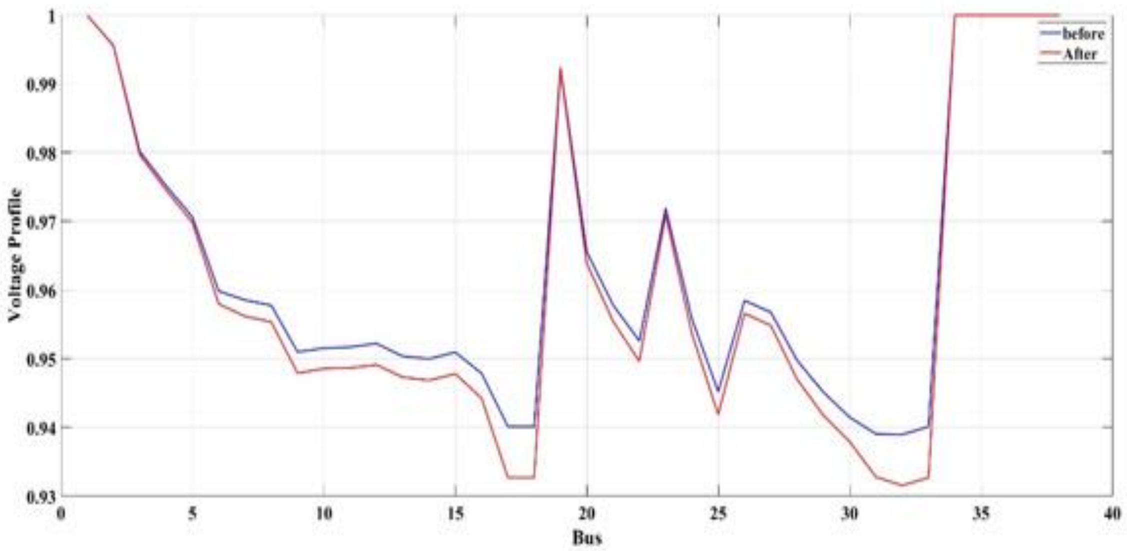

Fig.6. Voltage profile

Table 2. Comparison of evaluated indicators and parameters

	Before optimization	after optimization
Total operating cost ($/MWh)	462.9615	522.3834
total losses	42.9204	703.3529
voltage deviation	0.26111	0.3995

Where C_{wind} is the cost of the wind generator in ($/h), $C_{op.wind}$ isthe operating cost of the wind generator in ($/MWh) and p_wind is the power of the wind generator in (MW).Figure 7 shows the voltage profile before and after the optimization, which clearly states that after the optimization, the voltage profile of the buses has improved and also the amount of voltage deviations is acceptable compared to the previous state. It has gotten better. Figure 8 also shows the optimized amount of the objective function, which reached its minimum value in thirty iterations.Table 3 shows the comparison of evaluated indicators before and after optimization. According to the recorded values, the operating cost has been reduced to an acceptable level after optimization. The power loss has also decreased to a suitable extent; Also, the amount of voltage deviations after optimization has reached 0.1188.

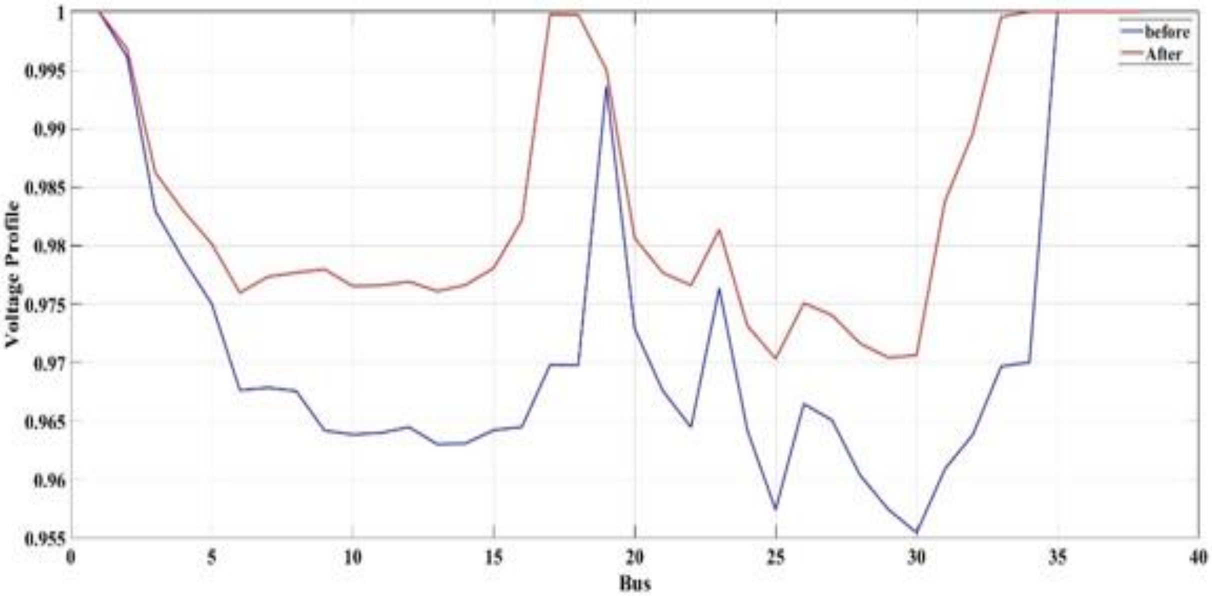

Fig.7. Voltage profile

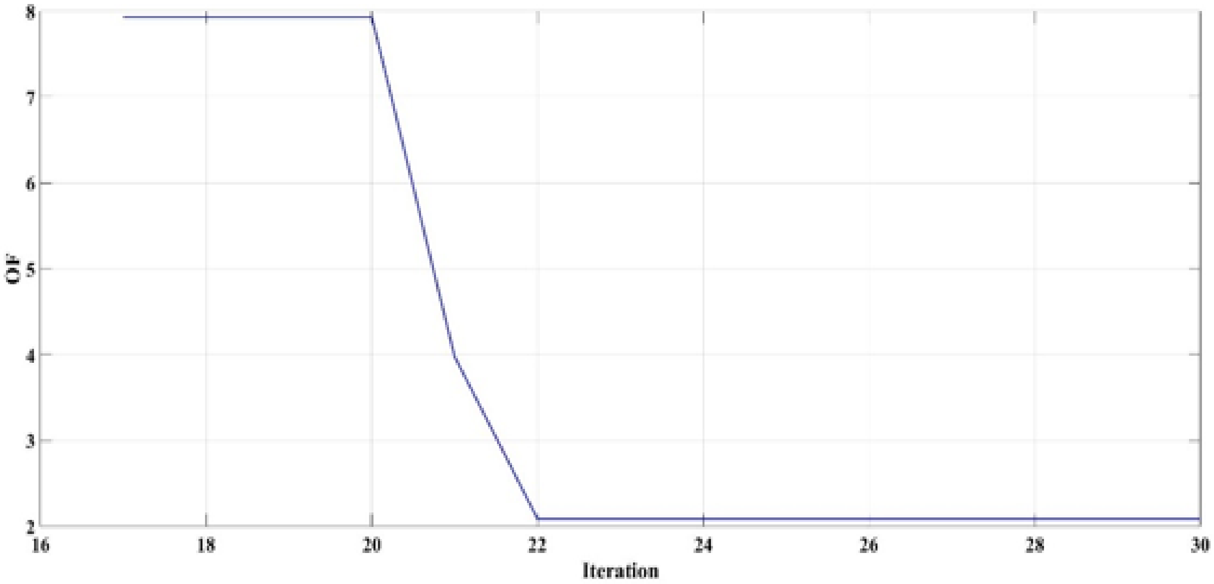

Fig.*8.* *Optimized objective function*

Table 3. Comparison of evaluated indicators and parameters

	Before optimization	after optimization
Total operating cost ($/MWh)	514.3656	438.7806
total losses	12.4132	3.2178
voltage deviation	0.1894	0.1188

C. The third study scenario

In this case, it is assumed that the wind and solar power plants are active in the microgrid and other production sources are still inactive. In this case, it is expected that the power losses and operating costs as well as the voltage deviation will improve after the optimization mode compared to before, which Figures 9 and 10 show this process well. Also Table 3 shows the evaluated indicators before and after optimization for this scenario.

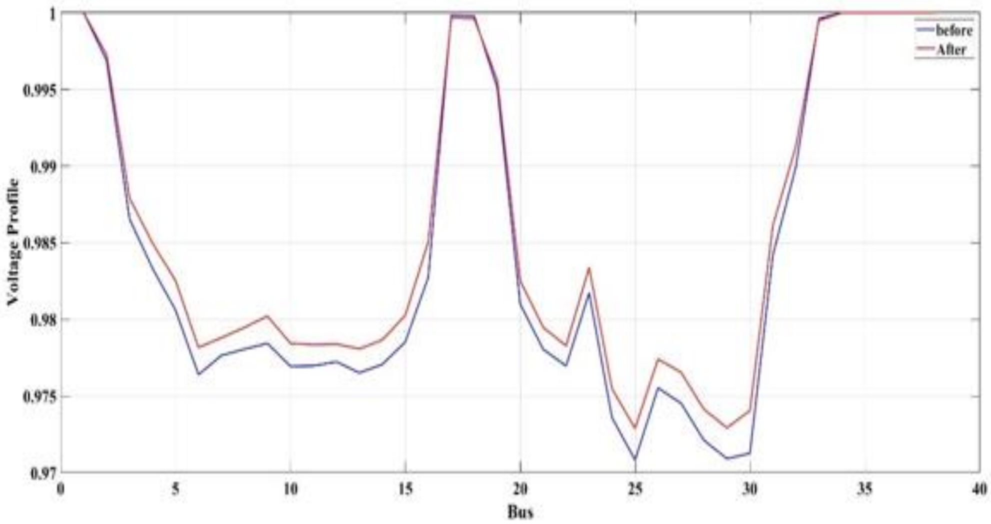

Fig.9. Voltage profile

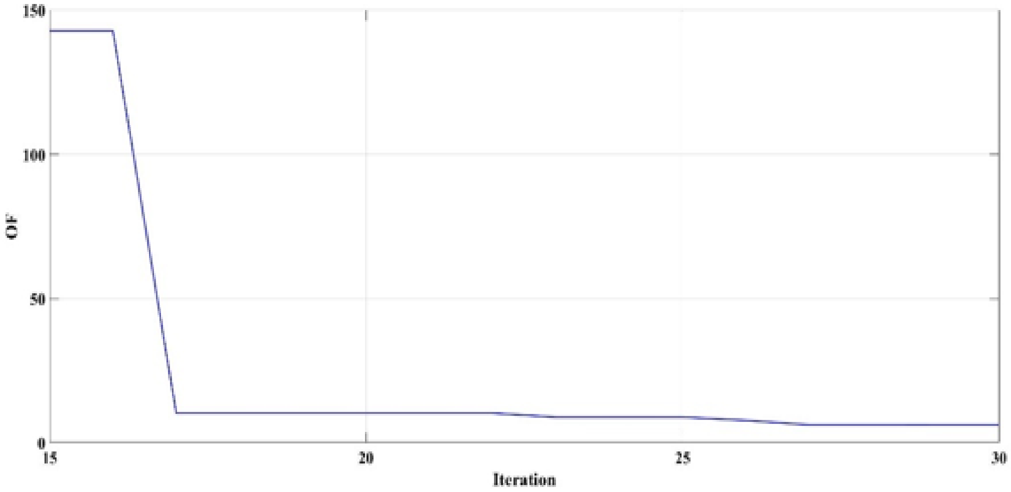

Fig.10. Optimized objective function

Table 4. Comparison of evaluated indicators and parameters

	Before optimization	after optimization
Total operating cost ($/MWh)	520.03	455.9418
total losses	0.1695	0.1543
voltage deviation	0.1166	0.1078

Conclusion

In today's modern systems, exploitation and optimization is essential. Microgrids are a small-scale example of centralized electrical systems and are used for various purposes such as minimizing losses, minimizing operating costs and voltage deviations, improving reliability and the possibility of using distributed generation units based on renewable energy sources. On the other hand, renewable energy sources such as wind power plants and photovoltaic systems due to their high efficiency, low cost of electricity production, easy access to these energy sources in most hours of the day and night, the ability to produce power on a large scale and ensure the quality of power production, more than any of the existing technologies for the exploitation of renewable energy sources have been expanded in the power system.

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