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Research Article

A new method for solving power flow problem in low voltage islanded microgrids based on loss control in generation units

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Abstract: Conventional power flow methods could not be used in islanded microgrids (IMGs) because the reference bus frequency and voltage are assumed to be constant. Usually, the presumptions of the power flow problem cannot be generalized to the intended characteristics of an islanded microgrid, and all distributed generators (DGs) play their role in providing active and reactive power to keep the frequency constant in a microgrid. Under such a situation, the problem should be modeled without the reference bus and taking into account the steady-state frequency and the reference bus voltage as a power flow variable. In this case, parameters such as load and line admittance change with changing frequency in every iteration, affecting the convergence of such networks and increasing the number of iterations. To reduce the number of iterations in such networks, new mathematical methods, such as the Levenberg–Marquardt method, are used.

By using a new equation for calculating various values voltages and angles as well as presenting and calculating coefficients to reduce iterations, this method speeds up the process of solving the power flow problem. The new method performs the calculations regarding power flow by approximating the first-order solution from the Jacobin matrix. It has also speeded up the solution process by calculating the coefficients of the power differences at each stage.

Keywords: Microgrid, power flow, Levenberg–Marquardt algorithm

Introduction

The microgrid control strategy should be designed in different modes, i.e. centralized, decentralized, and distributed. Any combination of these modes can also be implemented. Centralized control strategies require significant amounts of data in a reliable communication link [1].

To solve the power flow problem in networks, conventional and new power flow methods are used. Due to the structures and conditions of microgrids, some of these methods are not used in the problem of microgrid power flow, and some make changes in the structures or equations. In solving the microgrid power flow problem, due to the structural difference of these networks and power networks as well as changed in the parameters of the lines, new problems arise that require appropriate methods to be solved.

Until now, many methods have been proposed to solve the power flow problem in distribution systems, which could be divided into three general categories: the deterministic method, the probabilistic method, and the evolutionary method. In all of these methods, the parameters required for the power flow are the same, differing only in terms of convergence speed, number of iterations, and accuracy. It should be noted that in islanded microgrids, the frequency parameter is added to other power distribution parameters [2].

Backward/Forward sweep Method: This is one of the most widely used methods for power flow in radial networks. These methods have a low computational burden and high accuracy. In some distribution networks, a loop is used to increase the reliability and improve the voltage rate of the busbars. The advantages of this method are high speed, low memory storage, and good convergence. This method faces problems in distribution networks that have a mesh [3].

One of the most well-known methods for solving nonlinear problems is the Newton-Raphson method, in which, we start with an initial conjecture, write the Taylor series for the equations, and then discard the high orders. The result is the conversion of a nonlinear equation into a linear one. In this method, the number of iterations does not depend on the number of busbars and often converges. Since fixed point methods, such as that proposed by Gauss-Seidel, have little or no convergence in radial networks, our method can be a good alternative to fixed-point methods such as that of Gauss-Seidel [3, 2].

Mathematical methods are required to determine indefinite values and what is ignored in definite methods. Thereby, the probabilistic power flow method was first introduced in 1974 and further developed and extended to power system analyzes, including fuzzy logic or interval analysis. [1] presented a comprehensive review and history of probabilistic power flow articles. Probabilistic power flow solution can be divided into two categories of numerical and analytical solution methods. Probabilistic power flow methods emphasize a definite power flow using nonlinear equations for an extended period with different inputs and combinations. To use the real power flow equations, the results obtained from these methods are usually used as a reference for the results of other probabilistic power flow solutions to examine the accuracy level. However, some power flow methods require a long time to calculate [4, 5]. The main idea of analytical solutions is to obtain volumetric functions and line currents from random state variables and the functions of lots of random input variables, respectively. But there are two problems for the probabilistic solution of power flow equations. The first problem is nonlinear equations and the second is the interdependence of input power variables. In addition, abstractions that enhance the probabilistic power flow using the analytical method cause errors in the solutions. These power flow equations are linearized around the estimated points of the system using Taylor's first method [1-6].

In addition to analytical models, several studies examine power flow models based on evolutionary algorithms. These models depend on the boundary values of the problem variables. For example, Al-Riah [7] provides an algorithm based on the PSO technique to solve the power flow problem in an islanded microgrid. PSO is used to estimate the loss parameters to optimize the reactive power flow. However, their algorithm fails to calculate the active power flow between distributed generation resources.

An improved genetic algorithm (IGA) was proposed in [5] to solve the power flow problem. IGA responses include gradient methods. The combination of PSO and GA in [8] is used to solve the power flow problem in two different steps from PSO and GA. The proposed method takes a lot of time to make the power flow using PSO\GA [9].

A large number of the above studies are related to the power flow analysis models, which consider a constant frequency for the system. However, in an islanded microgrid where no reference bus exists, the frequency cannot be considered constant and must be calculated as one of the power flow variables. The power flow models, which only consider P-V or P-Q nodes as the distributed generation units, fail to measure the performance of islanded microgrids [5].

Problem statement:

The high-order Newton-Raphson method is used to solve the power flow problem in low voltage islanded microgrids based on the loss control methods in distributed generation units. This method has the following advantages:

- Highly accurate solution
- Low number of iterations to achieve convergence
- Increased convergence rate due to higher-order in the new method compared to traditional methods
- Controllability of the CPU time using the controlling parameters, such as the damping parameter (λ)
- Guaranteed convergence of solutions
- Possibility of method convergence for systems with a high R/X ratio

Proposed methodology for power low

Newton-Raphson power flow method is an old methodology for nonlinear flow in power networks, which is widely used due to its advantages. In the universal power network, due to the ideal conditions such as the sufficient generation, appropriate impedance to network admittance ratio, and the presence of infinite or reference bus, this method has a very good convergence rate. Adding accelerating coefficients to this method further improves the situation and accelerates the convergence rate. However, favorable conditions do not always exist, and as each of these advantages is omitted, the convergence conditions deteriorate. Deteriorated conditions in such iterative methods, the number of iterations increases, and in some cases, it leads to divergence of the existing algorithm. Naturally, with increasing frequency, the time to obtain the solution increases based on conditions, type, and the number of network buses, which makes this solution seem implausible and impractical [6].

One of the cases in which sub-optimal conditions prevail is microgrids. The conditions of this type of network are different from other power systems such as universal power networks. In these networks, the generation rate is limited and is often in the form of distributed generation. This does not cause major problems in microgrids that can connect to the universal power system, but the problem occurs when the microgrid is unable to connect. In these cases, the generation sufficiency, reference bus voltage stability, voltage control bus generation stability, and frequency stability, which are the fixed points in the Newton-Raphson algorithm, will be uncertain. This leads to a sharp decrease in the convergence rate and a sharp increase in the number of iterations [9-10].

Another problem in both connected and islanded microgrids is that the $\frac{R}{X}$ the ratio of these grids is high. This is because these grids generally operate at distribution-level voltages or have a radial structure or serve a small area. This has been shown to reduce the convergence rate and increase the number of iterations.

As mentioned above, in islanded microgrids, due to the uncertainty and insufficient generation, the actual power of the voltage control bus is not possible to be kept constant. This also contributes to the poor conditions of this type of grid and increases the non-convergence rate and the number of iterations [11-14].

Considering all of the above, to solve this problem as well as to calculate the reference bus voltage and network frequency accurately, an evolutionary type of Newton-Raphson power flow method is

provided, which has the potential to both calculate the mentioned factors and to overcome the problem of convergence and number of iterations in this type of network. It should be explained that there are methods, such as the recursive method, that are suitable for calculating this type of power flow, but the main problem of such methods is that they can only be used in radial networks and are not suitable to solve the loop network problem.

Modification of convergence of Newton-Raphson method

After solving the problem of reference bus voltage and grid frequency using the Newton-Raphson algorithm, the remaining problem will be reducing the number of iterations in this method. Iterations have increased due to the above-mentioned conditions and have reduced the efficiency of the algorithm. Several methods are used to increase the speed of this algorithm, such as the Levenberg–Marquardt method or acceleration coefficient.

Acceleration coefficient method:

The acceleration coefficient is the simplest method for increasing the convergence rate, which is used in many cases. In this method, a constant, usually experimental coefficient, which is often a number between 0 and 2, is multiplied by the difference between the previous iteration solution and the current iteration solution. This results in solutions closer to the optimal solution.

$$x'^{i+1} = x'^{i} + \mathrm{acc}(x'^{i+1} - x'^{i}) \quad (1)$$

One of the problems of this method is that the coefficient is assumed to be constant in all iterations. This reduces the accuracy in finding solutions that are closer to the optimal solution. Also, at the beginning of the algorithm, if the differences are wide, they can cause non-convergence or an increased number of iterations. In the set of boundary solutions, this method creates a fluctuation of the solution around the operating point, and therefore, loses its efficiency in some cases.

Levenberg–Marquardt Method:

In this method, the slope of changes of variables in each step is compared to the previous step, and using this slope, acceleration coefficients are created which help speed up the convergence rate of the algorithm. One of the advantages of this approach compared to the previous ones is that the previously constant acceleration coefficient changes in several iterations. One of the problems with this method is that there is still the possibility of errors in the initial repetitions. The number of internal iterations is constant and the method loses its efficiency in case of a small number of errors.

Self-correcting quasi-Schimanski Levenberg–Marquardt Method (new method):

The Levenberg–Marquardt method is an algorithm that is applicable to the Newton problem in the Newton Trust area. Using coefficients that are created according to the obtained solutions, this method accelerates the solution of such problems. In this method, using the algorithms that have been added, the coefficients change in each period and each function.

In this method, the correction factor is modified in each step according to the error rate and the number of iterations. This advantage makes the algorithm perform well with high error rates and have good accuracy at a low error rate.

New Levenberg–Marquardt mathematical algorithm

This algorithm is formulated as follows.

Step one:

First, the following initial constant values are selected by default; where m is the iteration limit at each stage of the inner loop, P0 is the acceptable error rate and N is the total iteration limit of the loop. Here, μ is the impact factor.

$$\mu_0 < \mu < 0 \tag{2}$$

$$0 < P_0 < r \tag{3}$$

$$m \geq 1\,, N > 0 \tag{4}$$

$$\mu_0 \epsilon [\mu_{min}, \mu_{max}] \tag{5}$$

$$\epsilon\delta[1,2] \tag{6}$$

Step two:

The initial values are given below. One of these values is the parameter β, which is one of the major differences between the new method and the Levenberg–Marquardt method. This is called the nonmonotonous parameter, which is defined as follows.

$$\Lambda_k = \begin{cases} \|F_k\|^{\delta} & if\ k = 0 \\ \dfrac{\sum_{i=0}^{m(k)-1} \eta^{m(k)-i} \mathcal{F}_k(i) + \|F_k\|^{\delta}}{\sum_{i=0}^{m(k)-1} \eta^{m(k)-i} + 1}, & if\ k > 0 \end{cases} \tag{7}$$

Where $\mathcal{F}_k(i)$ is defined as follows:

$$\mathcal{F}_k(i) = \begin{cases} \|F_k\|^{\delta} & if\ k < N \\ \|F_{k-N+i+1}\|^{\delta} & if\ k \geq N \end{cases} \tag{8}$$

The value of λ_0, which is the initial value of the correction parameter, is defined as follows.

$$\lambda_0 = \mu_0 \Lambda_0 \tag{9}$$

Where, μ is the lower limit of the method, which prevents the high number of iterations at lower and close-to-solution limits.

Step three:

At this step, the Jacobean values and the difference vector are defined as follows. It should be said that these are the values of every iteration (10).

$$F_x = F(x_k) \tag{10}$$

$$J_x = J(x_k) \tag{11}$$

The following equality should be established for the algorithm to be completed.

$$\left\|J_k^T F_k\right\| = 0 \tag{12}$$

To calculate the correction values in the required iterations (i) and at the K^{th} step, the following equation is used

$$d_{i,k} = -\left(J_k^T J_k + \lambda_k I\right)^{-1} J_k^T dP_{i,k} \tag{13}$$

The initial values in each step are modified as follows

$$x_{k,i} = x_{k,i-1} + d_{k,i-1} \quad (14)$$

Generally, the total correction values are as follows

$$s_k = \sum_{i=0}^{m-1} d_{k,i} \quad (15)$$

Step four:

Then, the maximum error rate in this step is calculated as follows. $\mathrm{Ared_k}$ is the difference between the values from the beginning to the end of the interval and $\mathrm{Pred_k}$ is the difference between the values in two consecutive iterations

$$r_k = Ared_k / Pred_k \quad (16)$$

If this error rate is acceptable, changes resulting from calculations will be applied. If this is not the case, the setting parameters will be adjusted automatically.

$$x_{k+1} = \begin{cases} If\ x_k + s_k & r_k \geq p_0 \\ Otherwise & x_k \end{cases} \quad (17)$$

Step five:

The two parameters of $\mathrm{A_{red}}$ and $\mathrm{P_{red}}$ are calculated as follows.

$$Ared_k = \|F_k\|^2 - \|F(x_k + s_k)\|^2 \quad (18)$$

By selecting the new m for the upper limit of the iterations and replacing k + 1 in the iterations, the new μ value will be calculated as follows and the algorithm returns to the third step.

$$\mu_{k+1} = max\{\mu, \mu_k q(r_k)\} \quad (20)$$

Where the parameter q is as follows.

$$q(r) = \max\{\tfrac{1}{4}, 1 - 2(2r-1)^3\} \quad (21)$$

Implementation of the proposed method in power problem

Step one:

First, the following initial constants will be selected by default just as the mathematical method. Where m is the iteration limit at each stage of the inner loop, P_0 is the acceptable error rate and N is the total iteration limit of the loop. Here μ is the impact factor of small errors of the problem.

$$\mu_0 < \mu < 0$$

$$0 < P_0 < r$$

$$m \geq 1\ , N > 0$$

The soft power of the problem (δ) and the initial values of μ, within their limits, are determined as follows.

$$\mu_0 \epsilon [\mu_{min}, \mu_{max}] \quad (25)$$

$$\epsilon \delta [1,2] \quad (26)$$

Step two:

Then, the values of the primary variables are defined as follows: Λ, a parameter called β, is a nonmonotonous parameter that is defined as follows in the first iteration. The values of ΔP and ΔQ should replace F in the mathematical problem, which is given here in the form $\begin{bmatrix} \Delta P \\ \Delta Q \\ P_{tot} - P_{sys} \\ Q_{tot} - Q_{sys} \end{bmatrix}_x$.

$$\Lambda_0 = \left\| \begin{bmatrix} \Delta P \\ \Delta Q \\ P_{tot} - P_{sys} \\ Q_{tot} - Q_{sys} \end{bmatrix}_{x_0} \right\|^{\delta} \qquad (27)$$

$$\lambda_0 = \mu_0 \Lambda_0 \qquad (28)$$

The initial values are $m(0) = 0$, $k = 0$ and $i = 0$. Then the following loop is executed.

Step three:

First, the algorithm termination condition is defined as follows.

$$\left\| J_k^T \begin{bmatrix} \Delta P \\ \Delta Q \\ P_{tot} - P_{sys} \\ Q_{tot} - Q_{sys} \end{bmatrix}_k \right\| = 0 \qquad (29)$$

This algorithm uses two loops, one internal loop, and one external loop. The internal loop performs the power flow calculations up to the number required by the external loop using the variable (counter) i. Then the correction factors are modified in the external loop and applied again to the internal loop. The value of the internal loop counter is determined based on the conditions of the external loop. It should be noted that the external loop counter is a variable k.

The power difference to the number of internal counters i is calculated as follows. $d_{i,k}$ is the vector of the power difference and the voltage with the number of iterations of i in the k[th] step.

$$\begin{bmatrix} \Delta\delta \\ \Delta V \\ \Delta\omega \\ \Delta V_1 \end{bmatrix}_{i,k} = -\left(J_k^T J_k + \lambda_k I\right)^{-1} J_k^T \begin{bmatrix} \Delta P \\ \Delta Q \\ P_{tot} - P_{sys} \\ Q_{tot} - Q_{sys} \end{bmatrix}_{i,k} \qquad (30)$$

Then at each stage of the internal loop, the problem variables, including V, δ, ω, V_1 are updated as follows, as the normal methodology.

$$\begin{bmatrix} \delta \\ V \\ \omega \\ V_1 \end{bmatrix}_{k,i} = \begin{bmatrix} \delta \\ V \\ \omega \\ V_1 \end{bmatrix}_{k,i-1} + \begin{bmatrix} \Delta\delta \\ \Delta V \\ \Delta\omega \\ \Delta V_1 \end{bmatrix}_{k,i-1} \qquad (31)$$

Then again, in the external loop, the counter of the internal loop becomes zero and the unit will be added to the external counter. The total correction is then calculated for the main loop. s_k is the sum of all corrections in all rounds of the internal loop in each iteration.

$$\begin{bmatrix}\delta\\V\\\omega\\V_1\end{bmatrix}_{k,0} = \begin{bmatrix}\delta\\V\\\omega\\V_1\end{bmatrix}_k \tag{32}$$

$$s_k = \sum_{i=0}^{m-1}\begin{bmatrix}\Delta\delta\\\Delta V\\\Delta\omega\\\Delta V_1\end{bmatrix}_{k,i} \tag{33}$$

Step fourth:

Then, the maximum error rate in this step is calculated as follows, where, $Ared_k$ is the difference between the power differences from the beginning to the end of the interval and $Pred_k$ is the difference between the power differences in two consecutive repetitions.

$$r_k = Ared_k/Pred_k \tag{34}$$

Now, if this error rate is acceptable, changes due to calculations will be applied. If not, the setting parameters are automatically modified.

$$\begin{bmatrix}\delta\\V\\\omega\\V_1\end{bmatrix}_{k+1} = \begin{cases} If \begin{bmatrix}\delta\\V\\\omega\\V_1\end{bmatrix}_k + s_k \quad r_k \geq p_0 \\ Otherwise \begin{bmatrix}\delta\\V\\\omega\\V_1\end{bmatrix}_k \end{cases} \tag{35}$$

Step fifth:

Then with the increase in parameter *m*, the number of iterations increases as follows. Using the obtained data, the main parameter of the acceleration coefficient λ, which is Λ and μ, is calculated as follows.

$$m(k+1) \in [0, \min\{m(k)+1, N\}] \tag{36}$$

Where $q(r_k)$ is the correction factor μ based on the error coefficient r_k.

$$\Lambda_k = \begin{cases} \left\| \begin{bmatrix}\Delta P\\\Delta Q\\P_{tot}-P_{sys}\\Q_{tot}-Q_{sys}\end{bmatrix}_k \right\|^{\delta} & if\ k=0 \\ \dfrac{\sum_{i=0}^{m(k)-1}\eta^{m(k)-i}\mathcal{F}_k(i) + \left\| \begin{bmatrix}\Delta P\\\Delta Q\\P_{tot}-P_{sys}\\Q_{tot}-Q_{sys}\end{bmatrix}_k \right\|^{\delta}}{\sum_{i=0}^{m(k)-1}\eta^{m(k)-i}+1}, & if\ k>0 \end{cases} \tag{37}$$

$$\mu_{k+1} = \max\{\mu, \mu_k q(r_k)\} \tag{38}$$

Where $\mathcal{F}$ is calculated as follows.

$$\mathcal{F}_k(i)=\begin{cases}\left\|\begin{bmatrix}\Delta P\\ \Delta Q\\ P_{tot}-P_{sys}\\ Q_{tot}-Q_{sys}\end{bmatrix}_k\right\|^{\delta} & if\ k<N\\ \left\|\begin{bmatrix}\Delta P\\ \Delta Q\\ P_{tot}-P_{sys}\\ Q_{tot}-Q_{sys}\end{bmatrix}_{k-N+i+1}\right\|^{\delta} & if\ k\geq N\end{cases} \quad (39)$$

Where parameter q is as follows:

$$q(r)=\max\left\{\frac{1}{4},1-2(2r-1)^3\right\} \quad (40)$$

Then $\left\|J_k^T\begin{bmatrix}\Delta P\\ \Delta Q\\ P_{tot}-P_{sys}\\ Q_{tot}-Q_{sys}\end{bmatrix}_k\right\|$ is calculated again. If it is equal to zero, the algorithm terminates; otherwise, the algorithm repeats.

The two parameters of A_{red} and P_{red} are calculated as follows.

$$Ared_k=\left\|\begin{bmatrix}\Delta P\\ \Delta Q\\ P_{tot}-P_{sys}\\ Q_{tot}-Q_{sys}\end{bmatrix}_k\right\|^2-\left\|\begin{bmatrix}\Delta P\\ \Delta Q\\ P_{tot}-P_{sys}\\ Q_{tot}-Q_{sys}\end{bmatrix}(x_k+s_k)\right\|^2 \quad (41)$$

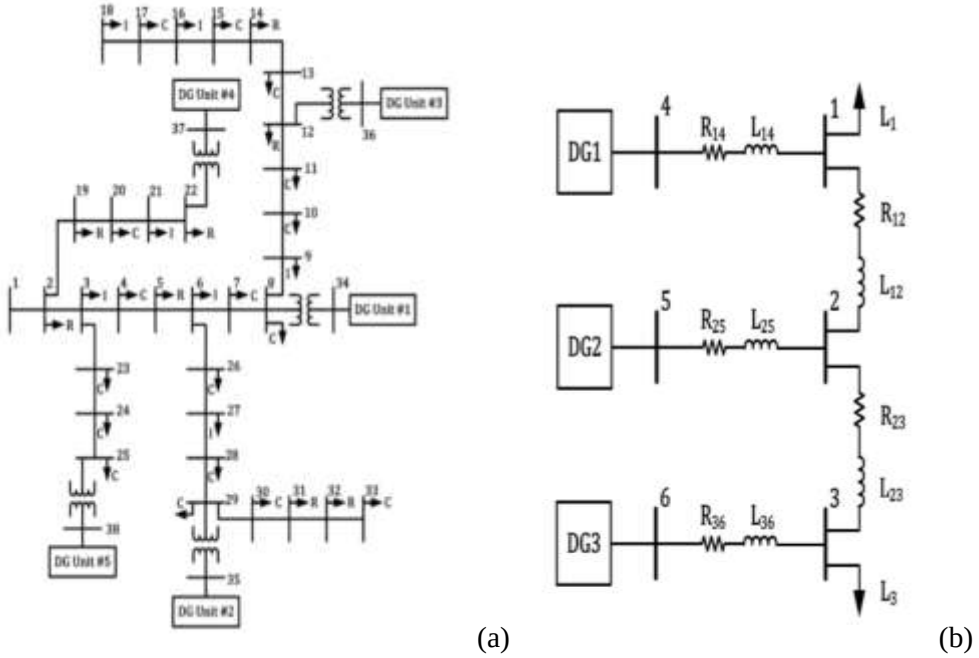
$$Pred_k=\sum_{i=0}^{m-1}\left(\left\|\begin{bmatrix}\Delta P\\ \Delta Q\\ P_{tot}-P_{sys}\\ Q_{tot}-Q_{sys}\end{bmatrix}_{k,i}\right\|^2-\left\|\begin{bmatrix}\Delta P\\ \Delta Q\\ P_{tot}-P_{sys}\\ Q_{tot}-Q_{sys}\end{bmatrix}_{k,i}+J_k\begin{bmatrix}\Delta\delta\\ \Delta V\\ \Delta\omega\\ \Delta V_1\end{bmatrix}_{k,i}\right\|^2\right) \quad (41)$$

Systems studied:

Standard 6-bus system: This system is as set out in Fig. (1). This network consists of two loads on buses No. 1 and 3 and three generators on buses No. 4, 5, and 6.

38-bus system simulation:

This system is shown in the following. There are five generators in the system, which are located on buses No. 34, 35, 36, 37, and 38. Details of the buses are given in the appendix.



(a) (b)

Figure 1. a. Schematic of IEEE 6-bus system [4], b. Schematic of IEEE 38-bus system [2].

Numerical results

To test and implement the new method, conventional networks were used to simulate its algorithms. This method has been implemented on IEEE tested networks and the results have been compared with the simple Newton-Raphson methods in microgrids as well as with the usual Levenberg–Marquardt method and the Newton-Raphson method using acceleration coefficient.

Results of simulation of 6-bus system with a typical loss

According to the simulations of this system, the number of iterations required for system convergence in different methods is as follows. According to the simulations, the error considered is $\varepsilon = 10^{-6}$. The number of repetitions required for convergence is 69 in the simple Newton-Raphson method, 30 in the Newton-Raphson method with a correction factor, 14 in the usual Levenberg–Marquardt method and 13 in the proposed method. The diagram of this simulation is as shown in Fig. 2. In this diagram, due to a large number of repetitions, the Newton-Raphson method was omitted. The figure below shows that in the initial iterations, the diagram of the new method converges more rapidly due to the change in the acceleration coefficient at low iterations. The obtained frequency is 0.9964.

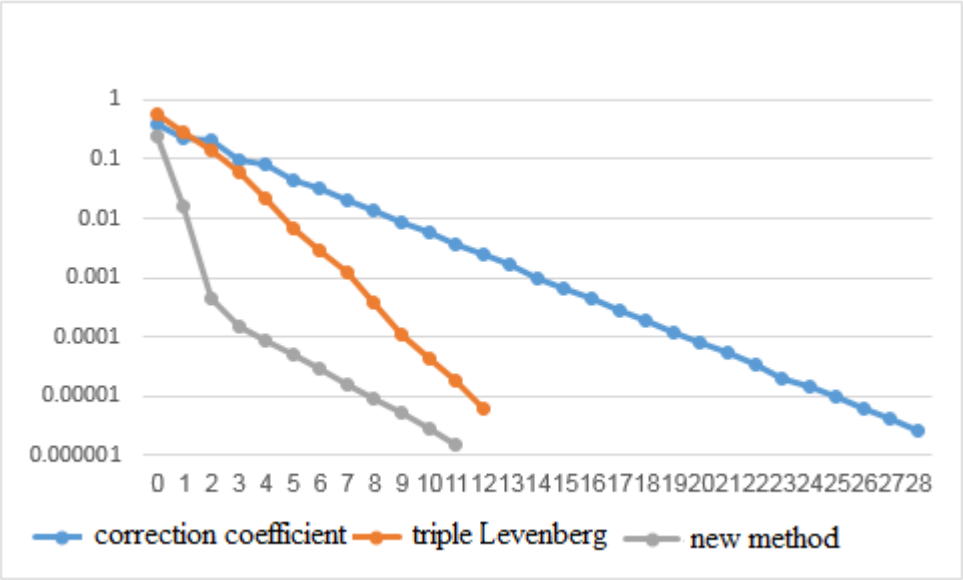


Figure 2: Power error in a 6-bus system with a typical loss

Results of 6-bus system simulation with reverse loss:

According to the simulations of this system, the number of iterations required for the convergence of the system in different methods is as follows. Based on the simulations, the error considered is $\varepsilon = 10^{-6}$. The number of iterations required for convergence is 74 in the simple Newton-Raphson method, 27 in the Newton-Raphson method with a correction factor, 16 in the normal Levenberg–Marquardt method and 14 in the proposed method. The diagram of this simulation is as follows. In Fig. 3, the Newton-Raphson method is omitted due to a large number of iterations. As can be seen, the new method converges more rapidly in the initial iterations. In addition, using the parameter η in the final iterations the slope of convergence increases in the diagram.

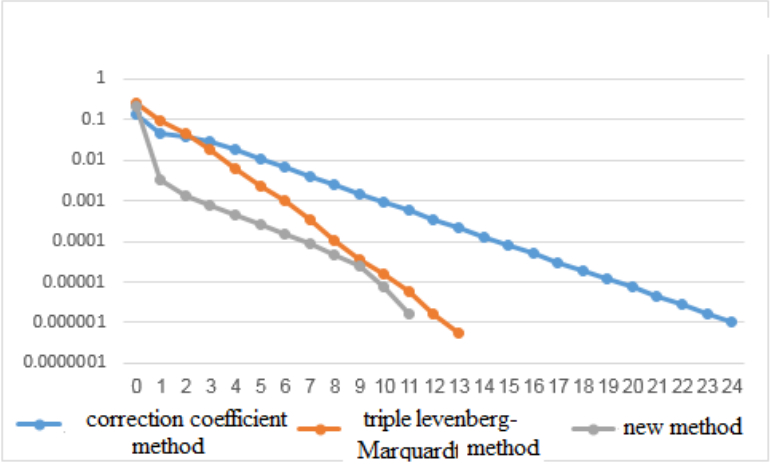


Figure 3. Power error in a 6-bus system with reverse loss

Results of 6-bus system simulation with a combined loss

According to the simulations of this system, the number of iterations required for the convergence of the system in different methods is as follows. According to the simulations, the error considered is $\varepsilon = 10^{-6}$. The number of iterations required for convergence is 35 in the simple Newton-Raphson method, 15 in the Newton-Raphson method with a correction factor, 14 normal Levenberg–Marquardt method, and 11 in the proposed method. The diagram of the simulation is as shown in Fig. 4. In this diagram, due to a large number of iterations, the Newton-Raphson method was omitted. The obtained frequency is 0.9997.

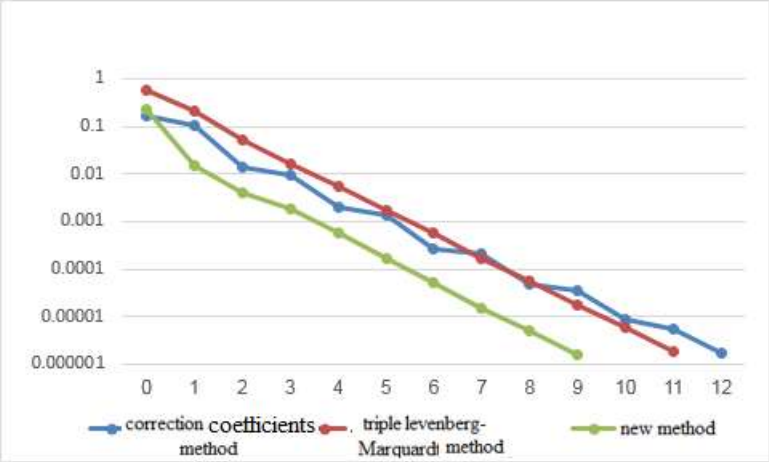


Figure 4. Power error in a 6-bus system with a combined loss

Results of 38-bus system simulation with typical loss:

According to the simulations of this system, the number of iterations required for the convergence of the system in different methods is as follows. According to the simulations, the error considered is $\varepsilon = 10^{-6}$. The number of iterations required for convergence is 21 in the simple Newton-Raphson method, 14 in the Newton-Raphson method with a correction factor, 9 in the normal Levenberg–Marquardt method, and 7 in the proposed method. The simulation diagram is as follows. The frequency is 0.9965 (Fig. 5).

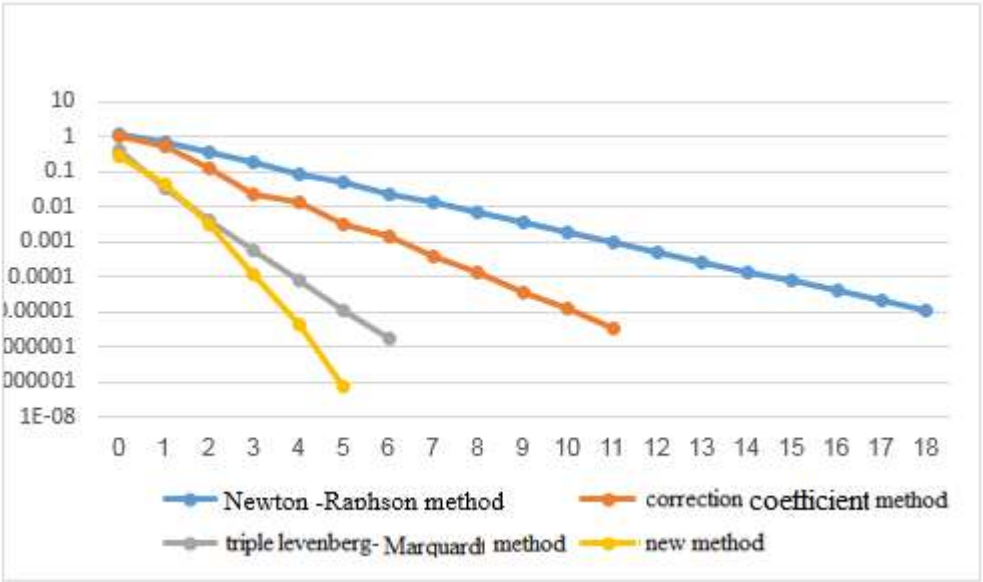


Figure 5. Power error in a 38-bus system with a typical loss

Results of 38-bus system simulation with reverse loss:

According to the simulations of this system, the number of iterations required for the convergence of this system in different methods is as follows. According to the simulations, the error considered is $\varepsilon = 10^{-6}$. The number of iterations required for convergence is 27 in the simple Newton-Raphson method, 27 in the Newton-Raphson method with a correction factor, 16 in the normal Levenberg–Marquardt method, and 16 in the proposed method. Fig. 6 shows the simulation results. Its frequency is 1.003.

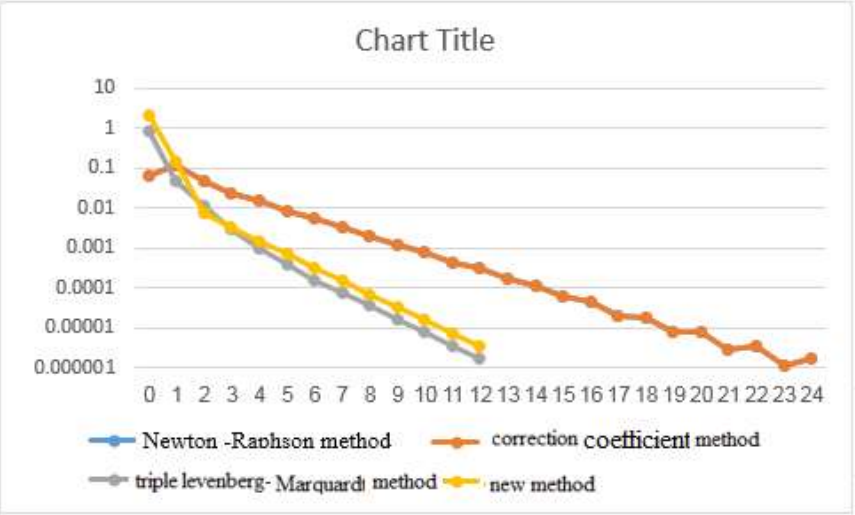


Figure 6. Power error in a 38-bus system with reverse loss

Results of 38-bus system simulation with combined loss:

According to the simulations of this system, the number of iterations required for the convergence of the system in different methods is as follows. According to the simulations, the error considered is $\varepsilon = 10^{-6}$. The number of iterations required for convergence is 21 in the simple Newton-Raphson method, 11 in the Newton-Raphson method with a correction factor, 10 in the normal Levenberg–Marquardt method, and 9 in the proposed method. The diagram of this simulation is Fig. 7. Its frequency is 0.9997.

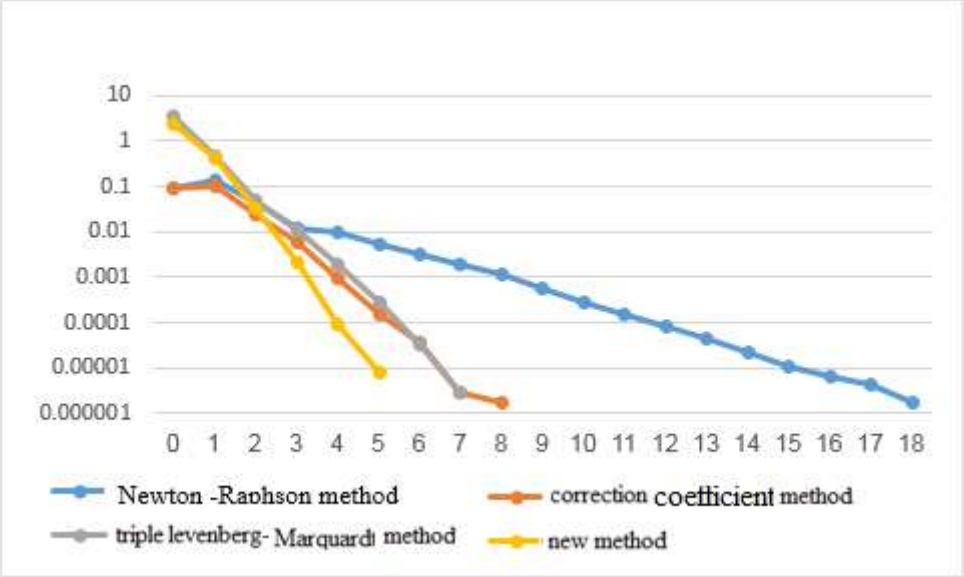


Figure 7. Power error in a 38-bus system with a combined loss

Table 1 shows the percentage change in the number of iterations of the proposed method compared to other methods.

Table 1. Percentage change of iterations of the proposed method compared to other methods

	Newton -Raphson method		Newton -Raphson method with the correction coefficient		Triple Levenberg–Marquardt method		New Levenberg–Marquardt method	
	Number of iterations	Improvement Percentage	Number of iterations	Improvement Percentage	Number of iterations	Improvement Percentage	Number of iterations	Improvement Percentage
6-bus system with normal loss	69	81	30	56	14	7	13	-
6-bus system with reverse loss	74	81	27	48	16	12.5	14	-
6-bus system with combined loss	35	68	15	26	14	21	11	-

38-bus system with normal loss	21	66	14	50	9	22	7	-
38-bus system with reverse loss	27	40	27	40	16	0	16	-
38-bus system with combined loss	21	61	11	27	10	20	8	-

Table 2 shows the percentage change in time consumption of the proposed method compared to other methods.

Table 2. Percentage change in time consumption of the proposed method compared to other methods

	Newton -Raphson method		Newton -Raphson method with the correction coefficient		Triple Levenberg–Marquardt method		New Levenberg–Marquardt method	
	Time	Improvement Percentage	Time	Improvement Percentage	Time	Improvement Percentage	Time	Improvement Percentage
6-bus system with normal loss	0.81	27	0.65	9.2	0.65	9.2	0.59	-
6-bus system with reverse loss	1.1	45.5	0.64	6.2	0.71	15	0.60	-
6-bus system with	0.74	17	0.59	-3.3	0.65	6.1	0.61	-

combined loss								
38-bus system with normal loss	1.5	13	1.3	0	1.4	7	1.3	-
38-bus system with reverse loss	1.5	-40	1.5	-40	1.9	-10	2.1	-
38-bus system with a combined loss	1.6	.	1.1	-45	1.6	0	1.6	-

Conclusion

A microgrid consists of the internal connection of sources of distributed generation, which provide electrical and thermal loads such as energy storage. Power quality and reliability in microgrids can be enhanced by using electronic power relations and controllers. The microgrid operates in connected and islanded states. In the connected state, the main network determines the voltage and frequency of the microgrids. In the isolated state, the control units of the distributed generation sources, which manage the active and reactive powers, are responsible for voltage and frequency regulation [15, 16]. There are many different ways to solve the power flow problem in the power system, each of which has advantages and disadvantages. But all of these methods could not be used in practice for solving the power flow problem in low voltage, islanded power systems. Methods based on the Jacobean matrix are suitable for such problems and may result in appropriate solutions. The number of iterations and time taken for the problem-solving in these methods has always been under discussion and many researchers have tried to reduce these two parameters. The results of this study showed that the Levenberg–Marquardt algorithm is a mathematical method that can solve this problem in fewer iterations and time.

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