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Features of the Method for Synchronizing Active Electrical Networks with Microgrid

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ABSTRACT

Currently, with the increasing degree of decentralization of power system management, small distributed generation is becoming the main source of power for consumers in local power connections. Such networks acquire Microgrid properties and adapt to work both independently and in parallel with an external network. Operating independently, Microgrid networks are able to transfer excess electricity to an external network under certain conditions. Due to the low inertia of power units and the stochasticity of their own loads, connecting Microgrid to an external network can lead to sharp power surges and drops, causing a shock moment on the shaft of generating equipment. The purpose of this paper is to develop and study an algorithm for managing Microgrid synchronization with an external network. A synchronization control algorithm is investigated and proposed, which makes it possible to connect generating units for parallel operation with an external network with minimal impact moment on the shaft. A comparison of the simulation results of the proposed method with the standard one is given. Based on the research data, statistical data were collected and analyzed.

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1. INTRODUCTION

Today, low-power power systems are being created on the basis of local power supply systems (LPSS) with small distributed generation, thereby increasing the decentralization of power system management. Such facilities include low-power plants with their own generating capacity of up to 25 MW, called Microgrid [1-3].

Microgrid combines power generation sources, consumers, energy storage devices, and control devices to form a complete managed power supply system (Fig. 1). An important feature of Microgrid is that, despite functioning within the distribution system, they can automatically switch to isolated operation mode in the event of network failures and restore synchronous operation with the network after the accident is eliminated, while maintaining the required quality of electrical energy. Thus, Microgrid is an intelligent automated system that independently reconfigures, manages the balance and distributes power flows, ensuring a smooth transition to isolated mode and automatic resynchronization.

Figure 1 shows the basic structure of the Microgrid network.

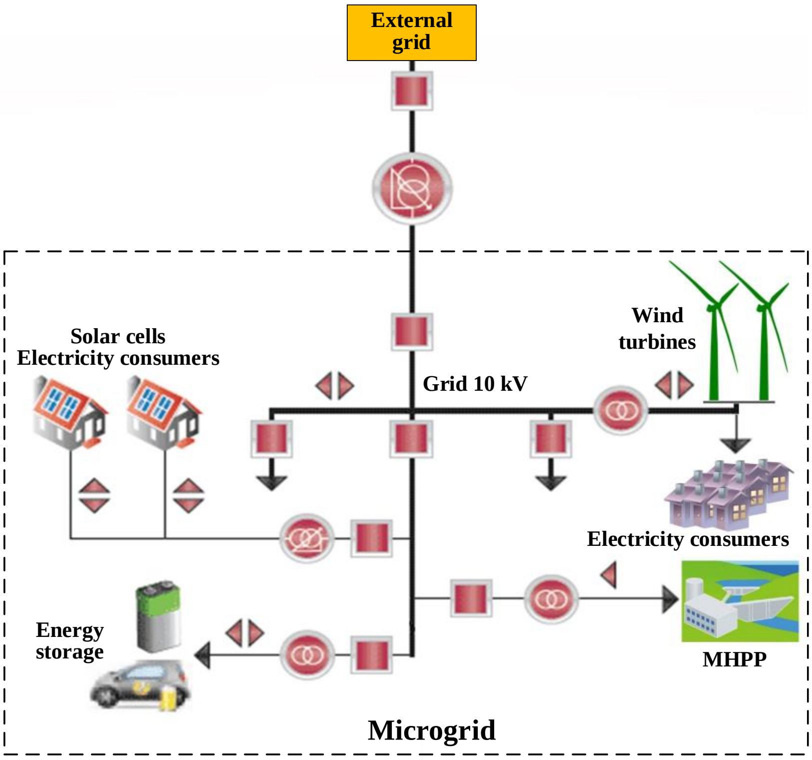


Figure 1. Basic structure of a hybrid Microgrid

There are quite a few technologies that provide high-quality and reliable power supply to consumers from local energy sources, which are able to get power from backup sources in emergency modes.

In conditions of isolated power supply to local consumers, when a number of circuit-mode situations are formed (after eliminating a short circuit in the external network, seasonal excess power, etc.), local sources are able to switch to parallel operation and transfer (sell) excess electricity to the external power system. When implementing this scenario, there may be problems with synchronization [4].

The low inertia of generator rotors and high stochasticity of consumer loads in Microgrid are the main factors affecting the synchronization process. They determine the intensity of frequency fluctuations and mutual angles during synchronization [5]. Figure 1 shows an example of a graph of frequency fluctuations in Microgrid in parallel operation with the power grid and after separation.

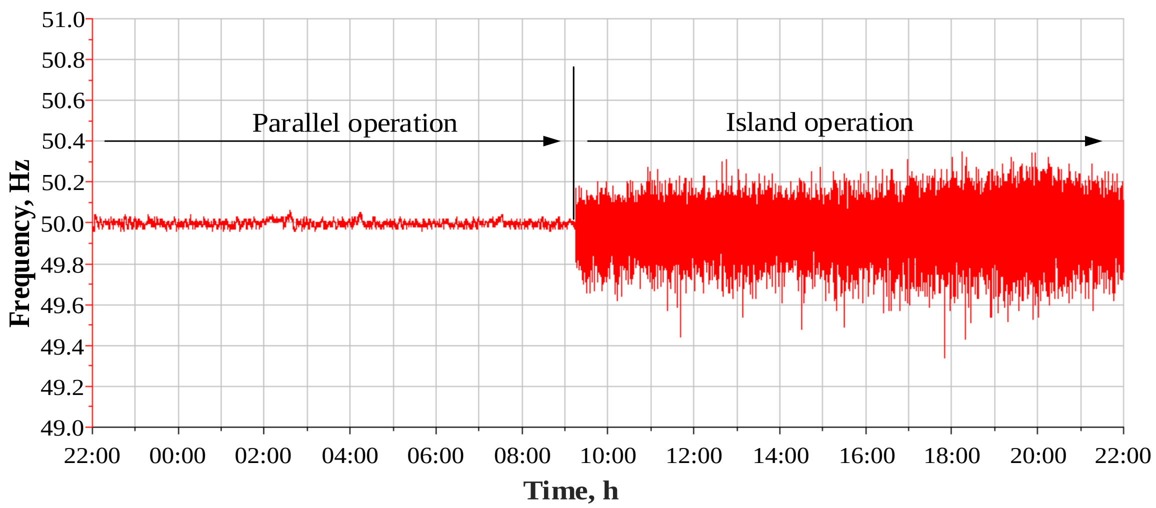


Figure 1. Frequency fluctuation in Microgrid in parallel and island mode of operation

As you know, enabling parallel operation of parts of the network with sources requires that synchronization conditions are met, such as:

- Equality of voltage frequencies;
- Equality of voltage modules;
- Zero phase shift between voltage vectors.

For successful and safe switching on of Microgrid generators for parallel operation with the electrical network, it is necessary that the equalizing current does not exceed the permissible value at the time of switching on the unifying switch. According to [6], the following maximum permissible deviations are set for the values of synchronized parameters (Table 1).

Table 1. Maximum permissible deviations of parameters during synchronization

Total power of the source, kVA	Frequency difference, Hz	Voltage difference, %	Phase angle difference, deg.
Less than 500	0.3	10	20
From 500 to 1500	0.2	5	15
More than 1500	0.1	3	10

In practice, due to restrictions on dynamic impacts from manufacturers of generating equipment and an increase in the service life, more stringent requirements are set, for example, for the difference in angles when switching on-no more than 3-5 degrees.

The task of syncing Microgrid with an external network for transmitting / receiving power occurs in the following cases:

- availability of excess (daily) generator capacity in the LPSS;
- restoration of parallel operation of the LPSS after separation in case of violations of the normal mode of the external power system (for example, short circuit).;
- if there is a seasonal excess of power in the LPSS;
- if there is a power shortage in the LPSS;
- when the unit is put out for repair.

Microgrid synchronization with an external network has its own characteristics, and in most cases, it is difficult to meet the synchronization conditions. Since the switch that combines the synchronized parts has its own turn-on time, there may be cases when a turn-on signal is issued when the conditions are met, however, a change in consumer loads can lead to a change in the slip sign, and the difference in voltage angles instead of decreasing begins to increase even before the switch is fully turned on. As a result, the switch turns on at an unacceptable angle, and under the influence of the equalizing current, a shock moment occurs, which can lead to disconnection of Microgrid generators with protections, reduce their service life and even damage.

2. RESEARCH METHODS

There are known methods of Microgrid synchronization with the network, which can be divided into passive and active synchronization methods [7,8]. A passive synchronization method is considered when the measured synchronization parameters on both sides of the switching device are equal or close to each other. This type is easy to implement and does not require an additional device for adjusting parameters during synchronization [9, 10]. The active synchronization method uses additional control to ensure that the synchronized parameters fall within the acceptable range, and this ensures faster and smoother connection of Microgrid to the external network [11-14].

Let's consider a new approach related to the passive synchronization method. For this purpose, a recloser is used as a switch that connects Microgrid with an external network [15-17], since synchronization takes place remotely from the generators. Reclosers are elements that perform the functions of dividing and reserving parts of 6-10 kV electrical networks. The recloser combines: a vacuum switch; a system of current and voltage converters; an autonomous operational power supply system; microprocessor relay protection and automation; a system of ports for connecting telemechanic devices; a software package.

Thus, to avoid erroneous inclusions that occur in the situations described in the introductory part, we propose a synchronization algorithm on reclosers, the block diagram of which is shown in Figure 2.

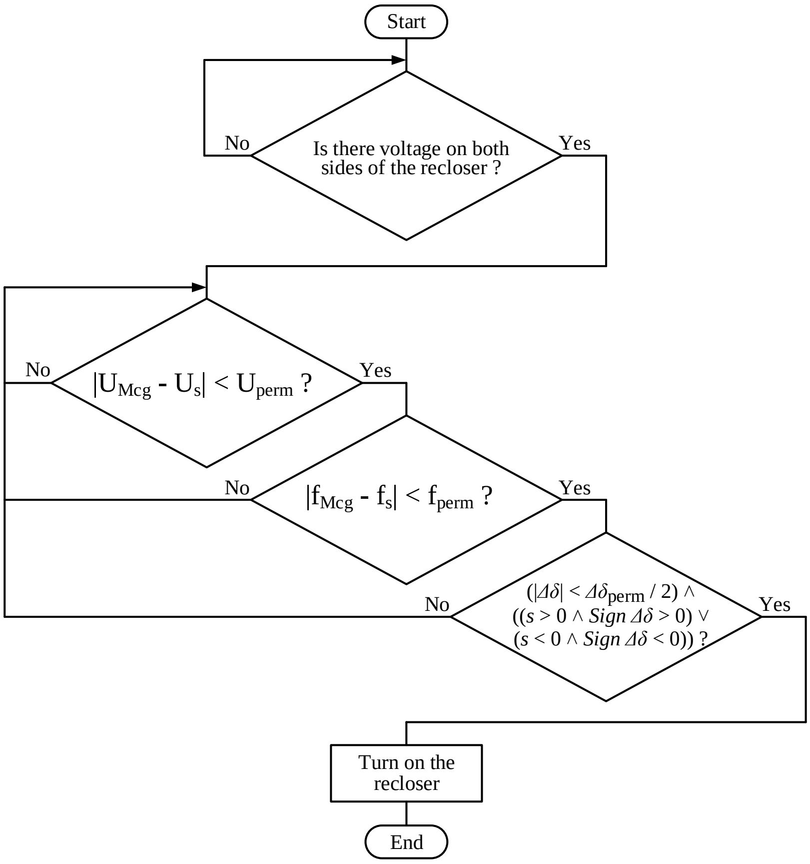


Figure 2. Block diagram of the proposed synchronization algorithm

Figure 2 shows the following values: U_{Mcg} – voltage in Microgrid, kV; U_s – external network voltage, kV; U_{perm} – permissible voltage difference, kV; f_{Mcg} – frequency in Microgrid, Hz ; f_s – External network frequency, Hz; f_{perm} – permissible frequency difference, Hz; $\Delta\delta$ – mutual stress angle, deg.; $\Delta\delta_{perm}$ – permissible mutual stress angle, deg.

The essence of the proposed algorithm is that when the first two synchronization conditions are met, the third condition is expected to be met. When the mutual angle reaches the value $|\Delta\delta| < \Delta\delta_{perm}$, and as long as this angle is not equal to $|\Delta\delta| \geq \Delta\delta_{perm}/2$, the command to activate the recloser is not issued (Fig. 3).

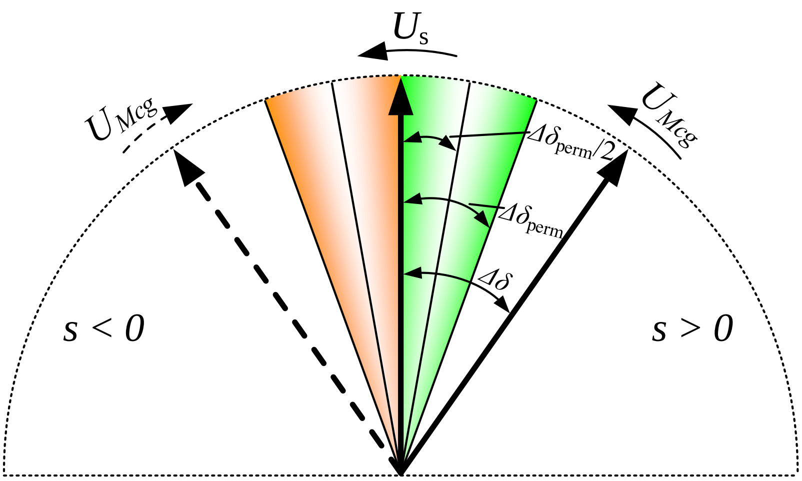


Figure 3. Explanation of the proposed synchronization algorithm

Taking into account the change of the sliding sign, the third synchronization condition can be written as follows:

$$-\frac{\Delta\delta_{perm}}{2} \leq \Delta\delta \leq 0 \tag{1}$$

for $s \geq 0$

where s is sliding, $s = f_{Mcg} - f_s$

or

$$\frac{\Delta\delta_{perm}}{2} \geq \Delta\delta \geq 0 \tag{2}$$

when sliding $s \leq 0$.

This is necessary in order to have a margin for the full time of switching on the recloser, and at the moment when the signal for switching on is given, $\Delta\delta$ does not exceed $\Delta\delta_{perm}$. In cases other than the one mentioned above, the command to enable the recloser is blocked, and Microgrid is not enabled for parallel work with the external network.

3. SIMULATION RESULTS AND THEIR DISCUSSION

The simulation was performed for the test scheme of Fig. 4. The recloser (R) serves as a unifying/separating element and is set based on the balance of generating device capacities and consumer loads. This arrangement allows Microgrid to quickly automatically separate from the external network in emergency modes [18], and continue working in isolated mode (the area highlighted in green).

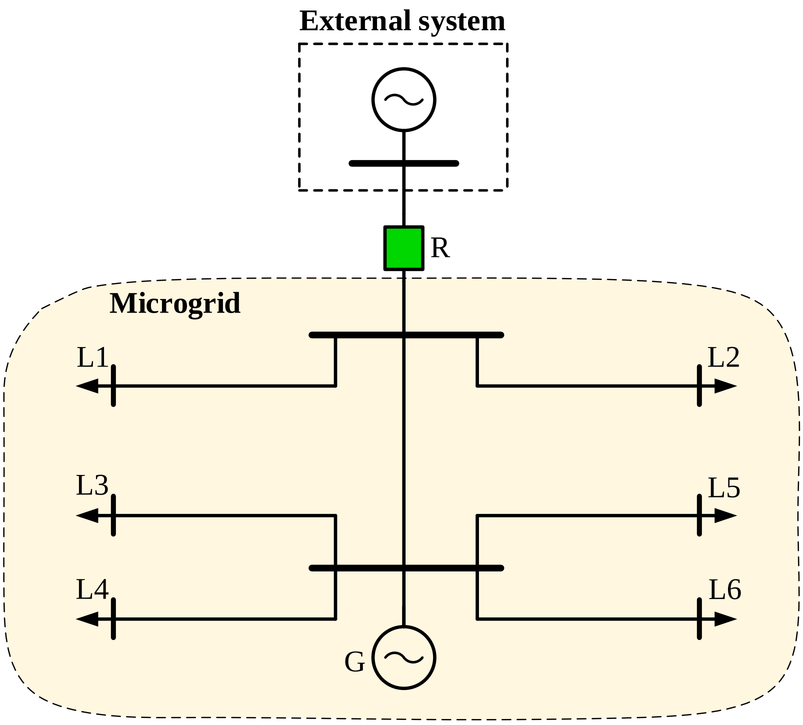


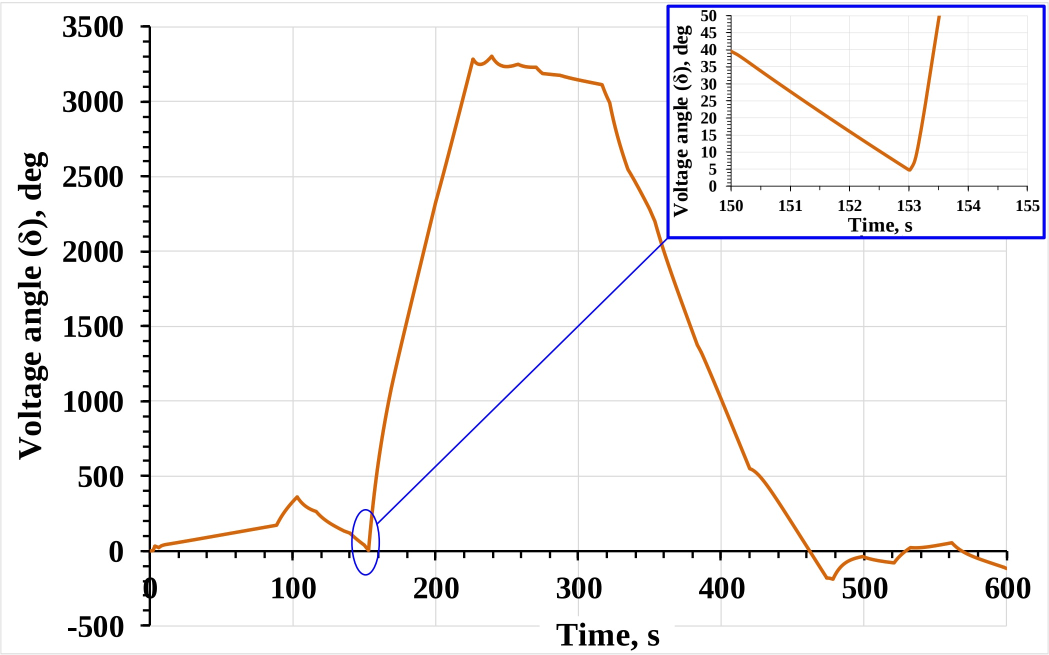
Figure 4. Simulated test scheme

In this example, Microgrid operates in redundant mode, the generator power (G) is 2.5 MW, and the total load power (L1-L6) is 1.95 MW.

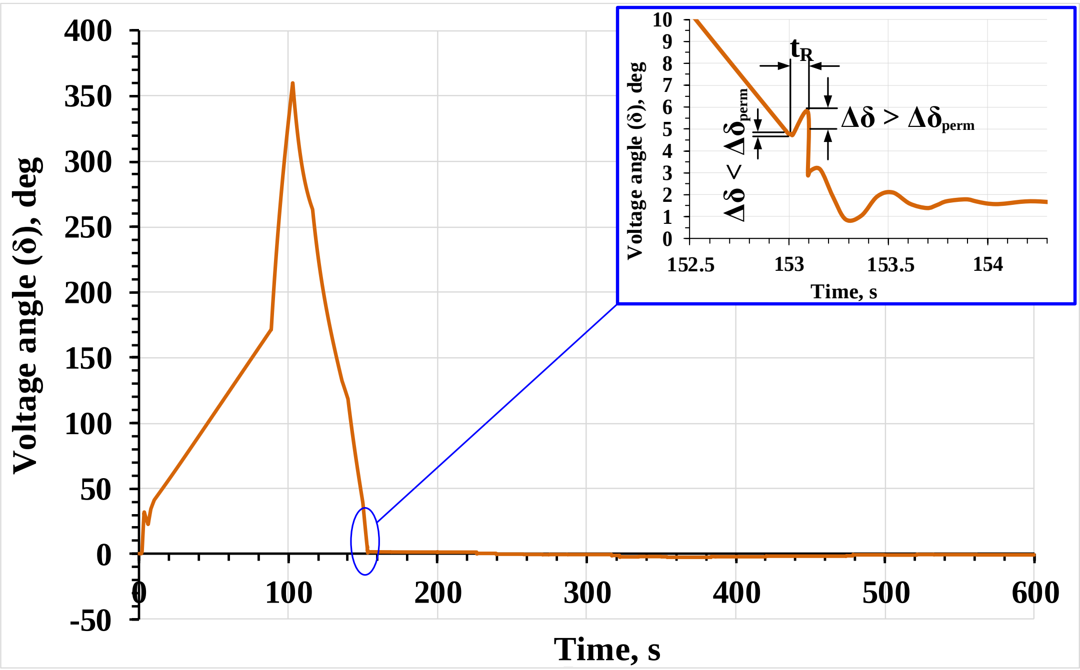
Acceptable parameter mismatches during synchronization are as follows:

$$\begin{gathered} |U_{Mcg} - U_s| < \Delta U_{perm} = 0.1\ kV; \\ |f_{Mcg} - f_s| < \Delta f_{perm} = 0.08\ Hz; \\ |\delta_{Mcg} - \delta_s| < \Delta\delta_{perm} = 5°; \\ t_R = 0.1\ s. \end{gathered} \tag{3}$$

The simulation was performed on the software Rustab RastrWin3. The results of simulating Microgrid synchronization with an external network without using the algorithm proposed in this paper are shown in Fig. 5-6.



a)



b)

Figure 5. Graph of the mutual angle change in the case of a sign change with forbidden (a) and allowed (b) synchronization (angle display in the range of ±180°)

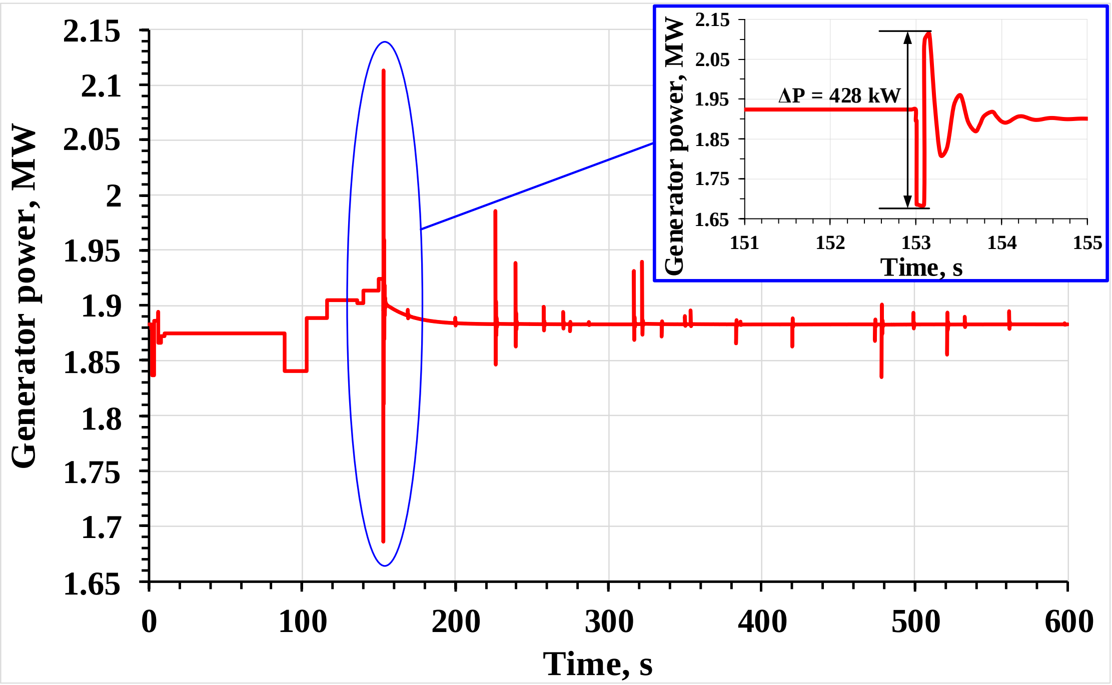


Fig. 6. Graph of generator power changes during synchronization

As you can see, changing the sign of the mutual angle at variable load capacities (Fig. 5, a) leads to an unacceptable mismatch of synchronous conditions. As a result, taking into account the time t_R, the Microgrid generator is connected to the external network at an angle $\delta = 5.8°$ (Fig. 5, b), which is unacceptable, and the impact moment equal to the power jump on the generator is $\Delta P = 428\ kW$ (Fig. 6).

In order to avoid large impact moments on the generator, we use the algorithm proposed in this paper. The simulation results are shown in Fig. 7-8.

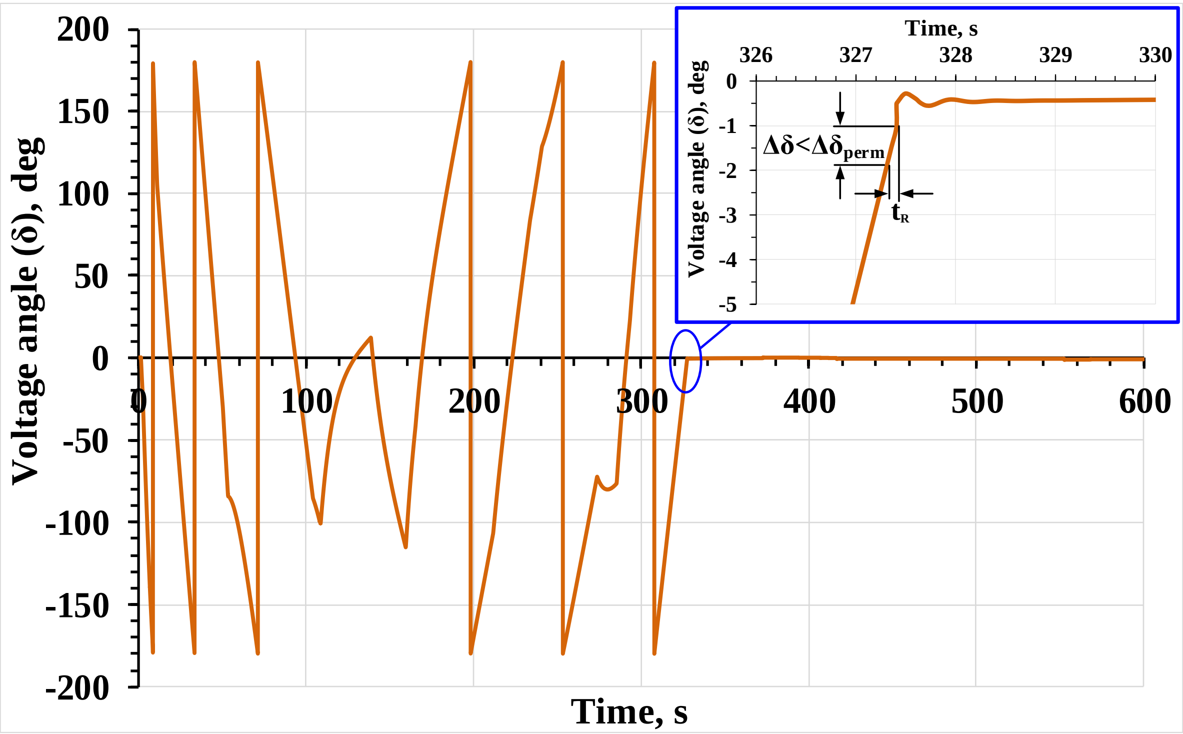


Figure 7. Graph of the mutual angle change during synchronization (angle display in the range of ±180°)

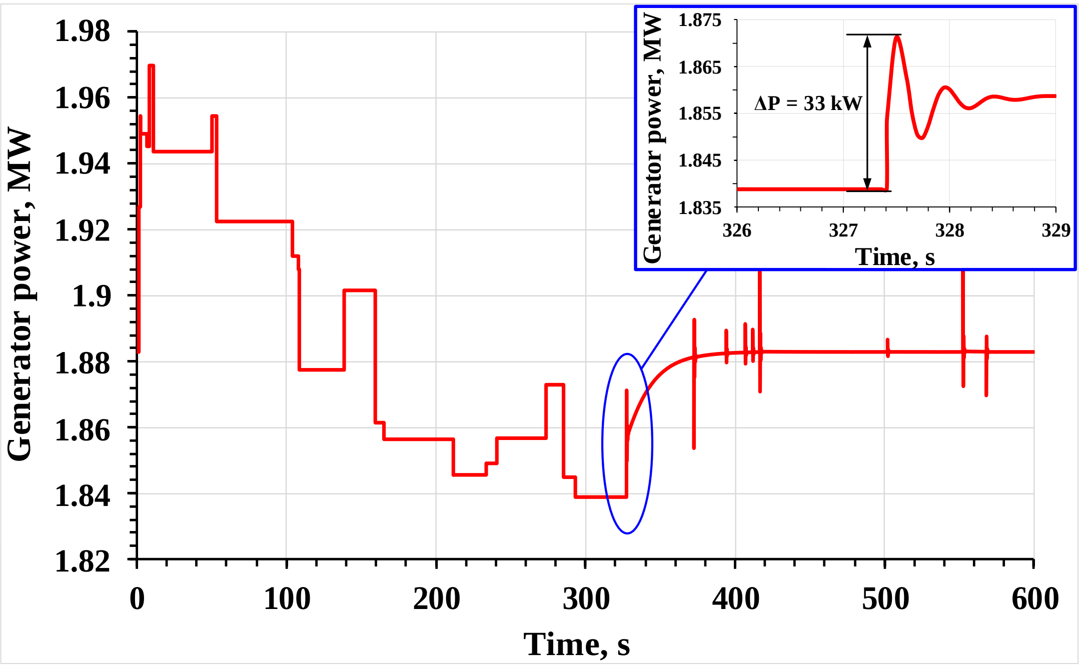


Figure 8. Graph of generator power changes during synchronization

The results of modeling synchronization using the proposed algorithm demonstrate the solution of the problem. Microgrid synchronization started at an angle $\delta = -1.92°$, and taking into account the time t_R, the connection for parallel operation was carried out at an angle $\delta = -1.02°$ (Fig. 7). At the same time, the power jump to the generator was $\Delta P = 33\ kW$ (Fig.8).

The proposed Microgrid synchronization algorithm with an external network was investigated using the test scheme Fig. 4. Based on the conducted experiments, statistical data were obtained, which are presented in the diagram of Fig. 9.

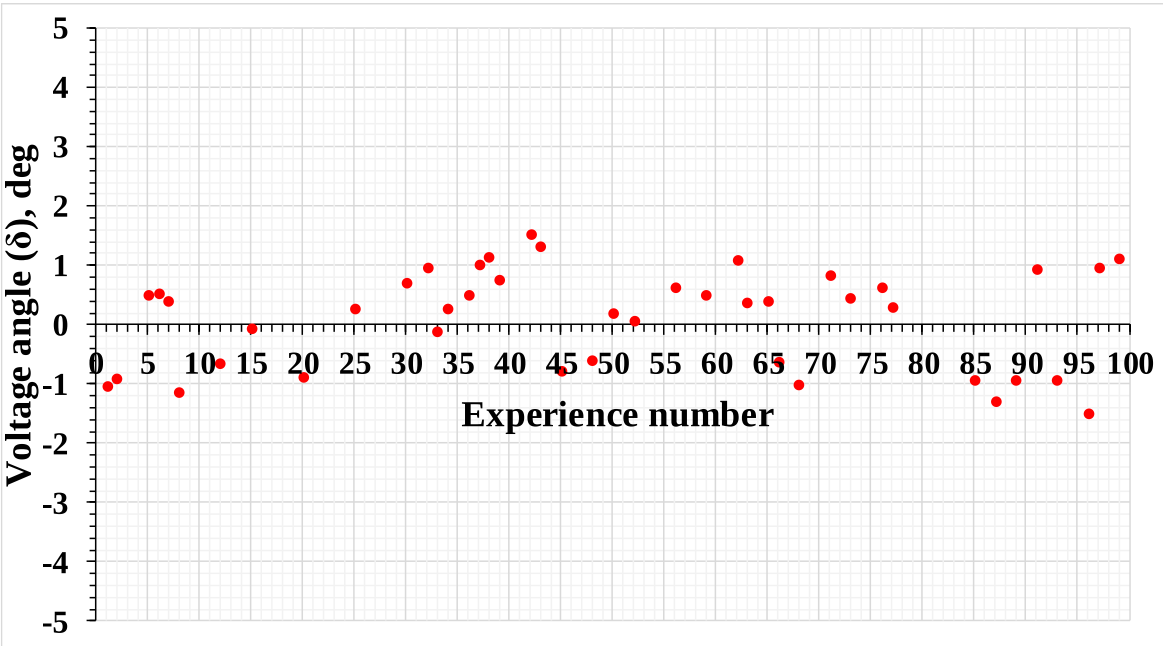


Figure 9. Statistical data diagram

Based on the results of statistical data processing, the following parameters are determined:

- the average switching angle $\delta = -0.83°$ and $\delta = 0.68°$ for negative and positive sliding, respectively;
- the average waiting time for synchronous conditions $t = 184\ s$.

Thus, analyzing the results obtained, we can conclude that the proposed method works. This approach is more secure during synchronization and reduces the resource consumption of generating equipment functioning as part of Microgrid.

4. CONCLUSION

The active use of smart elements leads not only to an increase in the degree of decentralization of power system management, but also to an increase in the reliability and efficiency of individual objects in the power system.

In this paper, based on the use of intelligent reclosers, a synchronization control algorithm is investigated and proposed. This method, according to the results of the study, proves its operability and allows Microgrid to connect to an external network with the lowest impact moment on the shaft of generating units.

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