

# Simulation of conditions for the occurrence and elimination of asynchronous mode in the power supply system

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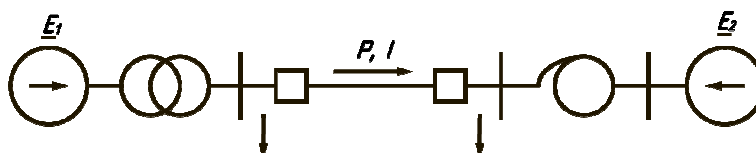
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**Abstract.** This article discusses the phenomenon of a two-frequency asynchronous mode as the most typical and common in power systems. The analysis of methods of registration and elimination of the asynchronous mode and a description of their principles of operation of these methods are carried out. The conditions for the occurrence of an asynchronous mode are considered and analyzed, the main signs of the transition of an electrical network to an asynchronous mode are highlighted. On the basis of the RUSTab software package, an experiment was modeled that simulates the asynchronous mode and synchronous oscillations in the network section included in the IES of the East. The critical values of the parameters of the elements of the experimental network are estimated. The composition and parameters of the control action have been determined, which makes it possible to exclude the asynchronous mode without changing the network topology. The results obtained show the efficiency of using asynchronous mode methods based on the constructed model.

## 1. Introduction

Power supply systems are among the most complex man-made objects. In modern industrial life, power supply systems play a leading role for normal life support. The complex heterogeneous structure of power supply systems [1] requires looking for new approaches to ensuring energy security and reliability.

Asynchronous running is the most severe mode after a short circuit, as it is accompanied by significant fluctuations in current and voltage, which can lead to equipment damage and loss of load stability. Asynchronous mode (AM) is usually considered on a two-machine system [3], on which it is possible to simulate a two-frequency asynchronous operation (Figure 1).



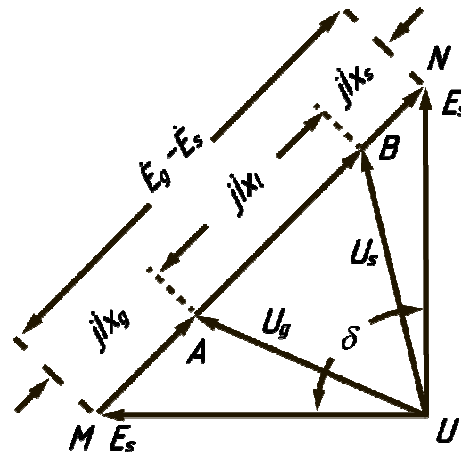
**Figure 1.** Two-machine power supply system with power take-off in the intermediate unit

In the event of a violation of stability, the transfer of active power is stopped, and since the power of the turbines remains the same, the speed of rotation of the turbines and generators of one power

plant (with a lower load) increases (generators are accelerated), and at another power plant (where there is a shortage of generating power) the speed of the turbines decreases.

The first characteristic feature of AM is a periodic change in the angle  $\delta$  between asynchronous EMF from zero to  $360^\circ$  [3].

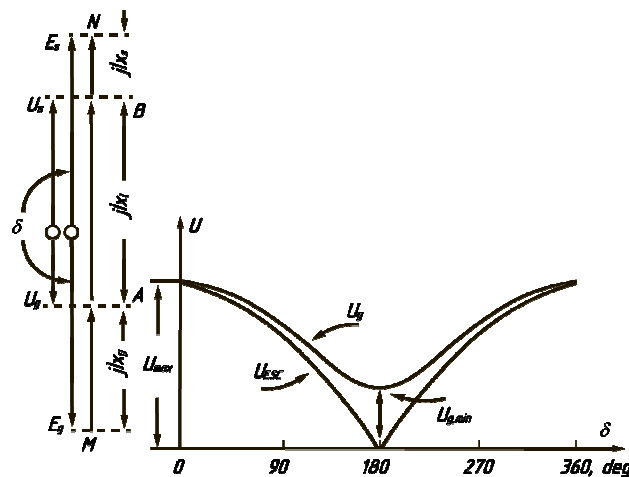
Figure 2 shows a vector diagram of the EMF and power transmission voltages during the asynchronous run at a fixed time (in order to simplify the consideration of the EMF vector of the system and the generator, they are considered equal in modulus).



**Figure 2.** Vector diagram of EMF and voltages

Each power transmission has a characteristic point at which the voltage at an angle of  $\delta = 180^\circ$  takes a minimum value or drops to zero. This point is called the electrical swing center (ESC).

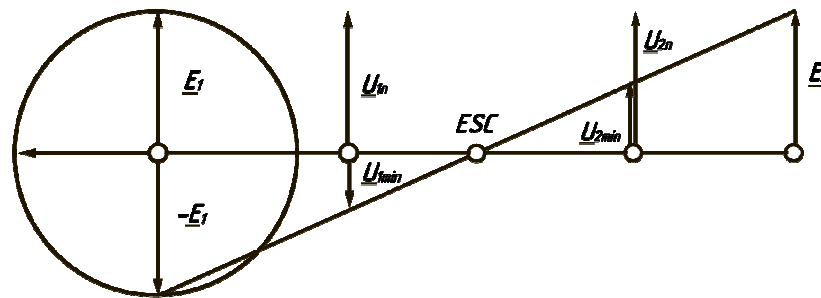
Figure 3 illustrates the dependence of the voltage in the ESC and at the generator on  $\delta$ .



**Figure 3.** Voltage change during asynchronous running

As the angle grows, the current through the electric power line increases, and at a value of the angle  $\delta = 180^\circ$ , the electric power transmission line turns on for a voltage twice rated. The magnitude of the current can cause both electrical and mechanical damage to the generators.

The moment of passage of the EMF vectors through the angle  $\delta = 180^\circ$  and the voltage distribution along the bond is shown in Figure 4.

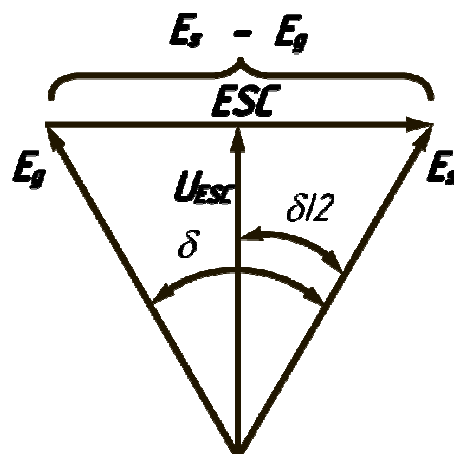


**Figure 4.** Voltage change along the power transmission in asynchronous mode at an angle of  $\delta = 180^\circ$

Figure 4 shows a planar projection of the voltage distribution at the moment of passing the angle  $\delta$  of the  $180^\circ$ .

Let us note that at the points of power transmission, the voltages at AM have different values; to the left of the ESC, the voltage vector makes a full revolution with a slip frequency, and to the right it oscillates in magnitude and angle, and the swing increases as it approaches the ESC.

Let us consider a section at the ESC point for an arbitrary angle  $\delta$ . The relative position of the EMF vectors and their difference, as well as the voltage at this point, is shown in Figure 5.



**Figure 5.** Mutual arrangement of EMF and voltage vectors in ESC

It can be seen from the above diagram that when the EMF of the system and the generator is equal, the dependence of the voltage in the electric swing center on the angle  $\delta$  can be represented as:

$$U_{EC} = E \cdot \cos\left(\frac{\delta}{2}\right);$$

the modulus of the difference vector is

$$E_c - E_g = 2 \cdot E \cdot \sin\left(\frac{\delta}{2}\right);$$

and, accordingly, the asynchronous mode current

$$I_{AM} = \frac{2 \cdot E}{X_\Sigma} \cdot \sin\left(\frac{\delta}{2}\right),$$

where  $X_\Sigma$  is the total resistance of the system under consideration.

The value of the active power  $P$  transmitted by the power transmission is equal to:

$$P_{AM} = \frac{E_G \cdot E_S}{X_\Sigma} \cdot \sin(\delta).$$

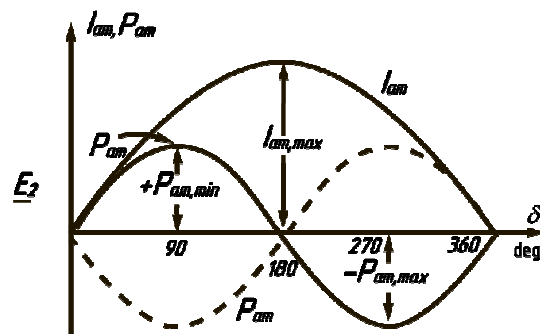
From the above ratios it can be seen that the active power, like the current, depends on the angle between the EMF vectors of the system and the generator, but in contrast to the current and voltage, which depend on the half angle, and the active power depends on the total angle  $\delta$ .

Periodic change in active power occurs with double slip frequency, i.e. in one cycle of the asynchronous mode, the sign of the active power changes twice.

Physically, this means that the generators of power plants operate in the generator mode during the first half of the swing, and in the motor mode during the second half.

The average power for the swing period, transmitted through the power transmission, is zero [4].

The relationships for current and active power are illustrated in Figure 6.



**Figure 6.** Relationships for current and active power in asynchronous mode

Thus, summarizing the above, we can note four signs of the asynchronous mode [5], according to which the automatic elimination of the asynchronous mode (AEAM) detects the transition of the system to asynchronism:

1. periodic change of angles between power plants;
2. periodic change in the voltage swing along the system transit;
3. periodic variation of the current swing in transit;
4. periodic change in active power transmitted between power plants.

## 2. Purpose of the Study

Development of criteria allowing using parameters mode measured directly at the substation with installed control devices determines in real time moments of opening and closing cycles of switches power lines to control asynchronous running on power system interconnection lines [6].

In the course of research on the topic under consideration, the following tasks were set:

- clarification of the structure of indicators of quality and efficiency of AEAM;
- identification of resources and ways to improve the efficiency of AEAM;
- determination of generalized parameters of two-frequency asynchronous mode;
- improvements in how to detect asynchronous mode.

## 3. Modelling transition process

All existing AEAM devices are capable of detecting precisely the two-frequency asynchronous mode, discussed above, since it is based on the theory developed on a two-machine system.

The method for calculating the transient process used in the RUSTab software package allows simulating and analyzing the asynchronous mode with high accuracy, provided that the computational

model is formed correctly [7]. This makes it possible for the AR to jointly simulate the operation of devices for automatic elimination of the asynchronous mode – AEAM.

The computational model contains assumptions that do not allow simulating the exact response of real devices for detecting asynchronous mode.

The simulation is performed in root mean square values, thus, the harmonic composition of the analyzed quantities is not taken into account.

The three-phase system appears to be symmetrical, which excludes the analysis of unbalanced mode.

The computational model is based on a two-machine system.

First, we consider simulating a transient that starts with a synchronous swing and goes into asynchronous mode.

This experiment allows you to get an idea of the principles of operation and tuning of the AEAM model.

The study area contains Nizhne-Bureyskaya hydroelectric power station (NBHES) located in Amur Region and Primorskaya GRES (PRIM.GRES), located in the near Luchegorsk city. The intermediate node is substation TS 220 Birobidzhan.

The power of the generator in the NBHES unit is approximately three times greater than that of the unit. Prim.GRES. The load of Prim.GRES exceeds the generating capacity at this node.

Three power lines are involved in the scheme. Two parallel lines have the same parameters, the third line has about twice the resistance of the first two.

The AEAM device is located at Substation 220 Birobidzhan. Figure 7 shows steady state operation, excluding the operation of compensating devices providing a fixed voltage.

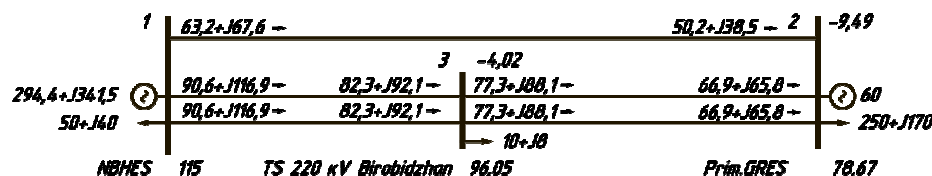


Figure. 7. Design scheme for the steady state

As a perturbation, the disconnection of two strong links with the balancing of the circuit for a weak link is modeled. Initially, to assess the parameters of the transient process, the ALAR devices are not involved and the transient process itself will develop only under the control of the speed regulators on the generators.

The graph of transient processes in frequency in the generating units is shown in Figure 8.

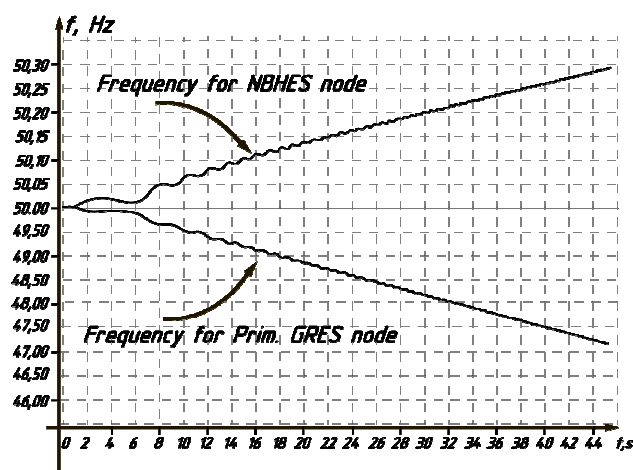


Figure. 8. Transient processes in frequency in generating units

It can be seen from the graph that in the event of an emergency situation similar to the one simulated in the simulation experiment, the internal capabilities of the generators to maintain the frequency are insufficient.

After the sixth second, an asynchronous run occurs, the difference between the frequencies of the generators increases, the system transitions to an unstable state.

To return the system to a stable state, it is necessary to have a control action from the side of the emergency automatics equipment.

The active and reactive power graph, see Figure 9, recorded at the intermediate node TS 220 Birobidzhan, gives an idea of the periodic change in power during synchronous swing and asynchronous run.

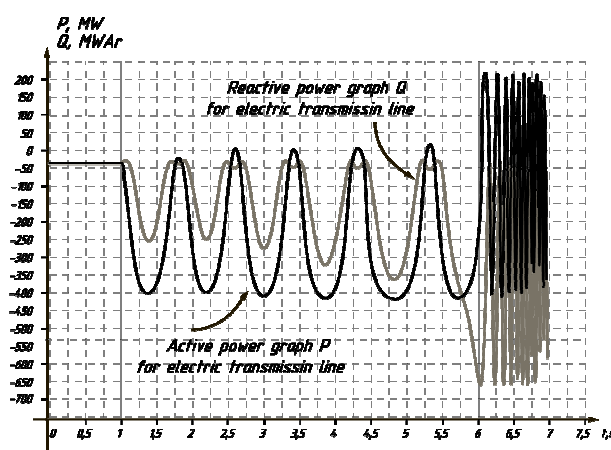


Figure 9. Active and Reactive power graph

#### 4. Simulation of AEAM-TS work

To detect asynchronous modes, AEAM-Ts have an angular detecting tool that predicts the occurrence of AM and triggers the device before the first asynchronous cranking [2]. This detecting device is used in cases where there is a real danger of a multi-frequency AM and when, during the first asynchronous rotation, deep voltage drops at substations located in the immediate vicinity of the electrical swing center are unacceptable

As a control action on the part of AEAM-Ts, shutdown of one generator unit per 100 MW at the NBHES node and disconnection of the load at the intermediate node TS 220 Birobidzhan are set.

Figure 10 illustrates the frequency graphs when simulating the operation of the AEAM-Ts.

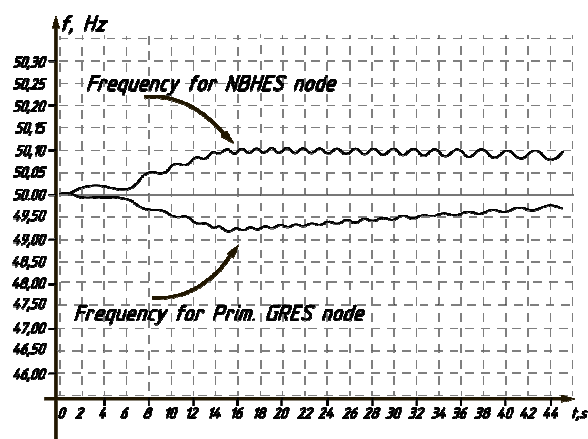


Figure 10. Frequency graph after AEAM-Ts action

It can be seen from the given graphs that the control actions launched the processes of the system exit from the asynchronous mode and further stabilization under the influence of the frequency and power control systems of generators.

## 5. Conclusion

Asynchronous modes of operation of power grids are rare. The consequences of asynchronous modes are associated with a high risk of damage to equipment and entail serious economic costs.

To effectively counter situations with the emergence of an asynchronous mode, it is necessary to comprehensively study the conditions for its occurrence, which is possible only with the help of simulation experiments [8, 9 and 10].

During the simulation experiment, the following results were obtained:

- An effective method has been developed to identify the moment of occurrence of a two-frequency asynchronous mode in a section of the power system of the Far East.
- The control actions necessary to eliminate the asynchronous mode without changing the network topology have been determined.
- It has been shown experimentally that a violation of connectivity and stability in the power system can lead to an avalanche-hazardous increase in voltage and frequency in asynchronous mode.
- Criteria for the effectiveness and optimality of the use of emergency equipment were obtained.

From the analysis of the experimental results, it follows that in order to reduce the costs associated with the operation of the power system in the AM, switching equipment with a higher speed is needed, since the transition of the system to a steady state proceeds rather slowly, and, accordingly, the duration of overvoltage in the system can lead to significant economic losses.

In general, there is a need to perform a wide range of simulation studies to analyze possible scenarios for emergencies and select measures to prevent them and reduce economic costs.

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