Device for reducing asymmetry

Eldor Usmanov1*, Bakhriddin Kholikhmatov1, Bakhodir Rikhsitillaev2, Kamoliddin Nimatov3

1Tashkent State Technical University named after Islam Karimov, 100095, Uzbekistan, Tashkent, University St. 2A
2Nuclear energy development agency under the Ministry of Energy of the Republic of Uzbekistan, Tashkent, 100025, Uzbekistan
3Karshi Institute of Engineering Economics, 225 Independence Avenue, Karshi, Uzbekistan

Abstract. This article focuses on the development and analysis of a device designed to reduce voltage asymmetry in electrical systems. Voltage asymmetry can lead to negative consequences, such as equipment overloads, increased energy losses, and unstable power supply. The article discusses the fundamental principles of the device, its components, and control methods to achieve an optimal level of voltage symmetry. The presented research results emphasize the device's effectiveness in improving the quality of power supply and ensuring the stable operation of electrical grids.

1 Introduction

In 0.4 kV networks, their operation is often asymmetrical, i.e. Voltages in different phases may differ from each other. Asymmetrical modes in electrical networks arise for the following reasons: 1) unequal loads in different phases; 2) partial-phase operation of lines or other elements in the network; 3) different parameters of lines in different phases.

Most often, voltage asymmetry occurs due to inequality of phase loads. In urban and rural networks of 0.38 kV, voltage asymmetry is caused mainly by the connection of single-phase lighting and low-power household electrical receivers. The number of such single-phase power receivers is large, and they need to be evenly distributed among the phases to reduce asymmetry. However, nowadays, due to the rapid development of household electrical appliances, such a solution is practically difficult [1-3].

2 Experimental research

In high voltage networks, asymmetry is caused, as a rule, by the presence of powerful single-phase power receivers, and in some cases, three-phase power receivers with unequal consumption in the phases. These consumers include arc-smelting furnaces. The main sources of asymmetry in industrial networks of 0.38-10 kV are single-phase thermal installations, ore-smelting furnaces, induction smelting furnaces, resistance furnaces and various heating installations. In addition, asymmetrical electrical receivers are welding machines of varying power. Traction substations of AC-electrified railway transport are a powerful source of asymmetry, since electric locomotives have single-phase power receivers [4-9].

Asymmetry negatively affects the operating and technical and economic characteristics of rotating electrical machines. The positive sequence current in the stator creates a magnetic field that rotates at a synchronous frequency in the direction of rotation of the rotor. Negative sequence currents in the stator create a magnetic field that rotates relative to the rotor at twice the synchronous frequency in the direction opposite to rotation. Due to these double-frequency currents, a braking electromagnetic torque and additional heating occur in the electric machine, mainly in the rotor, leading to a reduction in the service life of the insulation.

In asynchronous motors, additional losses occur in the stator. In a number of cases, it is necessary to increase the rated power of electric motors during design, unless special measures are taken to balance the voltage. In synchronous machines, in addition to additional losses and heating of the stator and rotor, dangerous vibrations can begin. Due to asymmetry, the service life of transformer insulation is reduced, synchronous motors and capacitor banks reduce the production of reactive power.

Fig.1. An equivalent circuit is a parallel oscillating circuit connected in series with a linear inductance and in parallel connected with a second linear inductance.
Research conducted by the authors when creating a balun showed that a parallel oscillatory circuit with a falling section of the amplitude characteristic can be used as a sensitive organ of the stabilizer. Let us consider the phase relationships of a parallel ferroresonant circuit connected in series with a linear inductance and connected in parallel with the second linear inductance (Fig. 1) of a linear choke, due to their smallness [10].

To carry out a theoretical analysis, we will accept the same assumptions as for the previously considered circuit. In addition, we neglect losses in the core. The study is carried out using the method of slowly falling section of the amplitude characteristic can be used as a sensitive organ of the stabilizer.

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Let’s determine the amplitude-phase relationship between voltage $U_{ВХ}$ and current $i_c$. The circuit under study is described according to (3), (4), (5) in to equation (2) from equality (1) we obtain [11,12]:

$$u = w \frac{d\phi}{dt} + L_0 \frac{di}{dt}$$  (1)

where

$$i = i_c + i_g + i_{дф}$$  (2)

here

$$i_c = w\phi \frac{d\phi}{dt}$$  (3)

$$i_g = wg \frac{d\phi}{dt},$$  (4)

$$i_{дф} = \frac{\kappa}{w} \phi$$  (5)

Substituting the corresponding current values according to (3), (4), (5) into equation (2) from equality (1) we obtain [11,12]:

$$u = w \frac{d\phi}{dt} + wCL_0 \frac{d^2\phi}{dt^2} + wgL_0 \frac{d\phi}{dt} + \frac{\kappa_0}{w} \phi$$  (6)

Let us introduce the basic and dimensionless quantities corresponding to equation (6):

$$y = \frac{u}{U_0}; x = \frac{\phi}{\phi_0}; \phi_0 = \sqrt{\frac{64\omega^4\omega^2}{35k}}; U_0 = \omega B \Phi_0; \tau = \omega t.$$  (7)

Taking into account expressions (7), after simple transformations, equation (7) will have the following form:

$$y = \frac{dx}{d\tau} + \omega^2CL_0 \frac{d^2x}{d\tau^2} + \omega gL_0 \frac{dx}{d\tau} + \omega^2CL_0 \frac{64 dx}{35 d\tau}$$  (8)

Taking dimensionless coefficients:

$$\beta = \omega^2CL_0; \gamma = \omega gL_0$$  (9)

we have

$$y = \frac{dx}{d\tau} + \beta \frac{d^2x}{d\tau^2} + \gamma \frac{dx}{d\tau} + \beta \frac{64 dx}{35 d\tau}$$  (10)

Let’s integrate this equation:

$$\int ydx + c = x + \beta \frac{dx}{d\tau} + \gamma \frac{dx}{d\tau} + \beta \frac{64 dx}{35 d\tau} \beta x^2$$  (11)

where $c$ is the integration constant.

We will look for solution (11) in the form:

$$x = X_m \sin(\tau + \psi) \quad \text{при} \quad y = Y_m \sin \tau$$  (12)

Derivative of $x$, has the form:

$$\frac{dx}{d\tau} = X_m \cos(\tau + \psi) + \frac{d\psi}{d\tau} Y_m \cos(\tau + \psi)$$  (13)

Taking into account the fact that $X_m > > \frac{dxm}{d\tau}$ and $X_m > > \frac{d\psi}{d\tau}$ $Y_m$ can be taken as a first approximation:

$$\frac{dx}{d\tau} = X_m \cos(\tau + \psi)$$  (13)

Substituting (13) and (4) into equation (11) we get:

$$V_m \cos \tau = -X_m \sin(\tau + \psi) - 2\beta \frac{dxm}{d\tau} \cos(\tau + \psi) + 2\beta \frac{d\psi}{d\tau} \sin(\tau + \psi) + \beta X_m \sin(\tau + \psi) - \gamma X_m \cos(\tau + \psi) - \beta X_m \sin(\tau + \psi)$$  (14)

After simple trigonometric transformations, we group the coefficients for the same trigonometric functions:

$$V_m \sin \psi = -X_m + 2\beta X_m \frac{d\psi}{d\tau} + \beta X_m - \beta X_m^2$$  (15)

$$V_m \cos \psi = -\gamma X_m - \beta \frac{dxm}{d\tau}$$  (16)

For steady state:

$$V_m \sin \psi = \beta X_m + \beta X_m - X_m$$  (17)

$$V_m \cos \psi = -\gamma X_m$$  (18)

The joint solution of equations (17), (18) gives the amplitude value of the input voltage, in relative units, and the phase angle between the power source voltage and the $FE$ magnetic flux.
To build circuit Current–Voltage characteristic and determine its amplitude-phase characteristics, it is necessary to determine dependencies \( I = f(\Phi) \) and \( \Phi = f(U_m) \).

Let us rewrite equation (2) taking into account (3), (4) and (5):

\[
i = wC \frac{d^2\phi}{dt^2} + wg \frac{d\phi}{dt} + \frac{K}{w} \phi^5
\]  

(introducing new dimensionless and basic quantities: \( I_{iz} = I_{ib} = \bar{\phi} \omega C \Phi \) and taking into account expressions (7), (9) we rewrite equation (21) in the form:

\[
z = \frac{d^2x}{dt^2} + \frac{\alpha}{\omega_C} \frac{dx}{dt} + \frac{64}{35} x^7
\]

or

\[
z = \frac{d^2x}{dt^2} + \frac{\alpha}{\delta} \frac{dx}{dt} + \frac{64}{35} x^7
\]

Let’s assume that

\[
z = Z_m(\sin(\tau - \Phi))
\]

Let’s substitute expressions (11), (12) and (25) into equation (24) and taking into account the fundamental harmonic of the magnetic flux we have:

\[
Z_m \sin(\tau - \Phi) = -(X_m^6 - 1)X_m \sin(\tau + \psi) + \frac{\xi}{\delta} X_m \cos(\tau + \psi) + \frac{\xi}{\delta} X_m \cos(\tau + \psi) + X_n \sin(\tau + \psi)
\]

After simple transformations and grouping of coefficients for the same trigonometric functions, we have [13-19]:

\[
Z_m \sin(\phi) = -(X_m^6 - 1)X_m \sin(\psi) - \frac{Y}{\beta} X_m \cos(\phi)
\]

\[
Z_m \cos(\phi) = (X_m^6 - 1)X_m \cos(\psi) - \frac{Y}{\beta} X_m \sin(\phi)
\]

A joint solution of equations (26) and (27) gives the amplitude value of the load current in relative units and the phase angle between the load current and the supply voltage:

\[
Z_m = X_m \sqrt{(1 - X_m^6)^2 - \left(\frac{Y}{\beta}\right)^2}
\]

\[
tg\phi = -\frac{(X_m^6 - 1)\phi - \frac{Y}{\beta} \phi}{(X_m^6 - 1) + \frac{Y}{\beta} \phi}
\]

The voltage across inductance \( L_0 \) is determined from the formula [20-26]:

\[
u = L_0 \frac{di}{dt}
\]

From here

\[
i_2 = \frac{1}{L_0} \int U_m \sin(\omega t) dt = -\frac{u_m}{\omega C \Phi}
\]

The current in an unbranched section of the circuit is determined as

\[
i = i_1 + i_2
\]

or in relative units

\[
z = z_1 + z_2 = Z_m \sin(\tau - \psi) - \frac{Y}{\beta} \cos(\tau)
\]

where \( \beta' = \omega^2 C L_0 \)

\[
Z_m \sin(\tau - \psi) = Z_m \sin(\tau - \psi) - \frac{Y}{\beta} \cos(\tau)
\]

\[
Z_m \sin(\tau - \psi) = Z_m \sin(\tau - \psi) - \frac{Y}{\beta} \cos(\tau)
\]

Let’s highlight the sine and cosine components:

\[
Z_m \sin(\phi) = Z_m \sin(\phi) + \frac{Y}{\beta'}
\]

A joint solution of equations (31) and (32) gives the amplitude value of the current, in relative units, in an unbranched section of the circuit and the phase angle between this current and the supply voltage [27-32]:

\[
Z_m = \sqrt{(\frac{Z_m \sin(\theta)}{1 + \tan^2(\phi)})^2 + (\frac{Z_m \cos(\phi)}{1 + \tan^2(\phi)})^2}
\]

\[
tg\phi = tg\phi + \frac{Y}{\beta} \phi
\]

3 Research results

The results obtained from formula (34) have both positive and negative meanings:

- a negative value of the angle \( \phi \) corresponds to the phase advance of the load current from the supply voltage;
- a positive value of the angle \( \phi \) corresponds to a phase lag of the load current from the power source voltage.

Thus, if a transreactor is connected to the unbranched section of the considered circuit, then from its secondary windings you can receive a signal to control the thyristors connected to the arms of the diode bridge. This connection will allow you to obtain a rectified voltage, the value of which varies in inverse proportion to the voltage of the supply circuit [33, 34].

In Fig. 2 shows a diagram of connecting the proposed device to a three-phase circuit.
4 Conclusion

As can be seen from this diagram, each control system is respectively connected to the same phase of the four-wire circuit as the capacitors that regulate the power. Therefore, when the voltage changes in phase “A”, “CY1” will operate, receiving power from phase “A” and turn on the “KB” connected to this phase [35,36]. Thus, using a parallel oscillatory circuit in the capacitor bank control system, it is possible to create a system for smoothly controlling the power generated by the capacitor banks into the supply network [37].

References

34. Sattarov Kh., Sapayev M., Suyarov A., Turaev, A. Improving efficiency in a distribution network with asymmetric load due to connected solar panels with a phase relationship. E3S Web of Conferences, 2023, 401, 04001, https://doi.org/10.1051/e3sconf/202340104001
35. Jurayeva K., Sattarov Kh. Issues of investigation of the dependence of static characteristics of magnetoelastic converters of mechanical quantities on the influence of external. E3S Web of Conferences, 2023, 389, 01060, https://doi.org/10.1051/e3sconf/202338901060