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Topic "Methods of connecting three-phase electric circuits" and its advantages of interdisciplinary training

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Abstract. This article highlights the topic "Connection of three-phase electrical circuits in a star and a triangle", which is an interdisciplinary and interconnected circuitry with general patterns, features, and issues of the formation of theoretical and practical knowledge.

1 Introduction

The topic "Star and delta connection of three-phase electrical circuits", taught to students of higher educational institutions in the field of theoretical electrical engineering, is inextricably linked with the topic "Star and delta connection of three-phase electrical machines" in the field of the discipline of electrical machines, which provides for the connection of electrical consumers in a star and triangular way using three resistances.

When connecting consumers according to the "star" scheme, the three-phase system can be three-wire or four-wire. With this connection method, electrical resistances or single-phase power consumers are connected between each line wire and the neutral wire. With such a connection of consumers, the currents in the linear wires are equal to the currents in the corresponding phases of the source, that is:

$$I_L = I_f \quad (1)$$

When connected by a star, the phase currents IA, IB, and IC appear in the phase resistances of consumers, the values of which are directly dependent on the value of the resistances ZA, ZB, and ZC, respectively. Because, in general cases, phase resistances may not match in modules and arguments. In this case, the vector values of the corresponding phase currents have the following form [1].

$$\vec{I}_A = \frac{\dot{\vec{U}}_A}{Z_A} = \frac{U_f}{Z_A} * \ e^{-j\varphi_1} = I_A * e^{-j\varphi_A} \quad (2)$$

$$\vec{I}_B = \frac{\vec{U}_B}{Z_B} = I_B \ * \ e^{\frac{-j2\pi}{3} - j\varphi_2} = I_B * e^{-j\left(\frac{2\pi}{3} + \varphi_B\right)} \quad (3)$$

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$$\vec{I}_C = \frac{\vec{U}_C}{Z_C} = I_C * e^{-j\left(\frac{4\pi}{3} + \varphi_C\right)} \quad (4)$$

The sum of these currents forms the current I_0 flowing through the neutral wire. The vector diagram of currents and voltages for a symmetrical load connected by a star in phases is shown in Figure 1a. According to the vector diagram, the direction and module of the current vector I_0 on the neutral wire depend on the nature and magnitude of the currents in each phase.

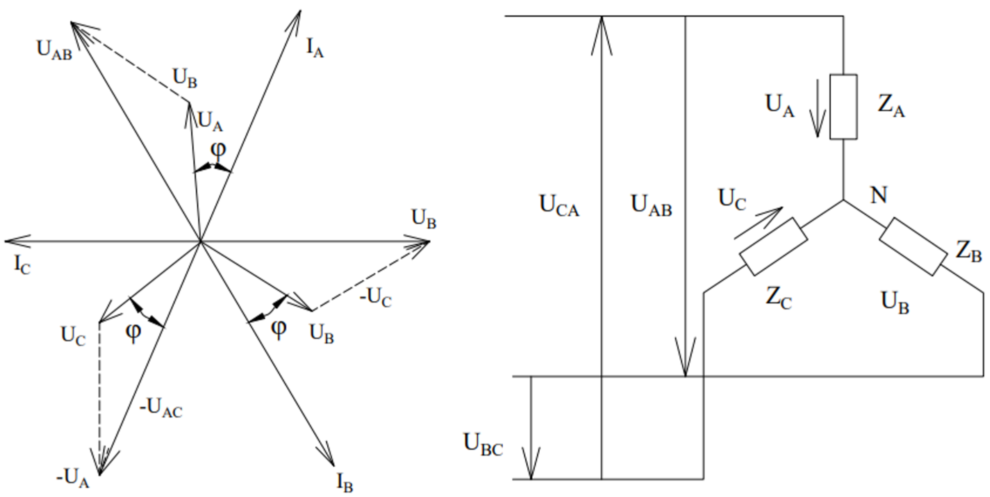

Fig. 1. Vector diagram of currents and voltages

Suppose the resistors loaded on each phase ZA, ZB, and ZC are quantitatively heterogeneous and have the same character. In that case, it can be seen that the current module in the neutral part (conductor) is always the largest but smaller than in the current phase. This feature is most often used in practice for the transmission of three-phase current over a four-wire network. Therefore, to save non-ferrous metals, the diameter of the zero core can be smaller than that of the phase (linear) cores.

Suppose the loads differ significantly from each other in phase. In that case, the value of the current in the neutral conductor can theoretically reach its maximum value. Still, it may even exceed the value of the maximum phase current, as a result of which the phase symmetry is violated, and the device fails. With a symmetrical phase load (ZA=ZB=ZC=Z load), the phase currents form a three-phase symmetrical system of current vectors, i.e., they have the following form [2].

$$\vec{I}_A = \frac{\dot{\vec{U}}_A}{Z_{yuk}} = \frac{U_f}{Z_{yuk}} * e^{-j\varphi_1} = I_f * e^{-j\varphi_{yuk}} \quad (5)$$

$$\vec{I}_B = \frac{\vec{U}_B}{Z_{yuk}} = I_f * e^{\frac{-j2\pi}{3} - j\varphi_2} = I_f * e^{-j\left(\frac{2\pi}{3} + \varphi_{yuk}\right)} \quad (6)$$

$$\vec{I}_C = \frac{\vec{U}_C}{Z_{yuk}} = I_f * e^{-j\left(\frac{4\pi}{3} + \varphi_{yuk}\right)} \quad (7)$$

When connecting three-phase consumers according to the star circuit, the phase voltage quantitatively differs from the linear voltage by $\sqrt{3}$ times. This difference can be seen in the following topographical diagram of a symmetrical system. CNM can detect $U_{BC} = \sqrt{3} * U_C$ or $U_L = \sqrt{3} * U_f$ or from a right triangle.

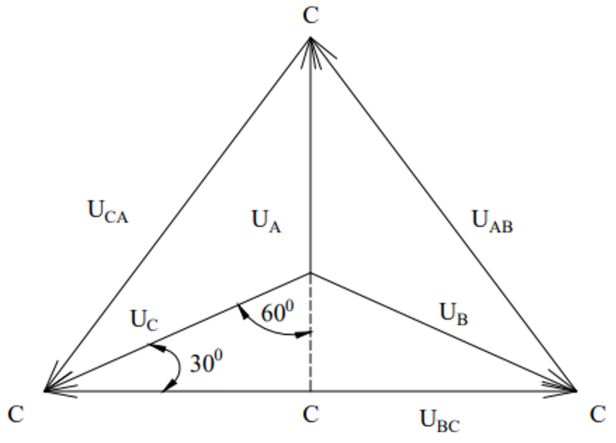

Fig. 2. Scheme of relationship between linear and phase voltages

In the vector diagram constructed for this case, the sum of the phase currents is zero, and the current in the neutral conductor is not equal to I_0. This allows these three-phase consumer groups to supply electricity only through three-wire transmission lines, saving one line in a three-wire system. The group of three-phase symmetrical consumers includes the most common three-phase asynchronous motors in practice, powerful (power) transformers, electric furnaces, rectifiers that convert alternating current to direct current, and others.

Students have explained the three-phase circuit through three resistors, and the connection of the electric motor in star mode is explained on the stent using the following diagram.

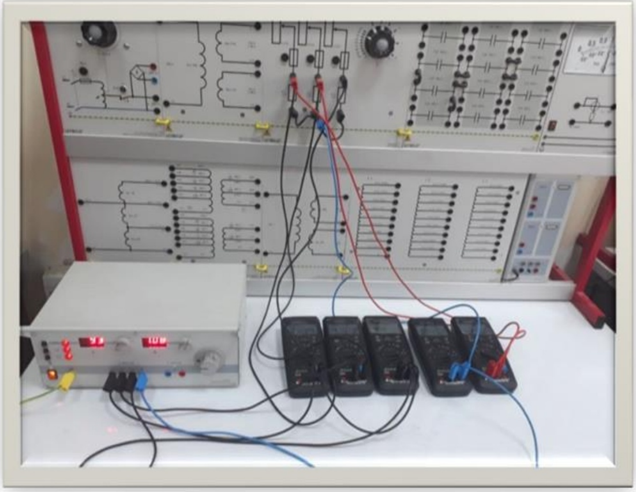

Fig. 3. Scheme of star connection of three-phase electrical circuits through simple resistors.

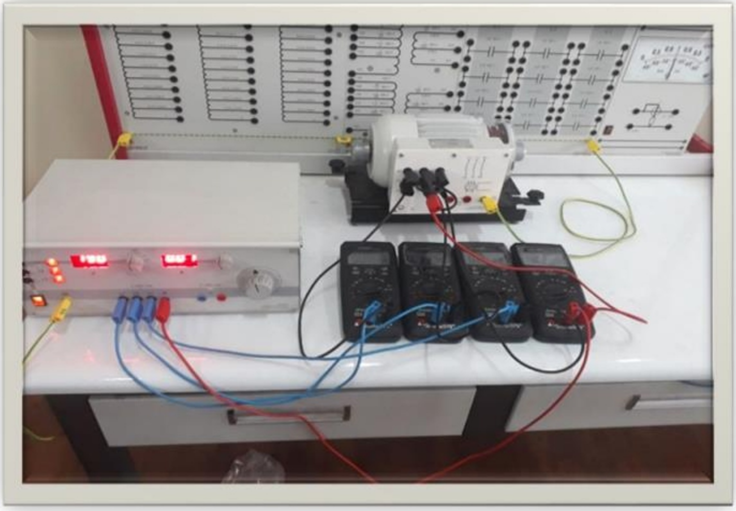

Fig. 4. Scheme of starting a three-phase electric machine with a star connection.

When connecting three-phase consumers in a triangular circuit, the beginning and end of the phase resistors are connected to the corresponding parts of the linear wires coming from the three-phase source, respectively. Let's consider the source as an alternating current generator. Regardless of the method of connecting the generator coils, the consumer creates only a linear voltages UAB, UBC, and UCA system. These voltages are the phase of a three-phase load; at the same time, stresses are also calculated. If we do not take into account the resistance of the electromotive force (EMF) and linear wires, then the symmetry of the linear (phase) voltages is preserved at any value of the load resistance (ZAB ≠ ZBC ≠ ZCA ≠ 0). The asymmetry of loads (resistances) on the phases of three-phase consumers leads to different power loads of some generator phases. Another advantage of connecting consumers using the triangle method is that the consumer is connected to the source with only three wires. EMF following:

$$\overrightarrow{E_A} = E_{Am}, \quad \vec{E}_B = E_{Bm} * e^{-j\frac{2\pi}{3}}, \quad \vec{E}_C = E_{Cm} * e^{j\frac{2\pi}{3}} \tag{8}$$

Method of connecting the generator coil depends on the rated voltage of the consumer phase resistors. If $U_L = G = \sqrt{3} * U_f$ the oscillator phase, the generator phase is connected as a star.

If the phase voltage of a three-phase consumer is equal to the phase EMF, i.e., Ufnom = Ef, then the phases of the generator are connected in a triangular shape.
In triangular consumers, the following voltage vectors are also formed:

$$\overrightarrow{U_A} = U_L = U_f \ \overrightarrow{U}_B = U_f * e^{-j\frac{2\pi}{3}}, \quad \vec{U}_C = U_f * e^{j\frac{2\pi}{3}} \tag{9}$$

These vectors form an equilateral triangle as follows.

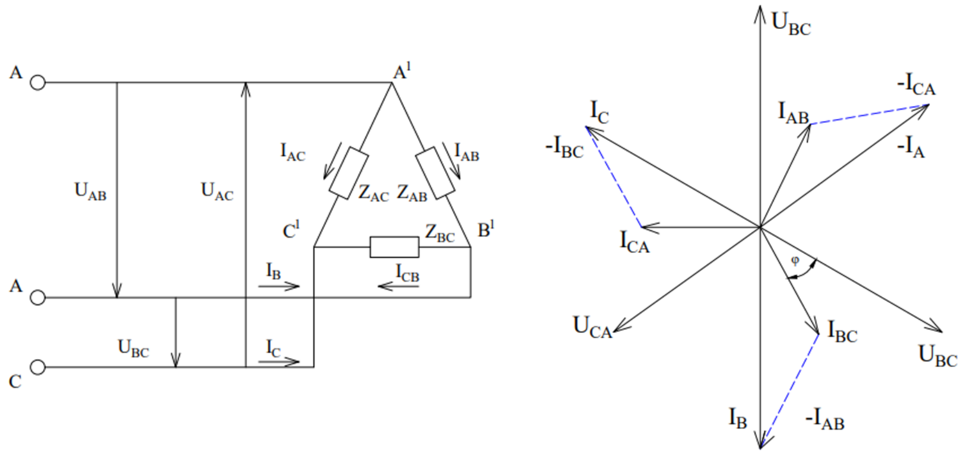

Fig. 5. Vector diagram of currents and voltages for a triangular circuit

According to the circuit connection scheme, phase currents $\vec{I}_{AB}$, $\vec{I}_{BC}$, $\vec{I}_{CA}$ f of consumers are connected with linear currents $\vec{I}_A$, $\vec{I}_B$, $\vec{I}_C$ in linear wires as follows, according to the first Kirchhoff law. [3]

$$\vec{I}_A = \vec{I}_{AB} - \vec{I}_{CA}, \quad \vec{I}_B = \vec{I}_{BC} - \vec{I}_{AB}, \quad \vec{I}_C = \vec{I}_{CA} - \vec{I}_{BC} \qquad (10)$$

Therefore, the linear current vectors are equal to the difference between the phase current vectors corresponding to them.

When three-phase circuits are connected in delta, line, and phase voltages are equal, and line and phase currents differ from each other by $\sqrt{3}$ values, we can see this difference as follows.

Assuming that the phase loads are the same, the phase and linear wires form a three-phase symmetrical system. According to the vector diagram shown in scheme 6, you can find the relationship between line and phase currents.

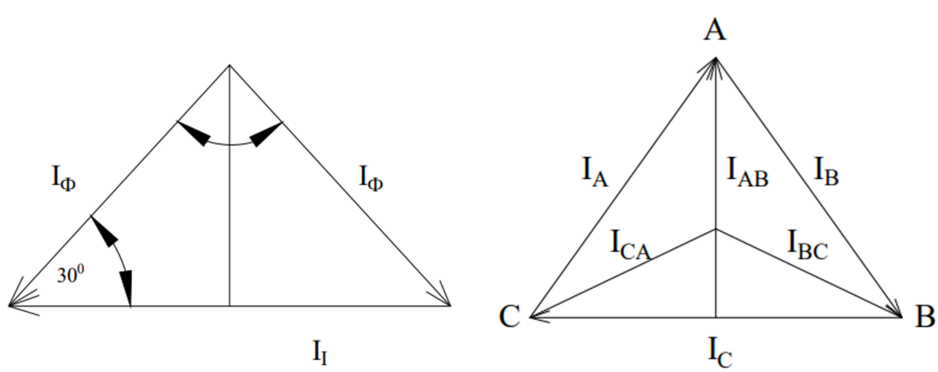

Fig. 6. Diagram of relationship between linear and phase voltages.

$$\frac{1}{2} * I_L = I_f * \cos 30° = I_f * \frac{\sqrt{3}}{2}; \quad \text{this results in } I_L = I_f * \sqrt{3} \qquad (11)$$

When a three-phase system is in a state of symmetrical load on the phases, the phase currents ZAB ≠ ZBC ≠ ZCA differ from each other in quantity and phase and are determined separately for each phase.

$$\vec{I}_{AB} = \frac{\vec{U}_{AB}}{z_{AB}}, \quad \vec{I}_{BC} = \frac{\vec{U}_{BC}}{z_{BC}} \ va \ \vec{I}_{CA} = \frac{\vec{U}_{CA}}{z_{CA}}; \quad (12)$$

If the resistance of each phase of the consumer is the same, then the phase currents $Z_{yuk} = Z_{yuk} * e^{j\varphi yuk}$ are equal to each other, i.e.

$$\vec{I}_{AB} = \vec{I}_{BC} = \vec{I}_{CA} \quad (13)$$

The vectors of the above phase currents, in turn, form a symmetrical system.

$$\vec{I}_{AB} = I_f * e^{-j\varphi yuk}; \quad \vec{I}_{BC} = I_f * e^{-j\left(\varphi_{yuk} + \frac{2\pi}{3}\right)}; \quad \vec{I}_{CA} = I_f * e^{-j\left(\varphi_{yuk} - \frac{2\pi}{3}\right)} \quad (14)$$

Accordingly, with a symmetrical load, the currents in the linear wires are quantitatively equal, their vectors are shifted by an angle of 2π/3 relative to each other in phase, and the magnitude of the linear current is √3 times the phase current $I_L = \sqrt{3} * I_f$, but at the same time, we see that UL = Uf. A three-phase electrical circuit through three resistors and the connection of an electric motor in a triangular manner on the designated stent are explained to students according to the following diagram.

Fig. 7. Schematic diagram of triangular connection of three-phase electrical circuits through simple resistors.

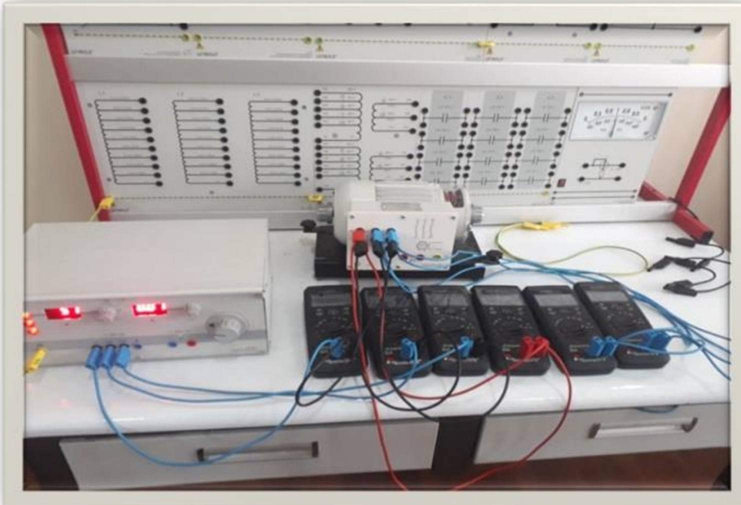

Fig. 8. Scheme of starting three-phase electric machine using a triangular connection.

Consider the process of connecting three-phase electrical machines to a network in the form of stars and triangles. The above formulas and diagrams are suitable for changing currents and voltages in star and delta connections of electrical machines of this type. When starting three-phase electrical machines, it is required that the value of the starting current does not exceed the power of the network. Otherwise, the voltage drop will be significant, which may lead to the shutdown of other electrical machines connected to the network. To prevent this, reducing the voltage applied to the stator is necessary to reduce the starting current when starting powerful electrical machines. You can reduce the starting current of electrical machines in the following ways:

a) Soft start (gradual increase in the voltage of the electric machine to a predetermined value);

b) starting from a reactor, autotransformer, or active resistor;

c) Start by switching from star to delta.

One of the most common ways is to connect electrical machines directly to the grid. In this method, the ammeter connected to the stator of the electrical machine is selected for 5÷7 times the rated current. With a decrease in the voltage supplied to the stator winding and a decrease in the starting current, the torque of the electric machine decreases in proportion to the square of the voltage. Such methods are used only when starting an electric machine in idle mode or with low loads [4-6].

During normal operation, if the electric machine is connected according to a triangular circuit and is designed to start with a small load, then starting such an electric machine is possible by connecting the stator according to the star circuit. At the end of the starting process, the stator of the electric vehicle switches to a delta circuit. Thus, when starting electrical machines, we can see the relationships between linear and phase currents.

In the star circuit, the current flowing through the windings of an electrical machine, which is started by the fact that the linear current is equal to the phase current, looks like this.

$$I_L^Y = I_f^Y = \frac{U_f}{Z} = \frac{U_L}{\sqrt{3} * Z} \quad (15)$$

In a triangular circuit, since the line current is $\sqrt{3}$ between the phase currents, the current flowing through the winding of the starting electric machine is as follows.

$$I_L^{\Delta} = \sqrt{3} * I_f^{\Delta} = \sqrt{3}\,\frac{U_f}{Z} = \sqrt{3}\,\frac{U_L}{Z} \quad (16)$$

So, from the above formulas, it can be seen that starting an electric car according to the star circuit is $\sqrt{3}$ times less than starting it according to the triangular circuit. Therefore, the start-up of electrical machines is carried out by switching from a star-connected circuit to a delta-connected circuit.

The following methods can be used in the interdisciplinary training of three-phase electrical circuits.

"The Chain" Method

This method is based on a logical sequence, and the questions complement each other as they move from simple to complex. As a result, problem situations arise. All of this teaches students to think independently and provides feedback during the lesson, which, in turn, contributes to a better understanding of the topic by students. With Proward, when using this method in the classroom, friendly relations are established based on consensus [7].

"Comparison" Method

Applying this method of comparison to the educational process allows teaching a subject by relating it to a subject that is part of the subject or close to it and has related aspects. The comparison method is more effective in teaching students a topic, which allows you to form teaching, knowledge, and skills based on information from other topics and related disciplines. [6] One of the advantages of this method is that students can reinforce their previous knowledge using the comparison method. The comparison method in this article can be used to organize the educational process for students, showing the interdependence of three-phase electrical circuits using the following schemes 3-4 and 7-8 connecting triangles and stars.

Conclusion

In this article, the topic of connecting three-phase electrical circuits into stars and triangles can be used in the course of interdisciplinary training of electrical machines on the topic of triangulation and star connection, the basic laws of connecting triangular and stars, vector circuits, techniques, and connections in two ways were collected and considered with using a special stand, which is designed to increase the speed of assimilation by students as a result of teaching a topic in this sequence.

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