

AUTOTRANSFORMERS

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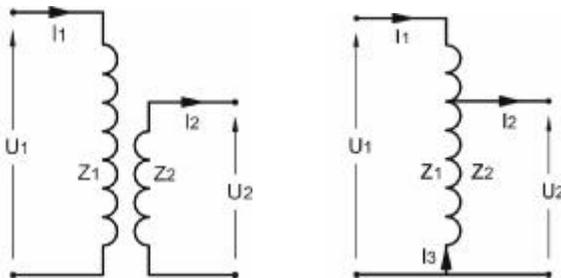
An autotransformer is a special variation of a transformer, in which primary and secondary windings have been combined, resigning from galvanic circuits separation. ELHAND TRANSFORMATORY produces single or three-phase autotransformers of the EA1, EA3-type and start-up transformers of the EA3R-type

Autotransformers – properties and application

When the primary side of a transformer with Z_2 number of windings is supplied with U_1 voltage, then on the secondary side with Z_2 number of windings, we receive U_2 voltage, in accordance with a transmission gear:

$$J = \frac{U_1}{U_2} = \frac{Z_1}{Z_2}$$

where: J - autotransformer transmission gear, U_1, U_2 - primary and secondary voltages, Z_1, Z_2 - number of primary and secondary windings coils



Drawing 1 Transformer and autotransformer diagram

In the transformer, the power is transmitted from the primary to the secondary circuit via the magnetic field. The energy flow through the autotransformer is accompanied by transformation and conduction phenomena. The conduction results from the direct combination of the autotransformer's primary and secondary circuits.



Drawing 2 Three-phase autotransformer of EA3-type

In order to describe the autotransformer operation properly, its transitive apparent power is presented in the following components:

§ Autotransformer electromagnetic power S_{WA} transmitted to the secondary circuit by means of transformation only

$$S_{WA} = (U_1 - U_2) I_1 = S_{PRZECH} \left(1 - \frac{1}{J} \right)$$

§ Autotransformer conduction power S_{PA} is transmitted to the secondary circuit through conduction

$$S_{PA} = U_2 \cdot I_1 = S_{PRZECH} \frac{1}{J}$$

The sum of the electromagnetic and conduction powers is the transitive power, being the autotransformer power output

$$S_{PRZECH} = U_1 \cdot I_1 \approx U_2 \cdot I_2$$

The autotransformer dimensions are determined by its electromagnetic power transmitted by means of transformation. When comparing a transformer and autotransformer of the same conduction powers, it is clear that the autotransformer has smaller electromagnetic power and is thus lighter:

$$S_{WT} = U_1 \cdot I_1 \approx U_2 \cdot I_2 = S_{PRZECH}$$

$$S_{WA} = (U_1 - U_2) I_1 = S_{PRZECH} \left(1 - \frac{1}{J} \right)$$

$$\frac{m_A}{m_T} \approx \left(1 - \frac{1}{J}\right)^3$$

where: S_{PRZECH} – autotransformer transitive power (output), S_{WT} – transformer electromagnetic power, I_1, I_2 – autotransformer primary and secondary current, m_A, m_T – autotransformer and transformer respective weights

The I_3 current in the common part of the autotransformer winding is small as compared with I_1 and I_2 currents. Thus, the cross-section of this part of the winding may be decreased, bringing about considerable savings.

Using smaller quantities of iron and copper for building the machine results in smaller losses and growth in the autotransformer efficiency.

There are two basic disadvantages with autotransformers. The first concerns the galvanic combination of the primary and secondary circuits, due to which, all disturbances, overvoltages are transmitted directly through conduction to the secondary circuit. Another shortcoming is the autotransformer short circuit low voltage when compares to a transformer:

$$\frac{U_{ZA}}{U_{ZT}} = \left(1 - \frac{1}{J}\right)$$

where: U_{ZA}, U_{ZT} – autotransformer and transformer respective voltage short circuits

Lowering the short circuit voltage is caused by considerably lower autotransformer windings impedance when compared to a transformer.

Autotransformers are applied in electromagnetic systems for connecting networks with different voltage levels, in start-up systems of large squirrel-cage induction motors, in laboratory application, and anywhere where the lack of the primary and secondary circuits galvanic distribution is permissible, and where the advantages resulting from lower weight and losses exceed the expenditure associated with limiting the short circuit current.

Starting up the squirrel-cage induction motors by start-up autotransformer of EA3R-type

One of the methods for starting up asynchronous squirrel-cage motors is to apply the supply with lowered voltage. The voltage is lowered in order to limit the start-up current.

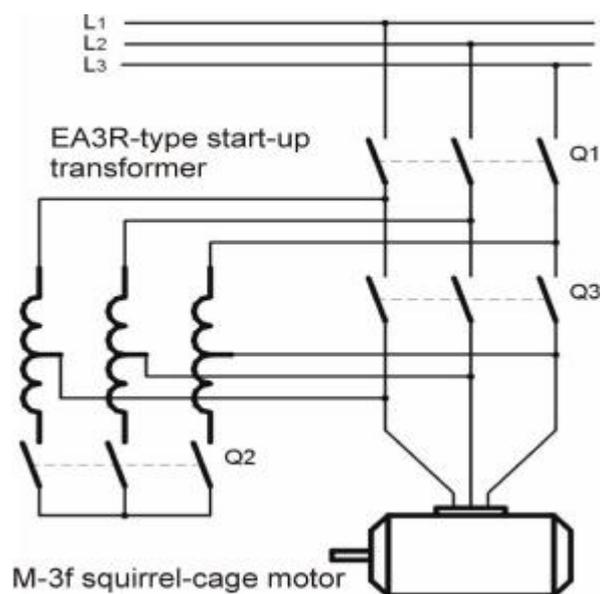
The method for starting up by means of the start-up autotransformer is used in particular in high-power drives, where switching from the star into stator winding triangle is technically difficult.



Drawing 3 Three-phase start-up autotransformer of EA3R-type

In its nature, the auto transformation start-up is similar to the start-up with the star-triangle switch. However, in case of an autotransformer voltage may be freely lowered for the time of the motor start-up, so that the current taken from the network does not exceed the set value.

If necessary, the start-up autotransformers are manufactured with several branches.



Drawing 4 Start-up system of the induction squirrel-cage motor with the start-up autotransformer of the EA3R-type

During the squirrel-cage motor start-up with the supply from the network with the U voltage through a transformer with the transmission gear ϑ , the voltage directed to the stator winding U_{RS} is as follows:

$$U_{RS} = \frac{1}{J} \cdot U$$

Then, the current running in the I_{RS} motor winding is equal to the secondary current of the autotransformer I_2 and reaches the following value:

$$I_{RS} = I_2 = \frac{1}{J} \cdot I_P$$

where: U – supply network voltage, I_P – start-up initial current when supplying the motor with full voltage

The autotransformer primary current I_1 , the current taken from the supply network during the start-up will reach the following value:

$$I_1 = \frac{1}{J} \cdot I_2 = \frac{1}{J^2} \cdot I_P$$

When selecting the transmission gear, it is necessary to make sure whether the moment developed by the motor at the lowered voltage is greater than the moment of the driven machine's resistance.

The motor initial moment M_{PR} , supplied by the autotransformer and when the voltage is lowered to U_{RS} value, is as follows:

$$M_{PR} = \frac{1}{J^2} \cdot M_P$$

where: M_P – initial moment developed by the machine at the full voltage

The dependencies presented show that the machine's initial moment is being decreased at the same scale as the current taken from the network.

The Korndorfer system presented in drawing 4, is a frequently applied solution when starting up asynchronous motors. The start-up takes place in two stages without voltage-free interruptions.

Initially, the motor start-up runs at the supply through autotransformer by lowered voltage. The start-up current is limited by suitably selected autotransformer transmission gear.

At the second stage, after disconnecting the Q2 switch, the motor is supplied from the network by the – switched on in series – inductions of the part of the autotransformer windings. These windings function as chokes limiting the start-up current.

Once the motor reaches a suitable rotational speed, by switching over the Q3 connector, the motor is supplied with the full voltage, directly from the network.

Bibliography

- [1] Mizia Wł. *Transformatory*. WPŚI Gliwice 1996
- [2] Mizia Wł. *Transformatory przykłady obliczeniowe*. WPŚI Gliwice 1999
- [3] Mizia Wł. *Parametry elektromagnetyczne autotransformatorów energetycznych*. Zeszyty Naukowe Politechniki Śląskiej seria Elektryka nr 138
- [4] Plamitzer A.M. *Maszyny elektryczne*. WNT Warszawa 1986