Development of three-phase zone rectifier of traction substation

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Abstract. The three-phase zone converter application for the traction power system of urban electric transport is discussed. The paper focuses on the zone rectifier application. The zone converter operation principles have been determined by adaptive control using. The utilization efficiency of a three-phase zone converter as a method for using the output voltage regulation at equally high energy performance has been estimated.

1. Introduction

In the current structure of the transport power supply system, there are some weaknesses, one of which is the high energy wastage indicator due to the variable-load operation modes, associated with the imbalance load in the traction network zones. The losses value depends on the traction network resistance and the current flowing in it. The system deterioration and the voltage level determine the system resistance and magnitude of the current, flowing through the contact network, respectively.

In view of the semiconductor technology development, especially controlled rectifiers, it becomes possible to adjust the load power distribution to traction units. In addition, when using controlled converters in the traction substation, it becomes possible to change the number of operating rectifying units depending on the acting load, which increases system energy performance.

Currently, for energy efficiency increasing of the electric transport and the traction energy systems, it is necessary to create and introduce new modern technologies. In this case, it is important to apply new circuit designs and control strategies of zone converters.

The main advantage of zone converters is an equal efficient operating mode in a wide range of output voltage regulation with equally high energy indicators. In comparison with the mentioned converters, the efficiency of bridge controlled rectifiers decreases with increasing regulating depth. Such ones are used in railway transport [9].

In power supply systems, three-phase controlled rectifiers with step-by-step output voltage control are used to reduce the ripple of rectified voltage and to provide a continuous current mode (Fig. 1) [4].

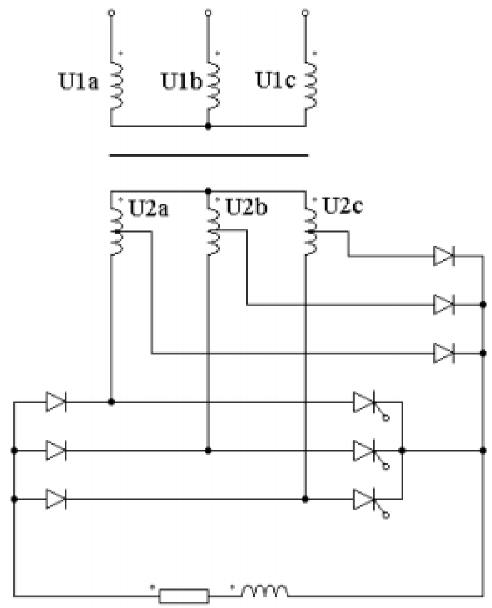

Figure 1. An example of a three-phase rectifier circuit with step-by-step output voltage control

The task is to obtain a circuit solution of a rectifier with zone-phase control and a minimum installed power of the transformer, using the method of structural synthesis.

2. Development of a three phase zone phase rectifier

A topological method is known for the synthesis of rectifier circuits [x], in which each resultant rectified voltage of secondary windings is considered as the maximum possible potential difference on the topographic potential plane. This plane contains the vector diagrams of the available stress systems, expanded and rotating in time, to which the PSD is attached. Thus, the structural synthesis of circuit solutions is based on the use of the geometric configuration of electrical circuits in the form of topological graphs containing secondary windings, combined by equivalent nodes using PSD.

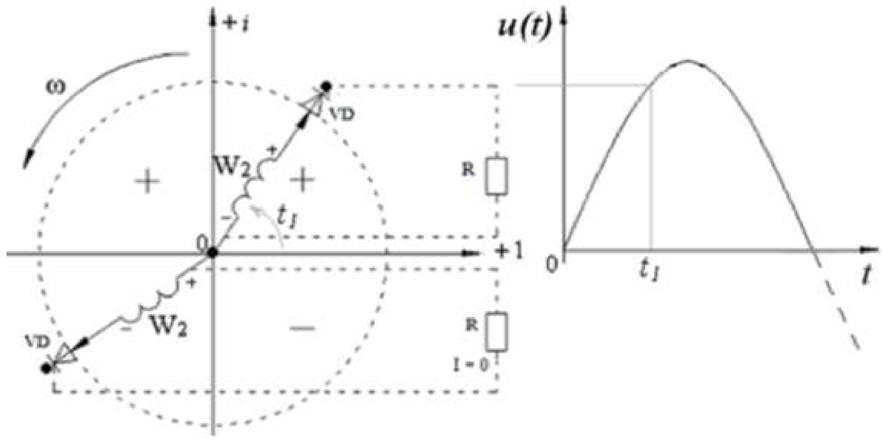

Figure 2. Relation between the topology of the rectifier elements and the vector diagram on the topographic potential plane and the construction of oscillograms by obtaining the projection of the maximum potential differences

Taking into account the already proven advantage of a three-phase symmetric system over any other, when constructing a rectifier with zone-phase control by the method of structural synthesis, the basis should be taken of the stress system, which is represented in the potential plane in the form of a three-beam star.

To organize the principle of zone regulation, each star beam can be divided into several zones. With the natural rotation of the vector diagram on the topographic potential plane, the individual projections of the three-beam star zones will periodically form the maximum values. The number of their combinations, in the form of maximum potential differences between the beginnings and ends of the vectors of the individual zones, which belong to all the rays, the stars and form the resultant stresses, will exceed the number of the zones themselves. This is because the three-phase system of vectors, divided into individual zones, whose projections have reached the maximum values, has a greater number of combinations than a similar single-phase system. Thus, it is possible to obtain not only the linear voltage between adjacent phases of the first zone, the second zone, but also the potential difference between the point of one phase of the first zone with respect to the point of the other phase of the second zone, etc.

Thus, for a three-phase system of voltages, it becomes possible to create a controlled zone-phase rectifier with a fractional number of phases.

The connection of the areas of different zones for each phase can be accomplished by switching controlled PSD, directing the sign-to-constant potential difference to the load.

First, it is necessary to designate the locations of the zones on the topographic potential plane (Fig. 3).

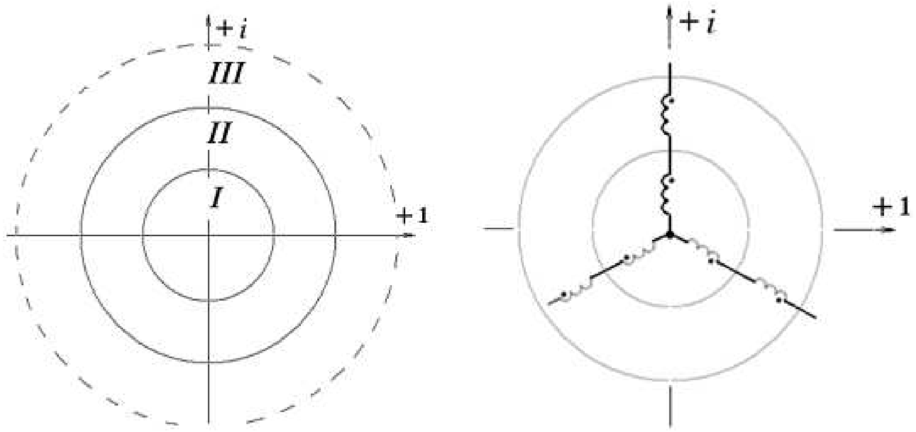

Figure 3. Sequence of construction of a three-phase zone-phase rectifier: The arrangement of the zones (I-first, II-second, III-third, etc.) on the topographic potential plane

Further in the center, we place a three-phase symmetrical system in the form of a three-beam star, each ray of which will be divided by zone boundaries into several parts. To simplify the problem, we take the condition for constructing the first two bands and determine the combinations of potentials that exist in this case between the initials and the ends of the vectors of the individual bands.

Thus, two working zones with a system of linear three-phase voltages has been obtained: for the first zone - U_{ab1}, U_{bc1}, U_{ca1}; for the second zone - U_{ab2}, U_{bc2}, U_{ca2}. Their values when accepting the equality of the number of turns for all parts of the secondary windings will differ by half: $U_2 = 2U_1$, where U_1 and U_2 are the linear voltage modules of the first and second zones, respectively.

In addition, there are two systems of three-phase voltages, formed by combinations of potential differences between the windings of different phases belonging to the first and second zones. Thus, three-phase stresses U_{ab12}, U_{bc12}, U_{ca12} between the first and second zone and U_{ab21}, U_{bc21}, U_{ca21} has been formed between the second and the first zone with the same linear voltage modules, which are $\sqrt{\frac{7}{3}} \approx 1,527$ times larger than voltage U_1.

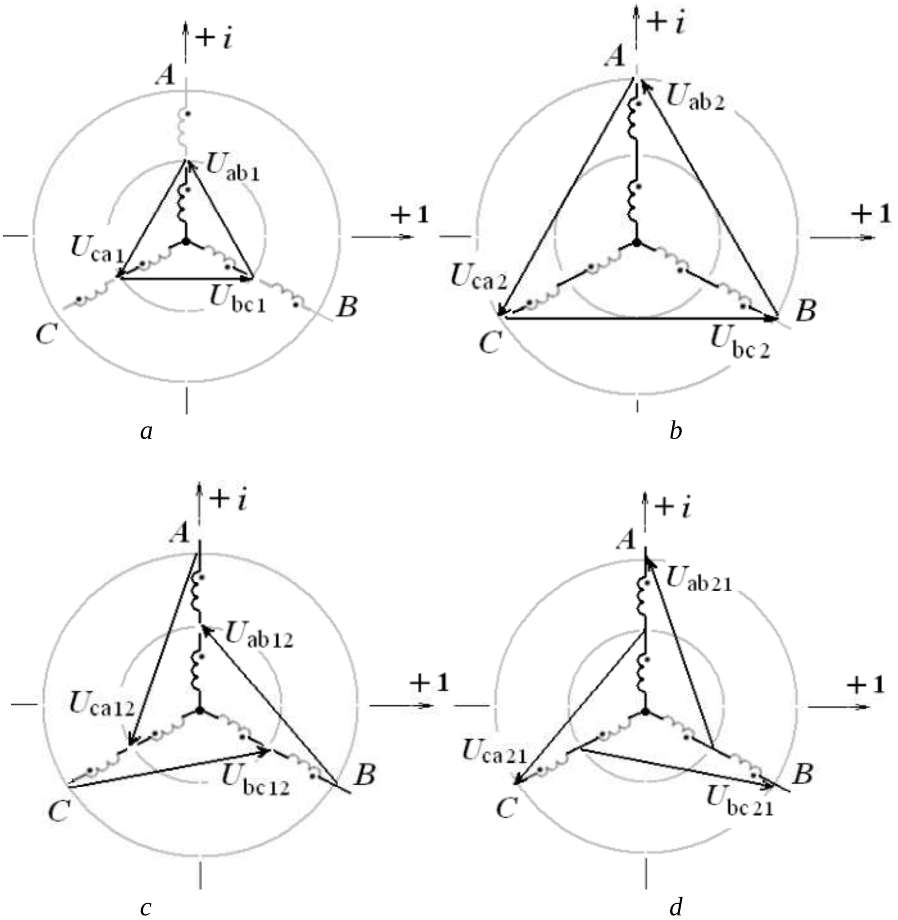

Figure 4. Formation of combinations of potential differences of secondary windings: a - linear voltages of the first zone; b - linear stresses of the second zone; c - combinations of voltages between the first and second zones; d - voltage combinations between the second and the first zones

3. Results and Discussion

In the course of topological analysis of vector diagrams, the questions of the methods of formation of resultant stresses for each zone has been solved; the final step will be the attachment to each node of the three-beam star by two SCR thyristors included in a different direction to obtain the sign-constant projections of stress systems in the form of potential differences for all phases.

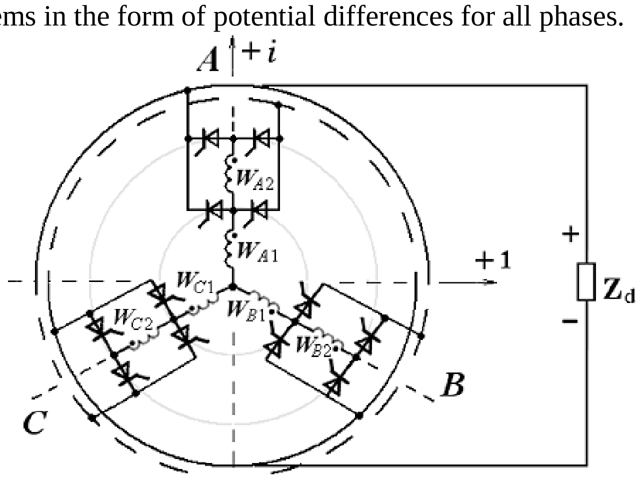

Figure 5. Schematic diagram of the three-phase zone-phase rectifier

So a simple scheme of a three-phase zone-phase rectifier has been obtained (Fig. 4), for which the installed power of the windings, taking the duration of the current flow through the windings to $2\pi/3$, is $\pi/3 \approx 1,047$.

In conclusion, it should be noted that the principle of obtaining the structure shown in figure 5 has no fundamental limitations and allows the construction of zone-phase rectifiers with any number of zones, a large number of fractional zones in which will significantly improve the smooth transition of the operating mode of the rectifier from one zone to another.

Conclusion

The paper has been demonstrated the possibilities of the method of structural synthesis and obtained a circuit solution of a three-phase zone-phase rectifier.

Advantages of the operation of zone-phase rectifiers in a three-phase network have been shown, which are expressed in increasing the power factor from 0.9 to 0.955 and the possibility of using intermediate fractional zones that improve the smoothness of the transition between neighboring zones.

The three-phase zone rectifier control regulates the cross currents, reduces the consumed currents, the voltage in all sections of the traction network and the specific electric energy consumption of the system.

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