

The twelfth-pulse rectifier for traction substations of electric transport

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Abstract. The article describes the influence of the voltages non-sinusoidal form of the supplying three-phase network to the rectified voltage's quality of the multipulse rectifier with a ring connection of the valve arm. The created mathematical model makes it possible to determine the shape of the rectifier's rectified voltage taking into account the asymmetry and non-sinusoidal voltage of the supply network. The results of calculations using a mathematical model are verified by way of physical model. The aim of research is to find out the most stable rectification scheme in case of three-phase network power supply of rectifier.

1. Introduction

The main functional element of the electric transport's tracking substation is the rectifier unit, which includes: a converter transformer, rectifier, power circuit and cathode breakers and extra equipments. In the traction energy system rectifiers transform alternating into continuous current in traction substations of mainline railroads, underground electric railway and urban electric transport.

Converters with a pulse of the rectified voltage curve number at least a six are used in the electric transport system. Until recently, "reversed star-to-star connection with a dividing reactor " and three-phase full-bridge circuit of zero six-pulse rectification circuits were widely used. On a trial basis, six-pulse rectifiers with cascade circuit of the rectifying elements switching were also used (scheme by Prof. VP Vologdin). By reason of the rectifier nonlinearity the voltage distortion of the supply network is unavoidable, and it is necessary to take into account a high power of traction substations. At the same time, these distortions become higher with a pulses number decrease of the rectifier unit outlet. Consequently, currently a multipulse rectifiers are implemented into the system of DC electric transport power supply [1].

2. Materials and modelling

The operational experience proves successful and safety of twelve-pulse series rectification circuits in traction substations of the West Siberian Railway. Currently, further performance indicators and safety improvement of twelve-pulse rectifiers are carried out using in the valve arms a new generation diode blocks, assembled under the new circuit solution [2].

The rectifier circuitry engineering development and an advanced semiconductors make it possible to reduce the diodes lost power and improve the rectifier reliability. As a gate circuit, instead of two series-connected bridge three-phase circuits, an valve arm's ring connections developed at the NSTU can be used (Fig. 1).



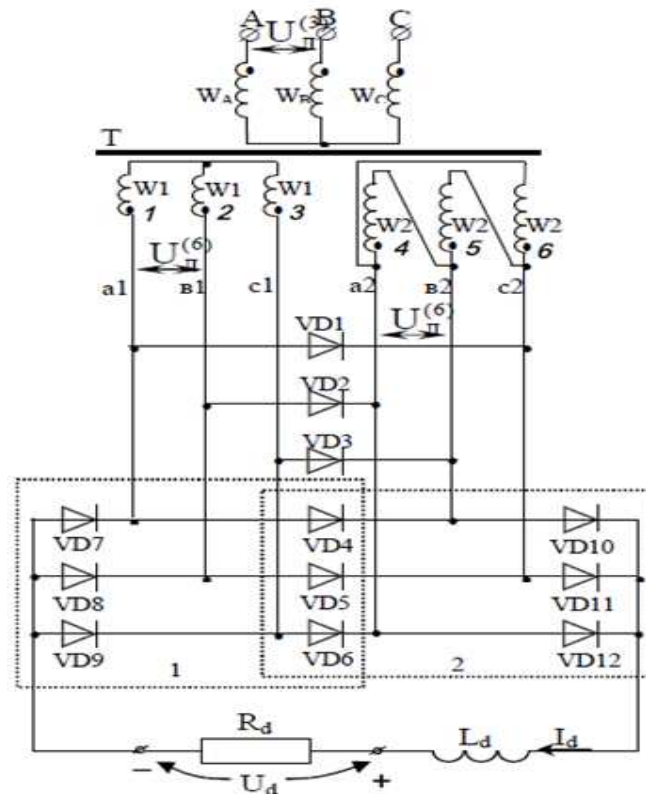


Figure 1. Circuit diagram of a ring rectifier.

The ring rectifier, shown in Fig.1, consists of three-phase transformer T and twelve valves VD1-VD12. One primary winding and two secondary windings [3], [4] are placed on the transformer limb and produce the wye and delta connection.

The star-connected secondary winding ends are concatenate to the lines connecting the diodes of the anode group with the diodes in the circuit middle, and to which the ends of delta-connected secondary windings the transformer are connected. And from different sides of the middle group diode are connected the star-connected phase terminal unit and the next delta-connected phase terminal. The phases output of each wye-connections are connected using an additional diode with that delta connection phase, with which it is not connected by a bridge connection diode. The middle bridge connection diodes and additional diodes VD1-VD3 are formed a closed ring of six diodes, connected only by the same name electrodes [2], [5].

Thus, it is evident, that due to the diodes quantity reduction in the current flow circuit the electric energy losses decrease. However, it is necessary to take into account that under real-life conditions the power supply of rectifying units is carried out by a three-phase asymmetric and non-sinusoidal voltage systems due to the fact that other nonlinear devices introduce their distortions into the voltage of the supplying three-phase network. In turn such network distortion has an effect on the rectifier operation as a whole and reduces electromagnetic compatibility and its performance indicators. With the purpose of determination the voltage distortion's influence degree of the mains supply to the rectified voltage form, a mathematical model was developed to calculate the rectified voltage taking into account the mains supply characteristics.

Taking into account system's unsinusoidality the three-phase system of mains supply voltage is determined by:

$$u_A = \sum_{i=1}^{\infty} u_{A(i)}; u_B = \sum_{i=1}^{\infty} u_{B(i)}; u_C = \sum_{i=1}^{\infty} u_{C(i)} \quad (1)$$

where $u_{A(i)}, u_{B(i)}, u_{C(i)}$ – instantaneous values of the mains supply phases voltage for the i -th harmonic component..

Hence the voltages supplying the valve arms of ring circuit is [6], [7], [8]:

$$u_{AW_1} = K_T \cdot u_A; u_{BW_1} = K_T \cdot u_B; u_{CW_1} = K_T \cdot u_C; \quad (2)$$

$$u_{AW_2} = \frac{K_T}{\sqrt{3}} \cdot (u_A - u_B); u_{BW_2} = \frac{K_T}{\sqrt{3}} \cdot (u_B - u_C); u_{CW_2} = \frac{K_T}{\sqrt{3}} \cdot (u_C - u_A), \quad (3)$$

where K_T – transformer ratio [3].

To determine the rectified voltage instantaneous values of the concerned rectifier, it is possible to divide the rectifying process into two steps, and so the rectified voltage of the entire converter is defined as the sum of the rectified voltages of each steps shifted to the correspond phase angle [8], [9]:

$$u_{d0} = u_{d01} + u_{d02} \quad (4)$$

where:

$$U_{d01} = \begin{cases} |u_{AW1} - u_{BW1}| \text{ есл } |u_{AW1} - u_{BW1}| > |u_{AW1} - u_{CW1}| \wedge |u_{AW1} - u_{BW1}| > |u_{CW1} - u_{BW1}| \\ |u_{AW1} - u_{CW1}| \text{ есл } |u_{AW1} - u_{CW1}| > |u_{AW1} - u_{BW1}| \wedge |u_{AW1} - u_{CW1}| > |u_{CW1} - u_{BW1}| \\ |u_{CW1} - u_{BW1}| \text{ есл } |u_{CW1} - u_{BW1}| > |u_{AW1} - u_{CW1}| \wedge |u_{CW1} - u_{BW1}| > |u_{AW1} - u_{BW1}| \end{cases},$$

$$U_{d02} = \begin{cases} |u_{AW2} - u_{BW2}| \text{ есл } |u_{AW2} - u_{BW2}| > |u_{AW2} - u_{CW2}| \wedge |u_{AW2} - u_{BW2}| > |u_{CW2} - u_{BW2}| \\ |u_{AW2} - u_{CW2}| \text{ есл } |u_{AW2} - u_{CW2}| > |u_{AW2} - u_{BW2}| \wedge |u_{AW2} - u_{CW2}| > |u_{CW2} - u_{BW2}| \\ |u_{CW2} - u_{BW2}| \text{ есл } |u_{CW2} - u_{BW2}| > |u_{AW2} - u_{CW2}| \wedge |u_{CW2} - u_{BW2}| > |u_{AW2} - u_{BW2}| \end{cases}.$$

Equations (1) - (4) represent a mathematical model that allows to calculate the rectified voltage instantaneous values as a function of the supply network's nonsinusoidal voltage. The mathematical model is implemented in the MathCad software package, and it is obtained graphs of rectified voltage's behaviour under condition of supply voltage curve's fifth harmonic different levels, which are shown in Fig. 2.

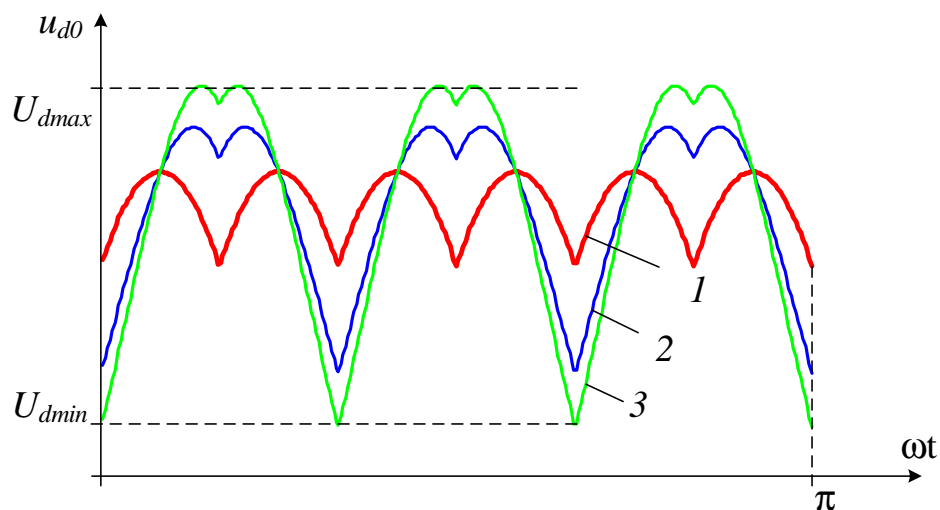


Figure 2. The rectified voltage under the conditions of: power supply sine voltage (1), 5-th harmonic – 4% (2), 5-th harmonic – 6% (3).

Figure 2 shows that the rectified voltage's quality of the twelve-pulse rectifier decreases with fifth harmonic increasing of the supply voltage curve [10].

As a part of the study, a physical analogue of a twelve-pulse rectifier was simulated to check the mathematical modeling results, and also a graphs of rectified voltage were constructed, that Fig. 3 shows. In addition, the parameters of the three-phase supply network were measured.

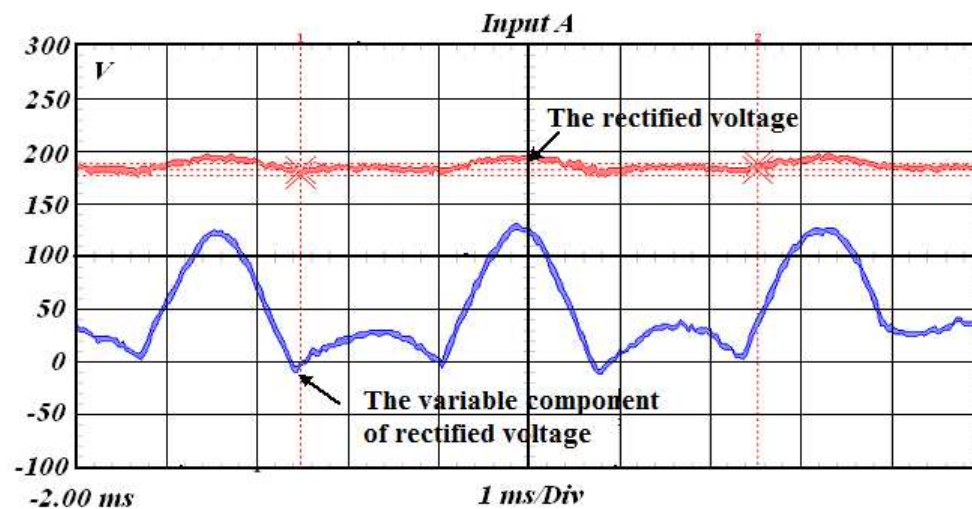


Figure 3. Oscillogram of a twelve-pulse rectifier's voltage

When the harmonic components' measured values of the supply voltage are substituted into the mathematical model, and the asymmetry conditions of the three-phase voltage system derived from the estimated data are created, the rectified voltage waveform corresponds to the mathematical model. The voltage curves shapes of the converter's output, which are obtained both theoretically and experimentally, have a precision in the range of 5%. Having regard to the above, it is fair to say that the obtained results of such mathematical model give an adequate valuation of the rectifying action quality.

3. Conclusion

Thus, the efficiency of using twelve-pulse rectifiers has been proved. Based on such circuit solution, a mathematical model for calculating the rectified voltage and a physical model for verifying the reliability of the results were developed. The forms of rectified voltages in both models are identical to each other and have good convergence, and therefore it is possible to make a rectification quality estimate.

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