Mathematical Model of Operability of a Single-phase Bridge Rectifier

Andrey Puzakov, Andrey Arhirejskij
Orenburg State University, Orenburg, Russian Federation andrew78@yandex.ru

GOAL OF THE STUDY

Rectifiers are widely used to convert alternating current to direct current. During operation rectifier voltage changes both under the influence of external factors (temperature) and due to degradation of semiconductor crystal. The task of determining the technical state of the rectifier (the presence and the stage of faults development) based on monitoring of its parameters is actual.

The purpose of this article is to develop a mathematical model of performance of the single-phase bridge rectifier. Mathematical model of the rectifier performance makes a connection between values of input (input voltage $U_2$), output (current rectifier $I_d$ and rectifier voltage $U_d$) and disturbing parameters (ambient air temperature $\tau$).

$$U_d = f(U_2, I_d, r_d(\tau))$$


Diode failures can be confined to the open-circuit fault (the resistance is equal to infinity at any polarity of applied voltage) (Fig. 1) and short circuit (the resistance equals zero at any polarity of applied voltage).

DIODE OPEN-CIRCUIT SIMULATION

Let’s consider the case of the open-circuit fault of one of the diodes in the single-phase bridge rectifier. To simulate the condition of this fault, a variable resistor is connected in series with the diode, critical value of the resistance of which will lead to cessation of the current flowing.

Analytically, the no-load voltage of the rectifier when one of the diodes breaks down can be represented as a sum of two summands corresponding to two half-periods of the rectifier operation:

$$U_{d1} = \frac{\sqrt{2}}{\pi} \cdot U_2 - 2 \cdot U_0$$
$$U_{d2} = \frac{\sqrt{2}}{\pi} \cdot U_2 - 2 \cdot U_0 \cdot \frac{r_{rev}}{r_{rev} + R}$$

where $r_{rev}$ – diode resistance in reverse direction, $\Omega$: $R$ – additional resistance included in series with the diode, $\Omega$: $U_0$ – threshold voltage of diode, $V$.

When the load is connected, the situation changes, in which case the rectifier voltage during breakdown of one of the diodes can be represented as an expression

$$U_{d1} = \sqrt{2} \cdot U_2 - 2 \cdot U_0 \cdot (1 - \frac{2r_d}{2r_d + R_L})$$
$$U_{d2} = \sqrt{2} \cdot U_2 - 2 \cdot U_0 \cdot (1 - \frac{2r_d + R}{2r_d + R_L + R})$$

where $R_L$ – load resistance, $\Omega$.

Fig. 2 shows the load characteristics of a single-phase rectifier when simulating the open circuit diode. Intersection of characteristics with line of the complete open circuit of one of the diodes is explained by the non-ideal current source (generator), the voltage of which decreases with increasing load current.

With an infinite power current source, the lines corresponding to the parallel open circuit would be located between the characteristics of fault-free two-half-period rectifier and one-half-period rectifier (complete open circuit of one of the diodes).

The diode resistance varies either when the temperature changes or when faults occur. Considering the temperature correction by comparing the input $U_2$ and output $U_d$ voltages of rectifier, it is possible to determine the nature and condition of faults of diodes.

CONCLUSIONS

Diode failures can be confined to the open-circuit fault (the resistance is equal to infinity at any polarity of applied voltage) and short circuit (the resistance equals zero at any polarity of applied voltage). The task for determining technical condition of the rectifier (presence and condition of faults) is related to its parameters.

To simulate the diode breakdown, a variable resistor is connected in series with the diode, critical value of the resistance of which will lead to cessation of the current flowing. It was found that output voltage of the rectifier at no-load operation is determined by value of the reverse resistance of diodes. If the rectifier works under load, its voltage is determined by ratio of the diode resistance to total resistance of the rectifier circuit.

Short circuit is simulated by the bridging the diode. The resistor connection in parallel with a diode is equivalent to a short circuit in its effect on rectifier operation, but it is not (pseudo-circuit). Only a complete short circuit can be implemented.

The general model of the single-phase bridge rectifier is presented. Diode resistance varies either when the temperature changes or when faults occur. Considering the temperature correction by comparing the input $U_2$ and output $U_d$ voltages of rectifier, it is possible to determine the nature and condition of faults of diodes.