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Mathematical Model of Operability of a Single-phase Bridge Rectifier

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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 $U2$), output (current rectifier I_d and rectifier voltage U_d) and disturbing parameters (ambient air temperature t).

$$U_d = f(U2, I_d, r_d(t))$$

where U_d – output voltage of the rectifier, V; $U2$ – alternate voltage at the rectifier inlet, V; I_d – load current of the rectifier, A; r_d – electrical resistance of the rectifier diodes (dependent on temperature), Ω.

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).

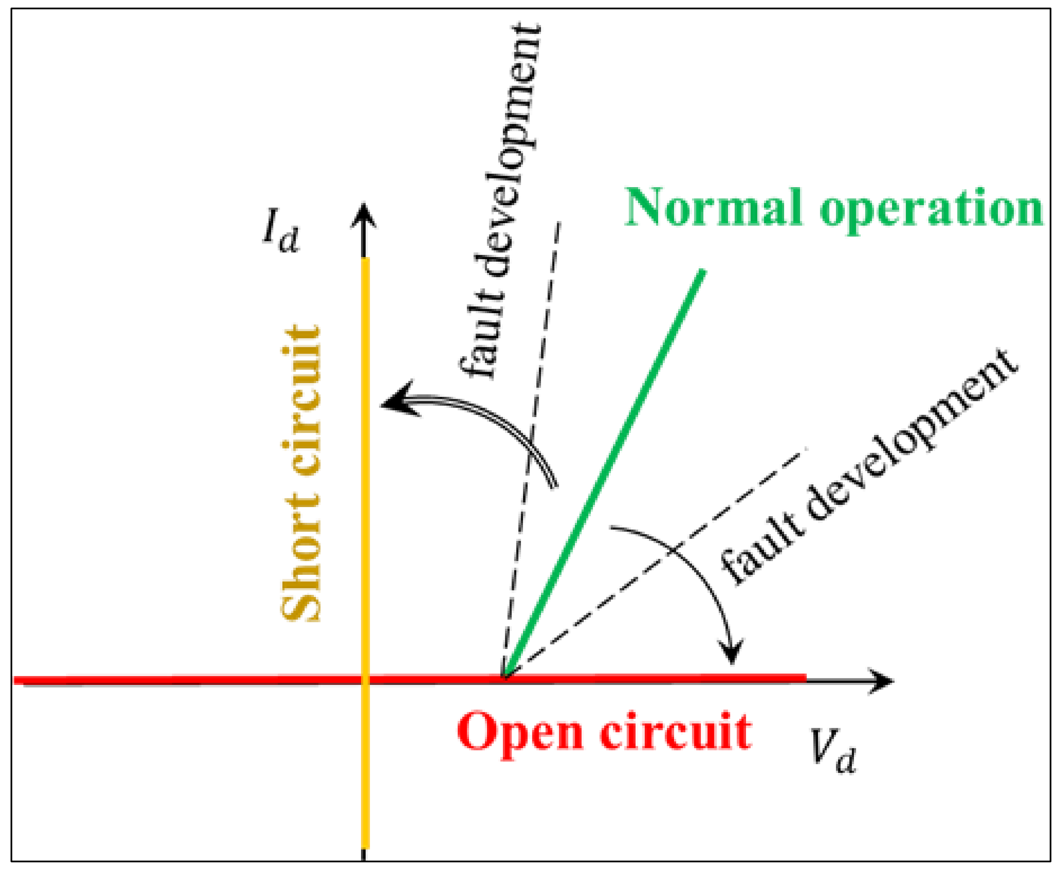


Fig. 1. Voltampere characteristics of the diode when faults occur

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:

$$\begin{cases} U_{d1} = \frac{\sqrt{2}}{\pi} \cdot U2 - 2 \cdot U_0 \\ U_{d2} = (\frac{\sqrt{2}}{\pi} \cdot U2 - 2 \cdot U_0) \cdot \frac{r_{rev}}{r_{rev} + R} \end{cases}$$

where r_{rev} – diode resistance in reverse direction, Ω; R - additional resistance included in series with the diode, Ω, 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

$$\begin{cases} U_{d1} = (\frac{\sqrt{2}}{\pi} \cdot U2 - 2 \cdot U_0) \cdot (1 - \frac{2r_d}{2r_d + R_L}) \\ U_{d2} = (\frac{\sqrt{2}}{\pi} \cdot U2 - 2 \cdot U_0) \cdot (1 - \frac{2r_d + R}{2r_d + R_L + R}) \end{cases}$$

where R_L – load resistance, Ω.

Fig. 2 shows the load characteristics of a single-phase rectifier when simulating the diode open circuit. 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 partial 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).

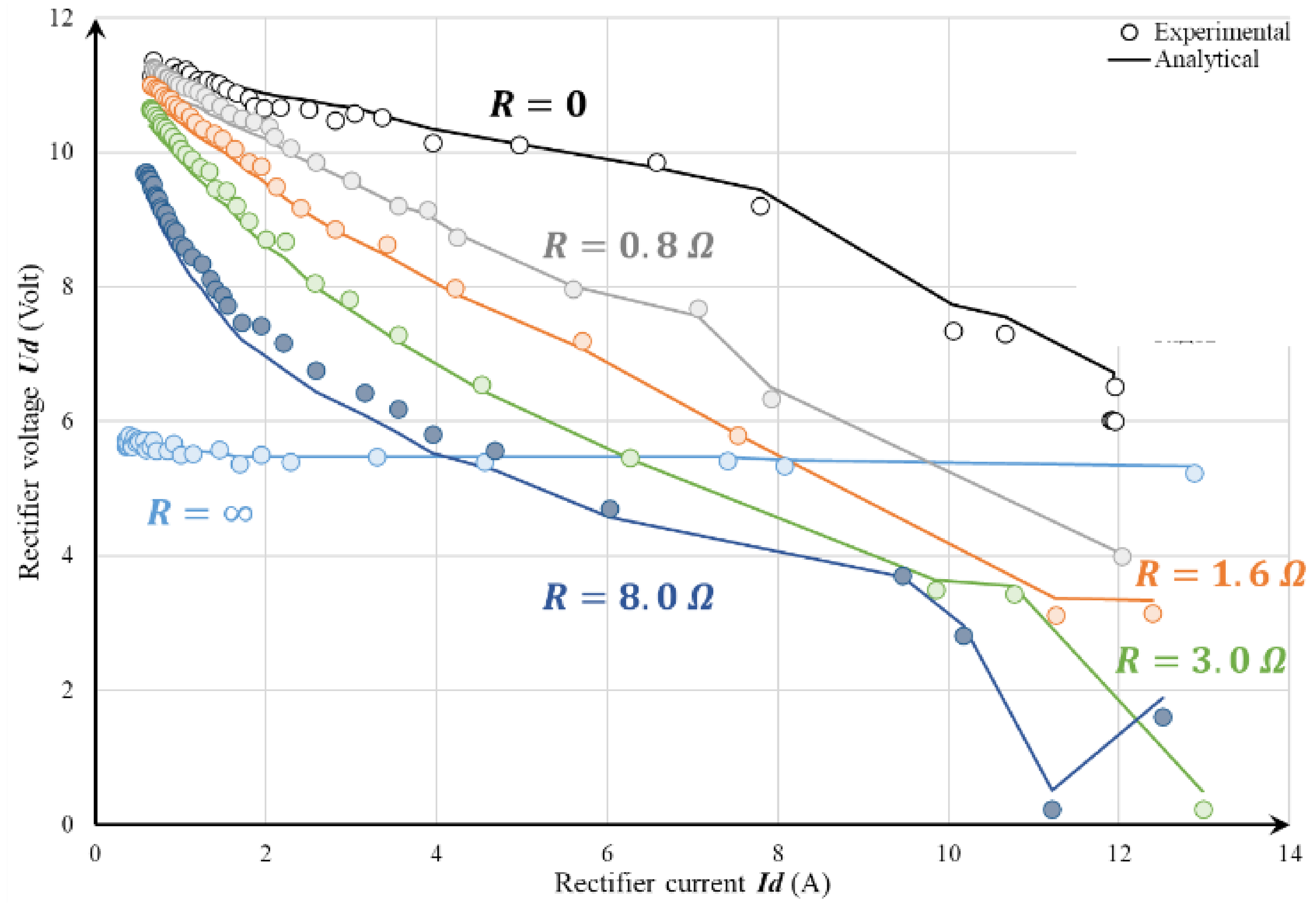
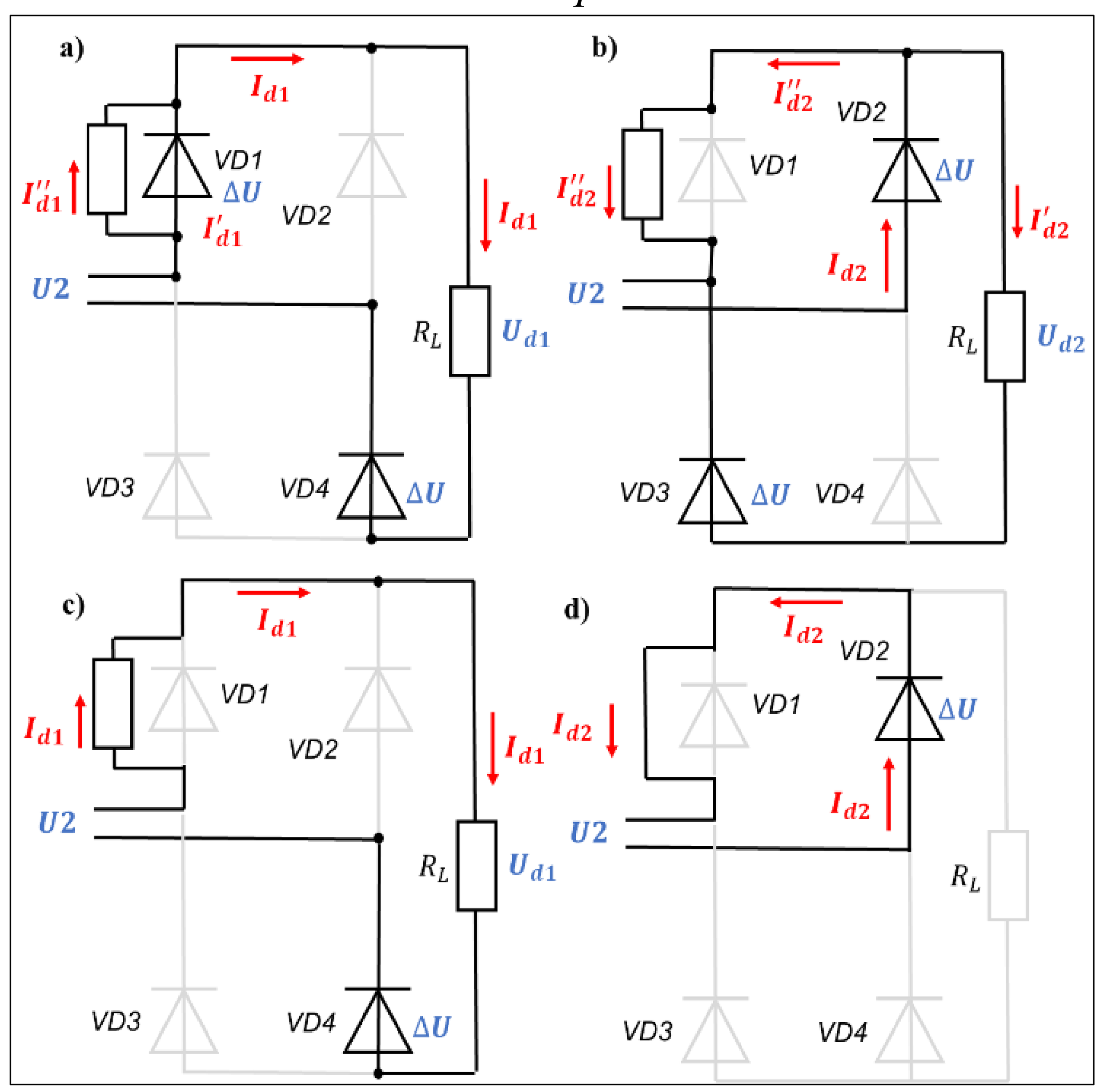


Fig. 2. Load characteristics of a single-phase rectifier when simulating the open circuit diode

THE DIODE SHORT CIRCUIT

Let's consider the case of short circuit of one of the diodes in the single-phase bridge rectifier. Simulation of condition of this fault cannot be implemented in practice since it is necessary not only to reduce the resistance of one of the diodes (for example, by parallel connection of low-ohmic resistor), but also to ensure the flow of current in one direction.

If we are limited to switching on the resistor, then in the first half-period the current will pass through the diode and the parallel resistor, and then through the load and (**Fig. 3**, a). However, in the second half-period (**Fig. 3**, b) some of the current will again go through this resistor ignoring the load. In terms of its effect on operation of the rectifier and the current source, this mode is equivalent to a short circuit, but it is not. This mode can be called a *pseudo-circuit.*



a) First half-period (partial pseudo-circuit); b) Second half-period (partial pseudo-circuit); c) First half-period (complete short circuit); d) Second half-period (complete short circuit)

Fig. 3. Rectifier operation when simulating the short circuit of one of the diodes

Therefore, in practice it is possible to implement only a complete short circuit of one of the diodes by shunting its outputs (**Fig. 3**, c, d).

Rectifier voltage at complete short-circuit of one of the diodes can be represented as an expression

$$\begin{cases} U_{d1} = (\frac{\sqrt{2}}{\pi} \cdot U2 - 2 \cdot U_0) \cdot (1 - \frac{r_d}{r_d + R_L}) \\ U_{d2} = 0 \end{cases}$$

Thus, the generalized model of the single-phase bridge rectifier performance under load can be represented as

$$U_d = (\frac{\sqrt{2}}{\pi} \cdot U2 - 2 \cdot U_0) \cdot (1 - \frac{2r_d(t)}{2r_d(t) + R_L})$$

Diode resistance varies either when the temperature changes or when faults occur. Considering the temperature correction by comparing the input $U2$ 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) based on monitoring of its parameters is relevant.

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 performance is presented. Diode resistance varies either when the temperature changes or when faults occur. Considering the temperature correction by comparing the input $U2$ and output U_d voltages of rectifier, it is possible to determine the nature and condition of faults of diodes.