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ALGORITHMS OF FAULT-TOLERANT CONTROL OF SWITCHED-RELUCTANCE DRIVE

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The research of fault-tolerant control of a switched-reluctance drive operating in emergency modes is very urgent owing to additional requirements to technical equipment that is integrated in various dangerous facilities such as nuclear, military, chemical, medicine, transport, petroleum etc. The article focuses on the modern switched-reluctance electric drive (SRD) which is very promising and gaining in popularity in industrial applications. Malfunction of the equipment and large-scale economic losses occur in the case of emergency mode of an electric drive. Nowadays it is necessary to improve reliability and fault-tolerance of electric drives. The increased requirements to fault-tolerant control of electric drives lead to the necessity to design some special control algorithms with full or partial functional recovery abilities. Thus, the problem associated with the design of fault-tolerant control algorithms of switched-reluctance drive is the purpose of this article.

In general case the control of switched-reluctance drive is carried out by series connection of phases on the basis of the position sensor signals. Herewith the overlap of angles of phases is absent and the commutation control is carried out as shown in Fig. 1.

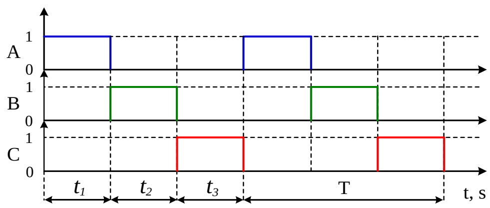

Fig. 1. Commutation control diagram under symmetric single switching of phases.

Figure 1 shows: A, B, C –indices of phases; t_1, t_2, t_3 – phase commutation time intervals for each phase; T – commutation period.

Instantaneous assignments for phase currents values I_A, I_B, I_C in SRD are formed by equations (1):

$$\begin{aligned} I_A &= I_\omega[1 + sign(\varphi(i_A, \alpha) - \varphi(t)]; \\ I_B &= I_\omega[1 + sign(\varphi(i_B, \alpha) - \varphi(t)]\,; \\ I_C &= I_\omega[1 + sign(\varphi(i_C, \alpha) - \varphi(t)], \end{aligned} \qquad (1)$$

where I_ω -value of the amplitudes of formed phase currents; α –electrical rotor angle in radians; $\varphi(i, \alpha)$ – the value of the formed angle for each phase; $\varphi(t)$ – instantaneous angle value from rotor position sensor. The diagrams below (Fig. 2, 4-7) illustrate the number of operating motor phases m = 3, 2, 1 in the course of the drive operational resource expiration . On the top of the diagram i_{set} (r.u) the instantaneous phase currents diagram i_A,i_B, i_C and their averages values $i_{A\,av}$,$i_{B\,av}$,$i_{C\,av}$ are shown.

It is obvious from the switched-reluctance motor design that all phases are electrically independent. It means that in the case of emergency, such as loss of phase, the reduction of the electric power resource will be 1/3 under the losses of each phase. Fig.2 shows the timing diagram of three-phase switched-reluctance drive operational resource expiration. There is a reduction of rotation frequency till 66% in two-phase mode, and at the one-phase mode the motor gradually stops. The diagram in Figure 2 presents the initial parameters of the drive fault-tolerant operation.

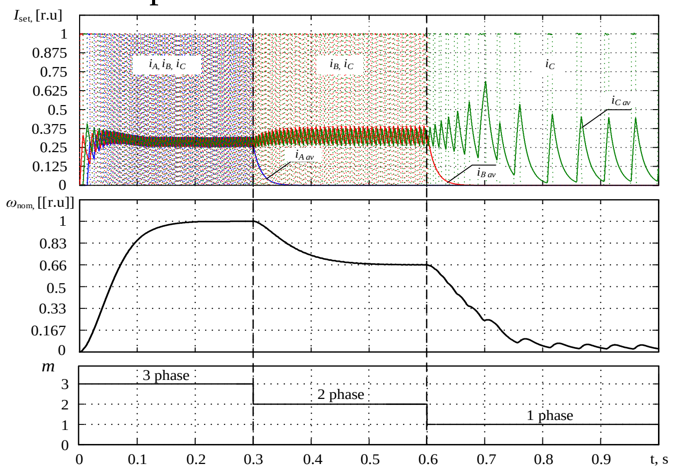

Fig. 2. Timing diagram of three-phase switched-reluctance drive operational resource expiration

Further improvement of fault-tolerance can be carried out using special fault-tolerant control algorithms of switched-reluctance drive by activation of functional backup by means either increasing phase currents amplitudes or increasing phases overlap angles or both of them.

In this case, the commutation of phases is carried out in series with overlapping phases as shown in Figure 3.

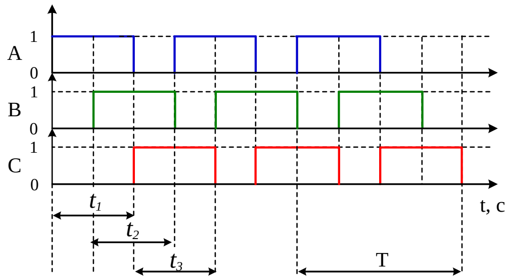

Fig. 3. Commutation control diagram under nonsymmetrical switching of phases.

Figure 3 shows: A, B, C –indexes of phases; t1, t2, t3 – phase commutation time intervals for each phase; T – commutation period. Instantaneous assignments for phase currents values I_A, I_B, I_C in SRD are formed by equations (2):

$$\begin{aligned} I_A &= I_\omega \overline{a}\,[1 + sign(\varphi(i_A,\alpha) - \varphi(t) + d\alpha_\text{к}]; \\ I_B &= I_\omega \overline{b}[1 + sign(\varphi(i_B,\alpha) - \varphi(t) + d\alpha_\text{к}]; \\ I_C &= I_\omega \overline{c}\,[1 + sign(\varphi(i_C,\alpha) - \varphi(t) + d\alpha_\text{к}], \end{aligned} \quad (2)$$

Fig. 4 presents the timing diagram of exhaustion the operational resource of three-phase switched-reluctance drive using the changing phases overlap angles algorithm (instead of symmetric single switching of phases**)** under emergency mode.

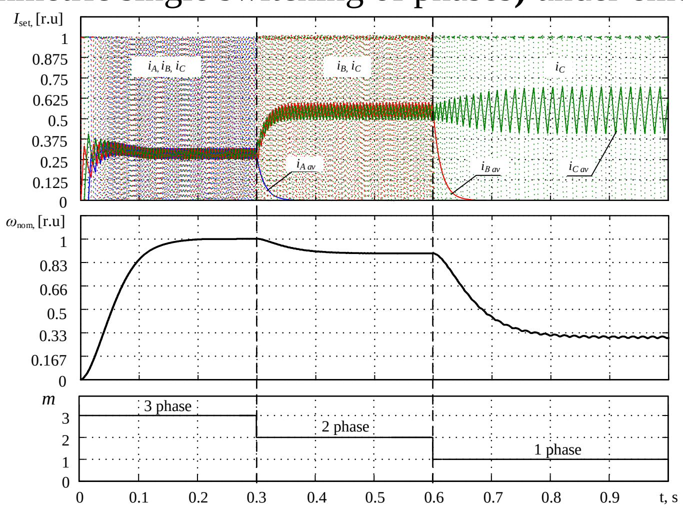

Fig. 4. Timing diagram of exhaustion the operational resource of three-phase switched-reluctance drive with using in emergency mode the changing phases overlap angles algorithm

If *m* = 3 (Fig. 4) all phases are operational, if *m* = 2 the motor operates in two-phase mode, if *m* = 1 motor breaks down and in case of residual inertia of mechanism it may continue to operate on the one remaining phase (if there are minimum 2 poles per phase).

In nonsymmetrical switching of phases in case of failure the rotation frequency level is equal to 90 % in two-phase mode and 32% in one-phase mode. In all remained operational phases there is active power compensation which increases by 1.5 times.

Now it is necessary to consider fault-tolerant control algorithm of three-phase SRD with increasing phase currents amplitude.

Instantaneous assignments for phase currents values I_A, I_B, I_C in SRD are formed by equations (3):

$$\begin{aligned} I_A &= I_\omega \overline{a} k_d [1 + sign(\varphi(i_A, \alpha) - \varphi(t)]; \\ I_B &= I_\omega \overline{b} k_d [1 + sign(\varphi(i_B, \alpha) - \varphi(t)]; \\ I_C &= I_\omega \overline{c} k_d \, [1 + sign(\varphi(i_C, \alpha) - \varphi(t)], \end{aligned} \qquad (3)$$

where I_ω – value of the formed phase currents amplitudes; α – electrical rotor angle in radians; $\varphi(i,\alpha)$ – value of the formed angle for each phase; $\varphi(t)$ – instantaneous angle value from rotor position sensor; k_d – coefficient Figure 5 shows the timing diagram of exhaustion the operational resource of three-phase switched-reluctance drive using the algorithm of increasing phase current amplitude in emergency mode.

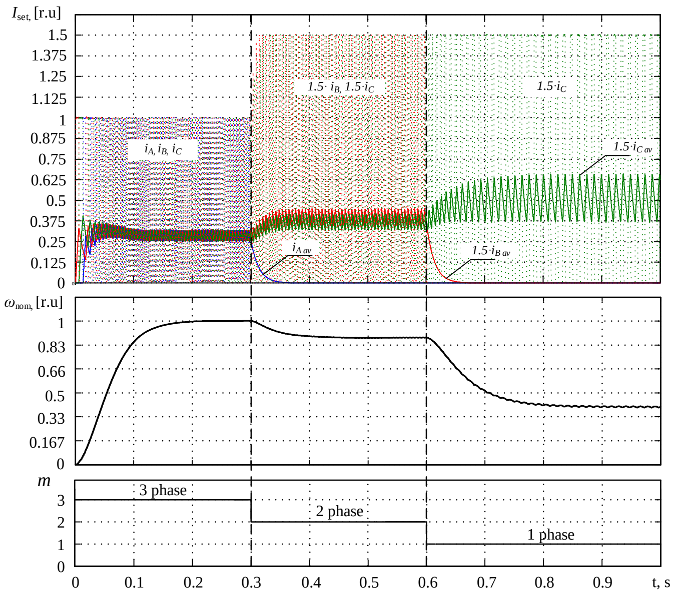

Fig. 5. Timing diagram of exhaustion the operational resource of three-phase switched-reluctance drive with using in emergency mode algorithm of increasing phase currents amplitude

If m = 3 (Fig. 5) all phases are operational, if m = 2 the motor operates in two-phase mode, if m = 1 motor breaks down. In case of using fault-tolerant control algorithm with increasing phase current amplitude in the case of failure the rotation frequency level is equal to 89 % in two-phase mode and 41% in one-phase mode. Currents in all remained operational phases increase by 1.5 times and it is leads to the active power compensation.

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ASSOCIATED PETROLEUM GAS TREATMENT

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Introduction

Associated petroleum gas (APG) is a form of natural hydrocarbon gas found with deposits of petroleum either dissolved in oil or presented in oil and gas-condensate fields. The volume of APG can vary from one to several thousand cubic meters. [1]

APG is a by-product of oil extraction. Russia, Saudi Arabia, USA are the leading countries possessing large oil deposits. Therefore, the issue concerning associated petroleum gas treatment is very topical in the Russian Federation. [2]

The reason for incomplete APG utilization is the substandard infrastructure and the composition of casing-head gas. [4].

Results and Discussions

Due to the necessity of gas treatment and its processing the scheme for associated gas preparation for small and medium size fields utilizing gas-piston installation aimed at production electrical and thermal energy was developed.

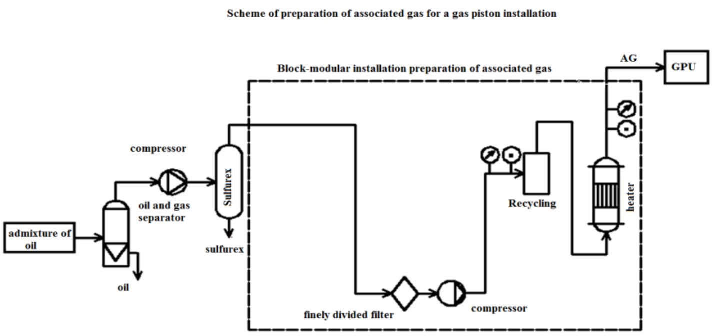

Fig. 1. Scheme of associated gas preparation for a gas piston installation