PROTECTION OF SUBMERSIBLE MOTORS FROM OPEN-PHASE OPERATING MODES

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ABSTRACT

Results of research of operational reliability and way of further improvement of protection devices of submersible motors from open-phase operating modes have been represented. Efficiency of maintenance of trouble-free operation of submersible motors has been revealed at breakage of mains supply phases. Fundamentally new method of protection of electric motors from breakage of phases has been proposed and for the first time the possibility of application of protective - switching device based on this method has been proved.

Keywords: protection, submersible, motors, phases, switching.

I. INTRODUCTION

It is known that breaks in supply of the electric power because of failures and off-schedule switching-off result in infringement of technological processes, failure of electric motors and great expenses for their repair, losses of production and finally in great moral and material damage.

Centrifugal borehole pumps with submersible motors have been widely applied for supply of water from the chinks. Installations with submersible motors have certain advantages as compared with other types with an engine mounted on a surface.

Operating experience and results of numerous researches, including that of the author, show that despite of development and manufacturing application of some concrete recommendations on increase of operational reliability of submersible electric pump installations, their reliability level still remains low.

The analysis of various researches has allowed to also reveal that such low operational reliability of submersible electric pump installations, is, basically caused by often failure of submersible electric motors. The reason is frequent emergency operation modes of submersible motors, which basically concerns to malfunctions in electric network, lack of reliable protection from open-phase operating modes and proper care of installation, as well as specificity of their operational conditions. Particularly big damage from operating modes in agriculture concerns to operation of submersible electric pumps, which are territorially scattered and switching-off of which results in the technological process termination [1, 2].

II. MAIN PART

Hence, support of the incorporated reliability level of electric pumps is rather difficult, but a task to be decided. Therefore, development and introduction of reliable accident protection devices of electric motors from breakage of phases with maintenance of their trouble-free work is of large economic value.

Conducted researches have planned a way of the further development and improvement of accident protection devices of submersible motors from open-phase operating modes. It appeared that not only switching-off, but also maintenance of trouble-free work of submersible motors in the most often and dangerous emergency operation modes in an agriculture - at breakage of phases of mains supply is expedient.

To achieve this purpose we have developed essentially new method of protection of electric motors from breakage of phases has been developed and for the first time the possibility of application of protective - switching device (PSD) based on this method [3] has been proved.

This method allows to control current on amplitude in all three phases, and as the initial information describing values of currents in controllable phases, to apply comparison of three electric values on amplitude of continuous action.

Block diagram of PSD, constructed on the basis of the stated principles and satisfied their requirements, has been shown on fig. 1.

The circuit contains the following elements: transforming element TE, rectifiers B, circuit of comparison CC, reacting body RO and switching device PU.

The forming elements included in the three-phase power supply system of electric motor, controls a current of load in all its phases and form loadings of electric motor EDS E_1, E_2 and E_3, proportional to a current, which are straightened by rectifier bridges and goes to the comparison circuit.

At normal operation of electric motor rectified voltages brought to the comparison circuit, are identical on absolute value and mutually counterbalanced. Thus on at the output of comparison circuit there is no signal (voltage), and there is no signal (voltage) on agencies either.

In case of arising of open-phase operating modes the balance of voltages in the comparison circuit is broken and in executive organ of corresponding(broken) phase a current occurs which influences the turning on of device and switches on phase-displacing capacities to the broken phase. Thus, the electric motor is changed to a single-phase operating mode. It is important that thus there is no dangerous superheating of stator winding.

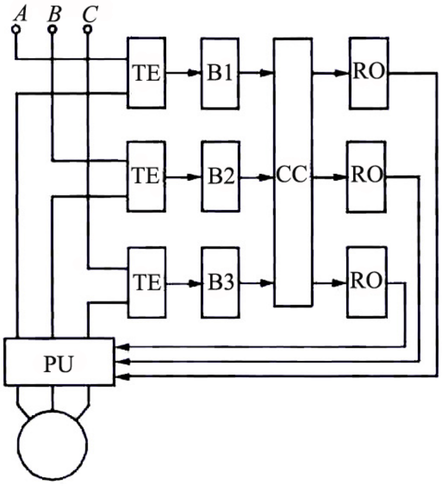

Fig. 1. The circuit diagram of protective-switching devices.

As is already mentioned above, for correct estimation of operating mode of electric motor it is necessary to control electric values in all three phases. Therefore, in the given circuit a purpose of forming element is to create three EMF from three-phase system proportionally to engine load currents. $\dot{E}_1, \dot{E}_2$ and $\dot{E}_3$, which are equal each other on absolute value at normal operation of electric motor.

A control of load of electric motors using voltage transformer is inexpedient, since it is impossible to control engine load on phase voltage.

Hence, $\dot{E}_1, \dot{E}_2$ and $\dot{E}_3$ should be transformed on current values. Transformation of EMF $\dot{E}_1, \dot{E}_2$ and $\dot{E}_3$ can be also made by different ways: using transreactors, ferrite rings or three current transformers. On fig. 2 the way of transformation of phase currents in EMF (voltages) $\dot{E}_1, \dot{E}_2$ and $\dot{E}_3$ using method of three current transformers is shown.

The primary winding of each of measuring current transformers is connected to the corresponding phase of the electric motor's power supply. In secondary winding of the transformers EMF $\dot{E}_1$, $\dot{E}_2$ and $\dot{E}_3$ are formed and voltage with a set ratio (1) - (3) on value of the brought current.

$$\dot{U}_1 = K_1 \dot{I}_A; \qquad (1)$$

$$\dot{U}_2 = K_2 \dot{I}_B; \qquad (2)$$

$$\dot{U}_3 = K_3 \dot{I}_C; \qquad (3)$$

Where $\dot{U}_1$, $\dot{U}_2$, $\dot{U}_3$ - are compared voltages $\dot{I}_A$, $\dot{I}_B$, $\dot{I}_C$ - phase currents of mains line; K_1, K_2, K_3 - complex factors conducted using intermediate current transformers. In our case (depending on requirements to protective device) $K_1 = K_2 = K_3$.

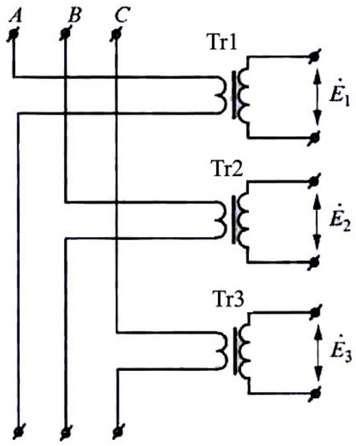

Fig. 2. Formation of values $\dot{E}_1$, $\dot{E}_2$ and $\dot{E}_3$ using method of three current transformers.

Amplitudes of values $\dot{E}_1, \dot{E}_2$ and $\dot{E}_3$ allow to control a load of the electric motor.

At breakage of one of phases of mains line the current in primary winding of the intermediate transformer equals to zero and in secondary winding EMF also equals to zero respectively. Voltage balance is broken, and at the output of the circuit of comparison depending on the broken phase there is a corresponding voltage which is sufficient for RO operation. So, at breakage of phase A, i.e. at $\dot{U}_1$ = 0,

$$U_{out1} = |\dot{U}_3| - |\dot{U}_1| = |\dot{U}_3|; \qquad (4)$$

At breakage of phase B, i.e. at $\dot{U}_2$ = 0, and

$$U_{вых2} = |\dot{U}_1| - |\dot{U}_2| = |\dot{U}_1|; \qquad (5)$$

At breakage of phase C, i.e. at $\dot{U}_3$ = 0,

$$U_{вых3} = |\dot{U}_2| - |\dot{U}_3| = |\dot{U}_2|. \qquad (6)$$

So, each RO operates only at damage on the certain phases. Such property of RO is called selectivity [4].

PSD circuit has been created based on theoretical researches and the analysis of principles of creation phase-sensitive circuits [5].

On fig. 3 the circuit diagram of phase-sensitive semi-conductor PSD for automatic translation of submersible motor into the single-phase operating mode at breakage of the phase is given.

The circuit consists of three identical intermediate transformers of current T_{r1}, T_{r2}, T_{r3}, forming auxiliary voltage proportionally to the load current of electric motor $\dot{U}_1$, $\dot{U}_2$, $\dot{U}_3$, three rectifying bridges *B1*, *B2*, *B3* with smoothing condensers *C1*, *C2*, *C3*, ballast resistors R_1, R_2, R_3, on the side of the rectified current, three diodes *D1*, *D2*, *D3*, three relays *P1*, *P2*, *P3* and two working capacities *C4*, *C5*.

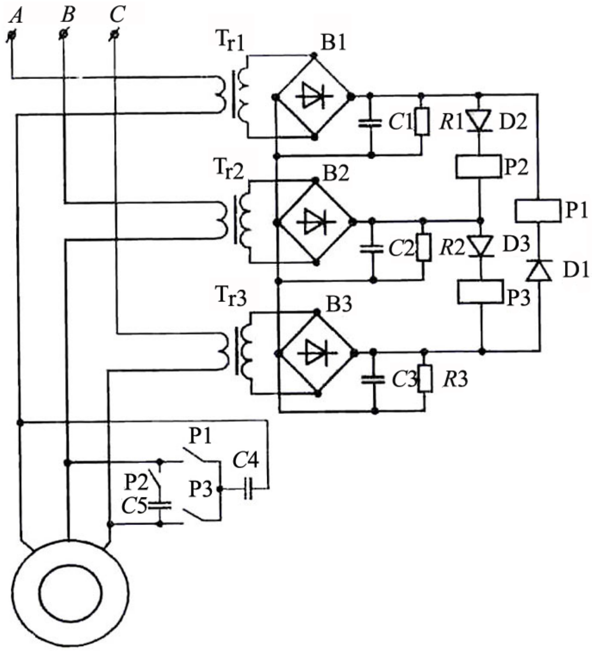

Fig.3. The circuit diagram of phase-sensitive semiconductor PSD .

Ballast resistors R_1, R_2, R_3 in the circuit shunt rectifiers and form a contour with small resistance through which a current via PO passes, besides the rectifiers giving big resistance for reversed direction currents.

The operating principle of the developed device is based on comparison of absolute values of three electric values (voltage) in pairs.

At normal operating mode of the electric motor working phase currents, passing through intermediate transformers of the current, form three auxiliary voltage $\dot{U}_1$, $\dot{U}_2$, $\dot{U}_3$, proportional passing current. These voltages of the alternating current are rectified rectifying bridges *B1*, *B2*, *B3* and are compared on value on voltages balance. In the normal mode the rectified voltage are counterbalanced in pairs, and there is no voltage on RO .

In case of loss of one of any phases voltages balance is broken, RO of broken phase operates and switches on broken phase of electric motor through a condenser to corresponding phase by its contact. Thus, the electric motor automatically goes into the single-phase operating mode and does not fail, and continues to work with a reduced power due to which the technological process provided by this electric motor does not interrupt that is of great importance for consumers. The device is simple on by the design and reliable in use. Depending on the requirements for PSD, it can operate only for switching-off at breakage of phase with revealing the broken phase that allows to quickly remove appeared malfunction.

The specified device can be mounted at the submersible electric pumps control and protection station.

Key parameters of PSD circuit elements are selected based on below-mentioned technique: characteristics of the circuit and first of all dependence of a target signal from input are influenced by ratio of internal resistance of sources, RO load resistance and circuit diodes characteristics. The account of all these factors allows to establish optimum ratios, at which the target signal possesses the greatest value at the minimal consumption of power by the proposed circuit.

It is expedient to select the elements parameters of the circuit in the following sequence. The type of reacting body with the corresponding value of resistance of relay coil R_n and operation voltage U_n is selected. At a preset value of operation power of RO S_n the value of ballast resistors R_b of the branches of PSD circuit providing minimum possible consumption of capacity of the circuit is determined. To select ballast resistors it is necessary to investigate conduct of the circuit in various modes: at normal work and open-phase modes. It is necessary to take advantage of the dependences connecting values of power consumption with ballast resistance. Thus, consumption of the circuit in open-phase mode is taken as the most essential one.

Dependences between power consumption and resistance of ballast resistors $S_n = f(R_b)$ at open-phase modes are shown on fig. 4. Curves 1, 2 and 3 are taken off at different load values resistance – $R_{n1} < R_{n2} < R_{n3}$. As is obvious from curves, the ballast resistors value corresponds to each load values resistance, at which minimum possible power consumption of the circuit is provided, reaching its minimum in the points *A*, *B* and *C*. For example, on the curve 1, taken off at R_n = 300 Ohm in the point *A*, optimum value of the ballast resistor R_b = 210 Ohm. Further increase or reduction of R_b causes increase in power consumption of the circuit.

Placing value of the maximum possible power consumption of the circuit on an axis of ordinates , we obtain optimum value of the ballast resistor R_b , in which an electromagnetic relay at emergency operation - breakage of phase will be reliably operate.

Correct selection of equivalent resistance of the circuit at known value of ballast resistors R_b does not cause the imbalance current in reacting body.

To determine power of the ballast resistor, it is necessary to know a value of the current I_b passing through it. In the normal operating mode at on all ballast resistors the current I_b identical on value flows. Normal operation mode whereas the voltages proportional to load current are continuously applied to the circuit are defining for selection of powers of ballast resistors R_b.

Power of ballast resistors R_b is selected according to the known expression

$$I_b^2 R_b \le P \qquad (7)$$

where I_b is the current flowing through the ballast resistor in the normal mode; R_b is the ballast resistor resistance; P - rated power of the resistor.

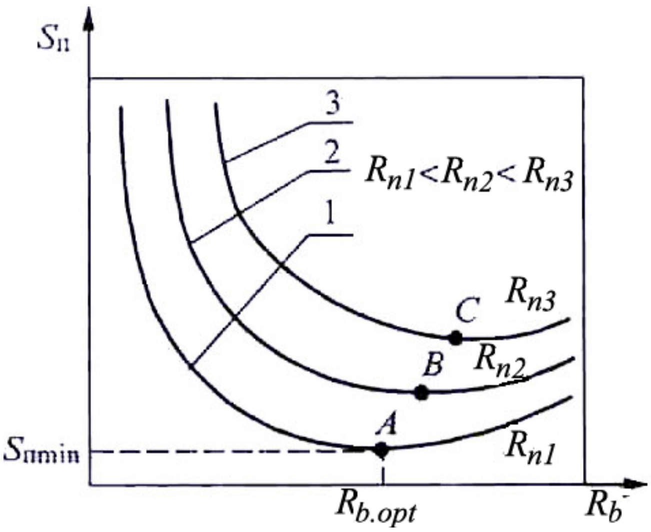

Fig. 4. Dependence of change of power consumption of the circuit on value of ballast resistors in open phase modes: 1 - at R_{n1}; 2 - at R_{n2}; 3 - at R_{n3}

Selection of corresponding type of the gate is connected with EMF. E_1, E_2 and E_3, level of which in this case is limited by consumption of the circuit.

In all cases long - continued direct current I_o of the gate should meet the requirement

$$I_o \leq K_r I_{d.m}\ , \qquad (8)$$

and reverse voltage

$$U \leq K_r U_{rem.m}\ , \qquad (9)$$

where $I_{d.m}$ - the maximal direct current in open phase mode; $U_{rev.m}$ - maximum allowable reverse voltage K_r - reliability factor for critical protection circuits, K_r = 0,5.

Then, based on minimum power consumption of the circuit parameters of the intermediate current transformer are calculated.

III. CONCLUSIONS

1. A new principle of protection of electric motors from the most often and dangerous emergency operation - breakage of phases keeping it in operation without damage to manufacture has been proposed.
2. General principles of performance of phase-sensitive semi-conductor protective- switching devices have been found out; theoretical preconditions in for substantiation of the proposed circuit are given.
3. For the first time the circuit of comparison of three electric values as protective element of electric motors has been analyzed. On the basis of analysis of the circuit a possibility of its application has been proved.
4. For the first time it is offered not to disconnect, but automatically translate asynchronous electric motors into a single-phase operating mode at breakage of mains line phase, thus providing continuous operation.
5. The developed technique of selection of parameters of PSD circuit allows to select a mode of the maximal sensitivity for reacting body at the set initial values of circuits.

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