Methods for Revealing hidden Failures of Automation System for Technological Processes in Oil and Gas Sector

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Abstract Current methods for revealing hidden failures of automation systems became obsolete and require innovative approaches. The oil and gas sector has specific features as opposed to conventional plants and requires maximum reliability and advanced methods for testing and analyzing the equipment for hidden failures. Our team have focused on diagnosing switching devices as one of the backbone elements of any plant and electric power supply system in general. The study in this field allows increasing the safety level at the power consuming facilities and planning short-term maintenance and preventive-maintenance measures at production facilities.

1. Introduction

Specific features of the automation system for technological processes in the oil and gas sector are the appreciable remoteness of the automation facilities and substantial power consumption [1]. This determines the high sensitivity of these facilities to power supply outages. Up to 30% of technological process failures in the oil and gas sector are connected with hidden failures of the switching devices [2].

Switching devices are one of the critical actuating elements in any automation system for technological processes that, first of all, perform disconnection of electric circuits in the case of emergency situations or events that can endanger service staff or intactness of electric installations. One of the main problems of switching device application, in the majority of cases, is their state of hidden failure, which reveals on the occurrence of emergencies in the supply grid [3]. Full-scale diagnosis of such failures is complicated and requires instrumentation of the facilities with mobile complexes of devices capable of tracing and timely revealing the emergencies [4]. The diagnosis is the determination of time and current characteristics of a switching device by reproducing sine current, which is a direct equivalent to a short-circuit in the circuit of the tested switching device.

The overwhelming majority of locally produced devices intended for diagnosing switching devices belong to the class of step-current regulators [5]. The operation of such devices can be briefly described on the example of an autotransformer with a large number of taps, each decreasing or increasing the input voltage by a given value. The main problem in the application of step regulators is the necessary balancing between the accuracy of diagnostic measures, working ranges of the input voltage and the cost of the device. To increase the accuracy of the device we need to narrow down the working range of input voltages or
sophisticate the control scheme and increase the number of taps. This also implies increased cost of the device.

Further, the diagnostic devices based on AC thyristor converters have become widely spread. A drawback of these regulators is non-sine voltage applied to the lead during regulation, which leads to discontinuous current with its harmonic composition appreciably depending on the thyristor firing angle.

As of today, there are attempts to create diagnostic devices on the base of radiofrequency (RF) stabilizers using novel high-power transistors [5]. However, until recently, such diagnostic devices have not been widely used, since one of their main weak points is high cost; they are substantially more expensive as compared to conventional low-frequency diagnostic devices [6].

The authors have stated the objective of creating and mathematically describing the device for diagnosing switching devices for automation systems for technological processes in oil and gas sector lacking the aforementioned drawbacks.

2. Method for initiating and regulating diagnostic interference

To solve the stated problem, a versatile method for initiating and regulating the diagnostic interference with the switching device was suggested [6]. The main idea of the method is reproduction of large testing currents using charging cells composed of high-value capacitors. The cells are initially charged and then discharged into the load via special oscillatory system that can be adjusted to work at different frequencies. The functional scheme of the device built on the basis of the suggested method is depicted in Fig. 1.

![Functional scheme of the device.](image)

Power rectifier (B) rectifies the sine voltage of the source. At some moment of time that corresponds to the specified phase shift in the grid, the controller fires a pulse that triggers power switch $K1$ [7]. Then, through switch $K1$, diode $D1$ and inductance $L1$ flows the current charging cell $C1$ up to the line crest voltage. After the semiperiod ends, switch $K1$ locks, switch $K3$ triggers and cell $C1$ discharges to the load transformer (LT) and auxiliary inductance $L2$. After the first semiperiod with the given angle, the control pulse triggers switch $K2$. Then, through the switch, diode $D2$ and inductance $L1$ the current flows that charges cell $C2$ up to the line voltage [7].

After the next semiperiod ends, the control pulse triggers switch $K4$, and cell $C2$ also discharges to the LT and $L2$.

Then the process repeats: cells $C1$ and $C2$ alternately charge and discharge, thus inducing sine current in the secondary winding of the LT, because its windings have subtractive polarity [8].

We have studied the electromagnetic processes in this device [8]. Fig. 2 depicts the studied equivalent circuit of one device operation cycle.
Figure 2. Equivalent circuit of one device operation cycle: $R$ is total resistance of discharging circuit, $R_0$ is total resistance of charging circuit, $U_0$ is line voltage, $E$ is counter EMF, $L$ is total inductance of discharging circuit, $L_0$ is total inductance of charging circuit

The process of triggering/locking switches $K1$ and $K2$ is accompanied by the generation of large current pulses, which can disrupt the switches. The inductor smooths these current pulses out:

$$I_0 = \frac{U_m}{\Delta t},$$

where $U_m$ is maximum reactor voltage; $\Delta t$ is current rise time in switch $K1$.

During the cell charging, the current rise should be aperiodic. To achieve this, an analysis was performed that showed that for the scheme consisting of $R$, $L$ and $C$ connected in series, the following is valid:

$$R > 2\sqrt{\frac{L_0}{C}}$$

The critical inductance $L_0$ of the reactor is determined from the following condition:

$$L_0 < \frac{R^2 \cdot C}{4}$$

This inductance is called critical because at this value the current rise becomes aperiodic. To limit the amplitude of charging current, it is usually recommended to select inductance of 20% less that the calculated one.

The discharging circuit in Fig. 2 contains $K2$, $L$, $R$, $E$ and $C$ and is described by the following differential equation:

$$\frac{1}{C} \int_0^t i(t) dt + L \frac{di(t)}{dt} + i(t)R = -E$$

This work considers a case when the device operation frequency is 50 Hz. Taking into account that electromagnetic processes in the scheme are oscillating, the instantaneous voltage on the capacitor can be determined:

$$U_c(z) = U_c(0) - E - e^{-\frac{z}{\sqrt{\frac{1}{RC} + \frac{1}{CR^2}}} \cdot \frac{L}{R} \sqrt{\frac{4L}{CR^2} - 1} \cdot \sqrt{E^2 \left( \frac{4L}{CR^2} - 1 \right) + \left( -ERC - 2Li(0) \right)^2} \times \sin \left( z + \arctg \left( \frac{E}{\frac{ER}{L} - \frac{2i(0)}{C}} \right) \right) + \arctg \left( \frac{4L}{CR^2 - 1} \right)},$$
where
\[ z = \sqrt{\frac{4L - CR^2}{4LC}} \cdot t \]

A mandatory condition of the presented scheme feasibility is accurate timing of power switches by the control system [9]. When meeting this requirement, we can determine the instantaneous current in the scheme:

\[ i_t(z) = \frac{1}{R \sqrt{\frac{4L}{CR^2} - 1}} \cdot \sqrt{\frac{E^2 \left( \frac{4L}{CR^2} - 1 \right)}{L \frac{Er}{CR} - 2Li(0)}} \cdot e^{\frac{z}{
\sqrt{CR}}} \sin(z) \]

The modeling of the suggested scheme was carried out using Micro-Cap package. Fig. 3 presents the scheme of the model that is equivalent to the functional scheme presented in Fig. 1.

**Figure 3.** Model in Micro-Cap: V1 is alternating supply voltage; SW1–SW4 are power switches; D1–D4 is rectifier; C1, C2 are accumulating cells; L is charging circuit inductor; K1, L1–L3 is LT consisting of winding and core; L4 is the discharging circuit inductor; R is active load represented by closed switching device.

The modeling had a number of assumptions, including the usage of ideal switches K1–K4 and zero active losses in the charging and discharging circuits.

The initial conditions were as follows: real device power, switching device resistance in locked state and device parameters received from preliminary calculations. The effective value of the line voltage is 220 V, transformation rate of the LT is 0.005, capacity of accumulating cells C1 and C2 is 4700 μF, active load (resistance of the switching device in locked state) R = 100 μOhm, inductance L4 = 2.1 mH, active load power is 22 kW. So Fig. 4 presents the waveform of testing current derived from the modeling.

**Figure 4.** Testing current waveform
Fig. 5 shows the waveforms of testing currents in the load for the cases of different firing angles of power switches SW1 and SW3.

![Waveforms of testing currents](image)

**Figure 5.** Waveforms of testing currents for different firing angles of power switches

3. Conclusions
The main strong point of the suggested method for initiating and regulating diagnostic interference in the process of revealing hidden failures in the automation systems for technological processes of the oil and gas sector is the possibility of its usage at any firing angles of the power switches. In this connection, a device built on the basis of the suggested method can vary the control input with great precision [10]. Another important advantage of the device is the absence of moving mechanical parts and, hence, almost absolute long-term wear resistance. Also we should note the absence of additional losses in the switching units that are commensurable from the main switching elements when working at elevated frequencies.

The peculiarities that were noted by us determine high reliability of the device when widely varying the load, even when working in the systems subjected to frequent short-circuits.

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