Improving methods for identifying electric motor parameters in case of stator winding damage

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Abstract. A method is proposed for estimating the parameters of electric motors. It has new properties that increase the sensitivity and efficiency in terms of detecting internal short circuits in the windings of controlled electric motors in non-stationary conditions.

1. Introduction
Asynchronous electric motors (AD) are the most widespread receivers of electrical energy [1-2]. To ensure reliable and failure-free AD operation as a part of technological processes, it is necessary to implement completely new methods for their protection with the possibility of preventive action, carrying out continuous monitoring of motor parameters. In contrast to the systems of classical protection, which are triggered by faults, the system being developed makes it possible to avoid severe emergencies by predicting and detecting damages at an early stage [3-7].

The peculiarity of the classical methods of protection is the delayed reaction to the occurrence of damage due to the finite time of measurement and evaluation of parameters. Therefore, localization of damage due to lack of time is of an emergency nature, which inevitably leads to undesirable disturbances for the power system. For the same reason, a detailed diagnosis of damage in this case, as a rule, is impossible.

2. Methods
The implementation of the preventive action protection system, which ensures the early detection of possible damage to the motor and the prediction of their evolution, is based on continuous monitoring with extrapolation and parameter estimation. This approach allows one to win some time for detailed diagnostics and development of response measures that impede the development of emergency situations and, consequently, sudden disturbances of the power system.

The method is based on the use of mathematical model of the device being protected, the input of which receives the same disturbances as the object itself [8]. The reaction of the protected object is compared with the reaction of the mathematical model. In accordance with the selected criterion for the proximity of the model and the object, the model parameters are set. The model parameters obtained in this way and available for measurement are used to assess the state of the protected object (Figure 1).
The following notations are used in Figure 1:
AM is the object being protected (asynchronous electric motor);
MODEL is mathematical model of the object being protected;
KB1 is block of the parameters correction;
KB2 is block of the parameters control;
1 is setting of initial parameters;
2 is correction;
3 is alert signal (turning off);
4 is setting acceptable values.

The input action is the supply voltage signal \( U(t) \), which is supplied to the AM object and at the same time to its model: a microprocessor device or a computer program. Output signals (currents of object \( i(t) \) and model \( i_M(t) \)) are compared with each other and the difference in their values \( \epsilon(t) \) goes to the parameter correction unit (KB1). KB1 determines the parameters of the model \( L_M \) and \( R_M \) according to the observed input and output signals of the object. As the parameters of mathematical model approach the parameters of the object, \( i_M(t) \) tends to \( i(t) \), so \( \epsilon(t) \) tends to zero. The task of KB1 is to set the parameters of the model in such a way that the signals \( i(t) \) and \( i_M(t) \) differ in the least possible way according to some criterion. Only when this condition is fulfilled can we speak about the compliance of mathematical model with the object under study.

AD equivalent circuit values corresponding to the nominal mode of operation are taken as the initial tuning parameters of the model. Then, in the working mode, the current parameters of the model corresponding to the object are calculated and compared with the allowable values. In case of output of the obtained parameters beyond the permissible area, which is a prerequisite for the emergency mode, the unit for controlling the parameters generates a warning signal to the maintenance personnel or a signal to turn off the protected object.

The definition of the initial tuning parameters of the model of an asynchronous motor is carried out on the basis of a standard Γ-shaped equivalent circuit [9], which can be converted into an equivalent circuit using successive transformations (Figure 2).

So, \( R_{eq} \) and \( L_{eq} \) can serve as initial parameters of the model.

A mathematical model of an asynchronous motor can be described by the equation:

\[
L_M(t) \frac{di(t)}{dt} + R_M(t)i(t) = u_M, \tag{1}
\]

where \( L_M(t), R_M(t) \) are adjustable model settings;
\( u_M \) is the output voltage of the model;
i(t) is the instantaneous value of the motor current.

It is necessary to adjust the model so that the parameters $L_M$ and $R_M$ tend to the engine parameters. The degree of adequacy of the model to the protected object during the adjustment is set according to the functional $E$, which directly depends on the instantaneous error

$$\varepsilon = i(t) - i_M(t).$$

(2)

As $L_M$ and $R_M$ approach the engine parameters, $i_M(t) \rightarrow i(t)$, $\varepsilon \rightarrow 0$, which leads to a decrease in the functional $E$. So the model must be adjusted in such a way that the functionality is minimized.

To adjust the model, we will use the gradient method, according to which each of the model parameters is adjusted in proportion to the rate of change of the functional according to the same parameter:

$$\frac{dx_j}{dt} = -\rho_j \cdot \text{grad}_X E,$$

(3)

where $X_j$ is adjustable model parameters ($j=0...n$);

$E$ is identification criterion;

$\rho_j$ is positive amplification coefficient.

If we select the functional $E=\varepsilon^2/2$ as the criterion being minimized, then the equations of the tuning contours taking into account equations (1) and (3) will take the form [10]:

$$\frac{dL_M}{dt} = -\rho_L \cdot \varepsilon \cdot \frac{di(t)}{dt};$$

$$\frac{dR_M}{dt} = -\rho_R \cdot \varepsilon \cdot \frac{di(t)}{dt};$$

$$\varepsilon = u(t) - L_M(t) \frac{di(t)}{dt} - R_M(t) \cdot i(t),$$

(4)

where $\rho_R$, $\rho_L$ are amplification coefficient.

To implement the described method and to obtain the instantaneous values of currents and voltages necessary to solve the resulting system of equations, a pilot plant was created, with the help of which both the normal operating conditions of the engine and various circuits are fixed.

The scheme contains the object under study – the AIR100S4U3 asynchronous motor of the brand ($P_n = 3$ kW). A distinctive feature of this electric motor is the presence of taps from phase coils with different numbers of turns, which allows one to simulate interturn circuits in different operating modes. The ends of the motor windings are brought out and connected as a star.

3. Results

Using this installation, instantaneous voltages and currents were obtained in the mode of starting the engine, as well as when different numbers of turns in the stator winding were closed. For instantaneous values, taking into account the initial conditions $L_{eq}$ and $R_{eq}$, the system of equations (4) is solved by the Runge – Kutta method using the MATLAB software package. The results of the calculation of equivalent parameters in different modes are presented in Figure 3.
Figure 3. R(t) and L(t) Charts for different modes: a) when the engine is started; b) when closing the first tap for the beginning; c) when closing the third tap for the beginning.
4. Conclusions
The desired quality of the transition process has a great influence on the choice of model parameters. From the analysis of differential equations (4), it follows that it is primarily determined by the correct choice of $\rho_R$ and $\rho_L$. To increase the protection performance, i.e. to reduce the time of transition process, you need to increase the $\rho_R$ and $\rho_L$.

Thus, on the basis of the proposed method, technical means and systems for continuous monitoring of AD parameters can be developed without shutting it down.

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