The method of calculating the setpoint of the overcurrent protection with the function of the detuning from inrush currents for a circuit breaker on the basis of the electronic trip unit

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Abstract. This paper presents for the first time an attempt to specify the method for calculating the value of the overcurrent protection setpoint with the function of detuning from inrush currents for the electronic trip unit ETU. The principle of protection is described in detail on the basis of comparing the rate of current rise in the protected circuit with the settings recorded in the ETU memory in the form of a binary code. The algorithm of action for the ETU based on the digital signal controller DSC is presented. Methods are proposed for improving the reliability of overcurrent protection and reducing the number of false outages. The procedure for calculating protection settings has been considered. Moreover, previously developed methods for calculating protection settings with a detuning from inrush currents are not suitable for the principle described in this work and vice versa the presented method for calculating protection settings with detuning from inrush currents is not suitable for methods based on other principles.

1. Introduction

Existing problems in the energy industry highlight the installation of modern safety devices. Autonomous protection of power supply, provides the ability to maximize the security of the consumer during an emergency power outage. Digital electronics play an essential role in ensuring the high reliability of the automated and automated systems that are being created, which control objects, processes and production systems. Modern digital devices are multifunctional and are widely used in automated systems for the transmission and distribution of electrical energy. Due to the wide protection functions, these digital devices can be integrated directly into circuit breakers. Such built-in devices are called the electronic trip unit ETU.

A variety of operating currents of consumers in electrical networks must be taken into account and taken into account when setting up the relay protection devices [1, 2, 3]. One of the main requirements for the protection of the power system is the speed of switching off emergency currents [4], which include short-circuit currents. Before using the electronic trip unit, the developers of the circuit breakers faced the problem of detuning from the starting current of the electric motor in the network. During the supply of full voltage to the selected stator of any asynchronous machine, there are two negative factors, this is the oscillatory damping nature of this starting torque of the motor and a rather large multiplicity of the initial starting current of the motor [5, 6, 7]. The fact is that when starting an
electric motor, its starting current $I_s$, the current during the engine acceleration and increasing its speed, exceeds the rated current of the motor $I_n$ by the multiplicity $k_{ov}$ of the nominal current [5].

Of the currently proposed methods of detuning from inrush currents, most are based on the principle of setting the current setting [8, 9, 10]. This is not a very effective way, since with the probability of occurrence of large inrush currents in the circuit, a setpoint of a large value must be entered accordingly. If there is a high current in the network, the wires are heated. This fact may affect the integrity of the design of the chain itself, because as a result of overheating, metal deformation may occur and a gradual violation of the insulation. Therefore, there is a need to create such a method of detuning from the starting currents in the protection of the power system, in which the current does not reach high values, but at the same time, the protection apparatus must recognize and distinguish the starting currents from short-circuit currents.

One of the functions that can be implemented in an ETU -based circuit breaker is detuning from inrush currents. Detuning is performed by comparing the rate of current rise in the protected circuit with the settings recorded in the ETU memory in the form of a binary code. The presence in the ETU of the built-in measurement function of the required values allows you to control the rate of current rise in the protected circuit continuously. However, the value of the setpoint, which is recorded in the memory of the ETU, must be pre-calculated. The value of the setpoint depends on many parameters of the protected circuit and is tied to a specific distribution topology of consumers of electrical energy. All of the above affects the reliability of the security system itself. Below we propose a method for calculating the protection setpoint for implementing the function of detuning from inrush currents based on a comparison of the rate of rise of currents.

2. The method of differentiation of inrush currents and short-circuit currents

The instantaneous value of the electromagnetic moment of the engine depends not only on the angular velocity, the parameters of the engine and the parameters of the power supply system, but also on the derivatives of these quantities and their initial values [11, 12]. With the advent of ETU based on DSC, it became possible to use the method of differentiation of inrush currents $I_s$ and short-circuit currents $I_{sh}$. In a given time interval, the currents $I_s$ and $I_{sh}$ limited by inductances. The inrush currents $I_s$ is limited by the leakage inductance of the motor windings, and $I_{sh}$- limited by linear cable inductance.

To implement this method [5] in the ETU, it is necessary to carry out multiple measurement of the load current $I_l$ at regular intervals. The measured load currents are compared with the current settings calculated for the same periods of time. ETU based on a digital signal controller is able to perform the necessary multiple measurements of various quantities. In addition, DSC is able to quickly perform both easy and complex mathematical operations [5].

Further, based on the measured values of the load current at the beginning of the period, the rate of increase of the load current $di_l/dt$ is calculated. Knowing the rate of current rise, it is possible to calculate the amount of current for each time period ahead. Thus, an array of load current data will be obtained. The data of this array are compared with the data array of the calculated settings of the same total time interval. In case of overcurrent load over the ETU setpoint, a trip signal is generated. Since the load current can vary during the half period, it is necessary to additionally measure the load current with which the real-time setting of one total time interval is compared. To implement the above-described function, the ETU based on the DSC operates according to the algorithm shown in Figure 1.
In order to increase the reliability of the automatic switch based on the ETU and reduce the number of false outages, variables N and K are introduced into the algorithm. Variable N in Figure 1 determines the number of measurements, and variable K determines the number of exceeding a given current in these measurements. That is, if out of five measurements in three dimensions there will be an excess of the setpoint, then it is likely that this is a short circuit. Thus, the likelihood of incorrect measurement interpretation is reduced. The values of K and N are set depending on the topology of the power system and are determined empirically. The calculation of the protection setting I\_mouth is given below.

3. Calculation for the selection of ETU settings by the method of current differentiation

When the engine is started, the load current I\_l of the network at regular intervals is determined by the starting currents I\_s of the same periods of time. Knowing the rate of rise of the inrush currents dI/dt, which is limited by the leakage inductance of the motor winds L\_s, it is possible to calculate the starting current I\_s in a given period of time. In the case of a short circuit, the current rise rate is determined by the total inductance of the cable, which depends on the linear inductance of the motor L\_c. The calculation of the maximum value of the load current rise rate dI/dt in the case of the inrush currents is shown below. It can also be determined experimentally. In the case of short-circuit current, knowing the cable parameters, the rate of current rise can also be calculated. Since the inductance affects the rate of change of current in the circuit, therefore, this inductance should be determined. Namely, the leakage inductance of the stator winding of the motor, as well as the linear inductance of the cable of the three-phase circuit of the power system.

Methods for calculating the inductance of cables of three-phase circuits and the inductance of the motor stator windings are well known [13, 14, 15] and are not given in this article. After we have determined the inductance of the windings of the induction motor and the linear inductance of the cable, we calculate the inductance of the entire system, which our circuit breaker operates on. The system includes: a switch, a three-phase line and consumers.

Next, you need to calculate the impedance of the entire system to determine the amplitude of the starting current according to Ohm’s law for the complete circuit. The formula of the impedance for one element of the system (1):

$$Z = \sqrt{R^2 + (\omega L)^2}$$
Then we calculate the impedance of all consumers, since they are connected in parallel, then the formula for these calculations will look like this (2):

\[ Z_{\text{nom}} = \frac{Z_1 \cdot Z_2 \cdot Z_3 \cdots Z_n}{Z_1 + Z_2 + Z_3 + \cdots + Z_n} \]  

(2)

Knowing the impedance and voltage of the system, it is possible to determine the amplitude of the inrush currents, i.e. the current that will be with the simultaneous connection of all consumers (3):

\[ I_m = \frac{U_{\text{nom}}}{Z_{\text{nom}}} \]  

(3)

Despite the fact that the case of simultaneous connection of powerful consumers is quite rare, but we also take it into account. When calculating the protection of the power system, it is necessary to take into account the “worst” case in which the inrush current will be the maximum of all possible options. If we do it differently and calculate with the gradual connection of consumers, then in the case of their simultaneous connection, the security apparatus will work to disconnect, which we do not need.

Further, knowing the amplitude of the current and the frequency of the network \((f = 50 \text{ Hz})\), one can make an equation that describes the AC current. In general terms, this equation looks like (4):

\[ i(t) = I_m \cdot \sin(\omega t) \]  

(4)

where \(\omega\) is the angular frequency (5),

\[ \omega = 2 \cdot \pi \cdot f = 314 \left( \frac{\text{rad}}{s} \right) \]  

(5)

where \(f = 50 \text{ Hz}\).

It is known that the rate of current rise is the first derivative of the AC current equation, in general, it will look like this (6):

\[ \frac{di}{dt} = \omega \cdot I_m \cdot \cos(\omega t) \]  

(6)

From the expression (6) we can find out the rate of rise of the starting current. The next step is to calculate the short circuit current. To do this, we need to calculate the line impedance and find the amplitude of the short-circuit current, according to Ohm’s law for the complete circuit. Similarly to the starting current, we make up the equations (1 - 6) and we obtain the values of the rate of increase of the short-circuit current.

Now that we know the rate of rise of the starting current, it is possible to calculate the array of setpoint data for given periods of time according to expression (6). The settings should be chosen with a small margin, i.e. slightly higher than the rate of rise of the starting current, but significantly lower than the speed of the short-circuit current, in order to protect the system from accidental disconnection in the presence of interference in the network.

When calculating the currents, it is necessary to ensure that the short-circuit current is greater than the starting current of the simultaneously switched on consumers. In another case, if you combine powerful consumers, while simultaneously turning on the starting current, which can reach values approximately equal to the short-circuit current, the protective function will be performed with errors.
In Figure 2 shows an array of protection setpoint for the corresponding time interval, which are recorded in the ETU memory in the form of a binary code.

4. Summary
In this paper, we described in detail the method for calculating the settings of the electronic trip unit for implementing the function of detuning from inrush currents based on a comparison of the speeds of the currents. It is shown that the connection of a larger number of consumers, due to a decrease in the total resistance of the circuit, there is an increase in the starting current, and hence the setpoint value for protecting the power system. Also given are formulas for calculating an array of protection settings that are written to the memory of ETU data that is permissible for high-quality detuning from inrush current when consumers are connected to the power system. For the implementation of the above-described function, the ER based on the DSC operates according to the developed algorithm. The introduction of the variables N and K increases the noise immunity of the system. Previously developed calculation methods for detuning from inrush currents are not suitable for the principle set forth in this paper and vice versa the presented calculation method is not suitable for detuning based on other principles.

Circuit breakers with built-in ETU based on the digital signal controller DSC have great advantages over traditional ones. Also have advanced standard features. The protection functions implemented in the ETU depend entirely on the operation of the DSC. When working with the network and consumers, it is also necessary to calculate the settings, so the procedure for calculating the main settings was provided to protect the power system circuit. Also solved the problem of detuning from the inrush current. In case of short circuit, shutdown occurs at an earlier stage of its occurrence. All of the above improves the reliability of the power system itself as a whole.

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