Relay protection features of frequency-adjustable electric drive

V V Kuprienko
Orenburg State University, 13, Pobedy Av., Orenburg, 460018, Russia
E-mail: ogu15210@mail.ru

Abstract. The features of relay protection of high-voltage electric motors in composition of the frequency-adjustable electric drive are considered in the article. The influence of frequency converters on the stability of the operation of various types of relay protection used on electric motors is noted. Variants of circuits for connecting relay protection devices are suggested. The need to develop special relay protection devices for a frequency-adjustable electric drive is substantiated.

1. Introduction
Frequency control means the control of an alternating current motor by varying the amplitude and frequency of the supply voltage.

Frequency-adjustable electric drives are widely used in industry [1, 2]. They allow one to change smoothly parameters of technological modes [3, 4, 5], to reduce significantly electric power consumption [4, 5]. However, a number of features should be considered in the design of the relay protection of such electric drives.

2. Problem Statement
Progress in the field of power conversion technology has led to a wide introduction of valve converters. Installation of high-voltage frequency converters (FC) changes not only the operating conditions of electric motors (EM), but the operating conditions of relay protection (RP) devices. Moreover, FC influence the operation of EM and RP not only in normal modes, but also in short circuits. When installing FC, EM is separated from its «own» breaker. With this EM connection scheme its protections (differential protection (DP), overcurrent protection (OP), ground relaying (GR), installed in the breaker cell of Q1 in figure 1, lose or change their functions.

On the other hand, disturbances in the supply network affect the adjustable-speed drive. Deep voltage drops and voltage distortions refer to those.

3. Research Questions
3.1. Features of the differential protection operation
With the usual connection of the EM (without FC) in the breaker cell of Q1 the DP, OP as an overload protection, as well as GR (figure 1) are installed. Moreover, cable line CL is included in the zone of DP, OP and GP action. With an electric motor power $\geq 5\,000\,\text{kW}$, as well as at lower power, if the current cutoff does not provide sufficient sensitivity, differential protection is the main protection of electric motors [6]. In figure 1 DP is switched on to the difference of the secondary currents of the
transformers CT1 and CT4. It protects the cable line CL and the entire stator winding of the EM from all kinds of interphase short circuits.

Installation of the FC leads to the fact that the secondary currents from CT1 (on the side of the power supply) and CT4 (from the neutral of the EM) have a different frequency. It is these currents that form the differential signal. As a result of their phase mismatch, a significant spurious differential current is generated. The need for nonoperation from it reduces significantly the sensitivity of the DP or even makes it inoperative.

![Figure 1. Layout diagrams of EM relay protection without using FC](image)

### 3.2. Features of the protections operation against overload and earth faults

The overcurrent protection (OP) also changes its functions, since the current through current transformers CT2, which the OP is connected to, will not be equal to the current in the stator windings of the motor. The ground relaying (GR), installed in the breaker cell of Q1, also will not protect the EM, since the FC breaks the contour of the passing of the zero sequence currents. And with the earth fault in the stator windings of EM the current in the CT3 zero-sequence current transformer, which the GR is connected to, will not flow.

In this way, OP and GR protections in the breaker cell of the Q1 in figure 2 change the coverage and its purpose. They will protect cable line CL1 and the input transformer of the high-voltage FC. Therefore, at the FC output (or as part of the FC), an additional GR must be installed, into which zone of action the stator winding of the electric motor should be included. The main protection functions of the EM are in this case encharged to the current cutoff (CC) and the OP, integrated in the FC. However, the CC and OP do not possess absolute selectivity and cannot protect the entire stator winding [7].

In this case, it is necessary to check the ability of current protection of the FC in design of a frequency-adjustable electric drive to provide full protection of the engine during overloads and short-circuits.

![Figure 2. Layout diagrams of EM relay protection with block connecting of FC](image)
3.3. Features of the microprocessor protection operation

Microprocessor relay protection units (MRPU) with the wiring diagram of FC that is shown in figure 3 can measure the current with a large error and operate incorrectly. This is explained by the fact that in MRPU instantaneous values of currents and voltages are processed by the program of digital filtering relative to the first harmonic of the power frequency and errors of current measurement of the MRPU are set for the frequency of the input signal in the range of 50 ± 0.5 Hz [8, 9].

At the same time, MRPU algorithms (calculation of effective values, calculation of vectors by instantaneous values, algorithm of two samples) are also implemented for the fundamental harmonic [9]. If the frequency of the input signals goes out of the range of 50 ± 0.5 H, then there is an additional error in the current measuring which for the 45÷55 Hz range is up to 2% per Hertz [10], and for frequencies below 45 Hz - is not standardized. In this case, the protections can refuse to operate or work falsely.

Therefore, for the possibility of using MRPU of EM, that is connected to the FC according to the scheme in the figure. 3, the development of algorithms, capable of operating at a frequency other than 50 Hz, should be required.

In special MRPU designed to protect transformers, compensation for the phase displacement caused by the connection of one of the transformer windings to the "triangle" is provided. A similar phase displacement arises in the case of an MRPU of a frequency-adjustable electric drive (for the reasons described above).

But the differential protection of conventional MRPU motors does not provide an algorithm for compensating this error. And it is more significant when the differential protection of the electric drive with the FC works, than in the protection of the transformer.

Obviously, the development of specialized MRPU is necessary for a frequency-controlled electric drive.

3.4. Relay protection of frequency-adjustable electric drive of pumps

Frequency-adjustable electric drives provide a smooth change in the technological parameters of the pumps (feed and pressure). And in view of their obvious advantages, they are widely used in pumping plants.

Availability of adjustable-speed drives of pumps reduces the accident rate due to the reduction in the number of inclusions and shutdowns of the pumping unit and the smoother nature of the changes in technological parameters.

Main pumps of pumping oil for safety requirements are located in the premises («pumping»), separated from high-voltage electrical equipment. EM of the drive are installed either in a pumping building with an explosion-proof design or in the next room of a indoor switchgear (IS), separated from the pumping by an explosion-proof partition [4, 11].

EM receives power through the cable line CL (figure 1). Breaker Q1, current transformers CT1 and CT2 and relay protection devices EM are installed in the IS in the motor cell.

High-voltage FC are placed in a separate block (BFC), which is located near the premises of the technological FC. In this case, cable line CL1 is laid from the power busses of the technological FC to the BFC (figure. 2) and from the BFC to the electric motor - cable line CL2.

As a result, when installing FC instead of single cable line CL in figure 1, it is necessary to lay two cable lines CL1 and CL2 in figure 2 when a high-voltage FC is connected to a separate cell (breaker Q2) of the technological IS (figure 3). In figure 2 between breaker Q1 and the FC and also between the FC and the EM, there are no additional switching devices, allowing one to change the scheme of connection of FC and the engine. In this case, the FC and the engine form a single unit with series-connected high-voltage FC, EM and two cable lines: CL1 и CL2.

With the FC connection diagram, that is shown in figure 2, two sets of protection are used: one of them - in the OP and GR compositions for the protection of the CL and the input transformer of the FC, the second (in the cell of the motor with the breaker Q1) can be left the same as in figure 1, provided that it is made on an electromechanical element base.
The need to have two sets of protections complicates the design and operation of a frequency-adjustable electric drive and requires the elaboration of a list of protections, their properties and functional capabilities.

The construction of relay protection in the case of using the motor connection scheme via the FC with a shunt disconnect switch causes additional difficulties.

4. Findings
The analysis of the considered schemes of connection of high-voltage FC and relay protection devices shows that each of the schemes has its advantages and disadvantages. The scheme of power supply with the connection of the FC to the motor cell is the simplest one (figure 2). However, in such schemes, the engine loses all of its protections installed in the IS cell. Protection of EM is bushing on the protections, built into the FC, the efficiency of which has not been sufficiently studied for EM.

All EM protections can be saved by connecting the FC to an additional cell (figure 3). However, in such circuits the motor protection made on the microprocessor element base may not work.

In design of a frequency-adjustable electric drive, it will be necessary to check the ability of the current protection of the FC to provide a full protection of the motor during overloads and short circuits.

The actual task is the development of microprocessor relay protectors, capable of operating at a frequency of the supply voltage that differs from 50 Hz.

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