Creation of a learning microprocessor system for protection of contact network feeders using adaptive parametric identification methods

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Abstract. Handling of high-weight trains, double trains, packet traffic schedule, recuperation on electric locomotives often leads to false protection relays, downtime of trains and increased wear of power switching and protective equipment of traction substations. The paper proposes methods to improve the selectivity of microprocessor relay protection of feeders of AC traction substations contact network by increasing the accuracy of extraction of the first current and voltage harmonic based on phase locked circuits, integration of learning subroutines by fixing the electric parameters and creating the sets of dynamic setpoints in accordance with the current train situation and adaptive parametric identification of dynamic assessment of current electric parameters of the traction network. It also analyzes structural diagrams of hardware and software of the proposed microprocessor protection system of contact network feeders.

1. Introduction

The main disadvantage of microprocessor protection devices of contact system feeders applied within the network of Russian railways is the probability of overlapping the areas of normal and emergency operation modes of reserve stages of remote protection related to short-term increase of the traction current and change of phase shift angle between current and voltage in normal operation mode when heavy trains take off, when switching the operation modes of electric locomotive engines, activation of recuperation modes, when trains get into protection coverage area and exit it in case of packed traffic schedule, as well as when handling heavy and double trains.

Some works of foreign scientists [1, 2, 4, 5, 6, 9, 10, 14, 15, 16] consider the methods to increase the selectivity of relay protection devices based on adaptive algorithms and learning elements. Among domestic studies we should mention the device of adaptive remote protection of standby stages of contact network feeders [7] and the device to monitor the state of high-voltage inputs [8]. The closest foreign analogues of adaptive systems are given in the following publications [11, 12, 13, 17].

The authors propose an upgraded microprocessor relay protection device containing, besides a set of standard units and algorithms of their operation, a control reference signals module based on phase locked frequency circuits, a learning routine and formation of a set of dynamic setpoints and adaptive parametric identification of transient operation modes of the traction power supply system.
2. Materials and methods

The object of the study includes standard protection and automation unit (PGU) of the 27.5 kV contact network feeder digital protection and automation device (DPA-27.5-CN), which includes measuring modules of current and voltage sensors (MCVS), protection controller module (PCM), automation controller module (ACM), as well as an integrated module of control signal setting based on automatic frequency control circuits (AFC).

The subject of the study is the operation algorithm of the 27.5 kV contact network feeder digital protection and automation device (DPA-27.5-CN) improved due to additional learning routines and the formation of a set of dynamic setpoints and adaptive parametric identification of transient operation modes of the traction power supply system.

The study was carried out using the methods of collecting and processing statistical information and experimental data, methods of system analysis and administration.

3. Creation of learning microprocessor system for the protection of contact network feeders

Data on the operation of DPA-27.5-CN microprocessor protection made it possible to identify the main reasons for its actuation in different operation modes of the traction power supply system (TPSS). The highest percentage of actuations is recorded not due to emergency and forced operation modes of the TPSS, but as a result of many factors, including: overlapping the areas of normal and emergency operation modes of reserve stages of remote protection related to short-term increase of the traction current and change of phase shift angle between current and voltage in normal operation mode when heavy trains take off, when switching the operation modes of electric locomotive engines, activation of recuperation modes, when trains get into protection coverage area and exit it in case of packed traffic schedule, as well as when handling heavy and double trains.

Work [7] proposes an improved operation algorithm of the third stage of DPA-27.5-CN directed remote protection, which includes an additional adaptive circuit for identification of complex resistance of the traction network. The test showed that the probability of overlapping the actuation zone of normal and emergency operation modes of standby stages during movement of heavy and double trains decreases only if the process is accompanied by gradual change of measured electrical parameters. The modes associated with short-term dynamic changes in current and resistance are not recognized.

The authors propose to use a more advanced algorithm, in which the above-mentioned disadvantages are eliminated by introducing an additional circuit of adaptive parametric identification of transient TPSS operation modes based on the analysis of the first current derivative and complex resistance.

Besides, it is possible to increase the selectivity of backup stages of remote protection of contact system feeders via the learning routine based on oscillograms of current, voltage, complex resistance of emergency modes in accordance with the existing train situation and the formation of the sets of dynamic setpoints.

Since the difference between current and voltage phases is a determining value when recognizing the emergency modes in the traction network, in the proposed system the accuracy of measurement of the initial phase of the first current and voltage harmonic is increased due to the subsystem for setting control reference signals based on automatic frequency control.

The essence of the proposed microprocessor protection system of contact system feeders using adaptive parametric identification methods is presented in the form of a flow diagram (Figure 1).
Figure 1. Flow diagram of hardware and software of microprocessor protection system of contact network feeders using adaptive parametric identification methods.
The measured signals from galvanic isolation and pre-scaling units of the input signals 1 and 2, after being pre-filtered, are to be phase evaluated by automatic frequency control circuits (AFC) 3 and 4 preceding the operations of program digital filtering of current and voltage 6 and 8. AFC circuits generate reference signals, front and rear edges of which coincide in phase with the measured signals of current and voltage at their transition through zero values [3]. The reference signals from the outputs of AFC circuits are supplied to microprocessor control device to determine current and voltage signal period and calculate the quantization interval by dividing by N duration of measured signals frequency expressed in clock frequency of a clock generator. The AFC circuits are primarily aimed to improve the accuracy of measurement of the initial phase of measured signals. The difference between phases of current and voltage is determining when recognizing the emergency modes in the traction network. Frequency filtering units 6, 7, 8, in the form of a software extract the main harmonic of current and voltage, as well as the harmonic signal in the frequency range from 100 to 450 Hz. On the basis of discrete values of current and voltage supplied from filters 6 and 8, the angle of phase shift between current and voltage of the main harmonic in subroutine 9 is calculated and further compared in subroutine 24 with the setpoint value.

Based on discrete values of a current signal coming from filters 6 and 7, current harmonics coefficient is calculated in subroutine 10. The calculated coefficient is supplied to subroutine 19, where it is compared with the value of the harmonic coefficient setpoint. Subroutines 12, 13, 14 calculate the complex resistance of the protected feeder and its first derivative, as well as the current derivative, based on data from filters 6 and 8.

Subroutine 11 is based on determination of voltage location in a preset limit characterizing normal operation mode of the traction network. If the voltage is within the preset setpoint range, the comparator units 16 and 17 compare the measured value of feeder current supplied from the filter 6 with the value of the setpoint current. If the measured current exceeds the setpoint value, then information is supplied from the output of the unit 16 to subroutine 19 for comparing the calculated harmonic coefficient with the setpoint value.

The need to analyze the harmonic coefficient is related to the nonlinear nature of the current signal. If harmonic coefficient exceeds the value of the setpoint, the current derivative coming from subroutine 13 is estimated and the forecast value of current time reduction exceeding the setpoint value by 20%. The “desensitization” of the current setpoint by 20% to the upper side is performed for the purpose of isolation from starting currents of electric locomotives. The analysis of the derivative current at the corresponding sign allows increasing the selectivity of protection at recognition of modes connected with short-term dynamic current shocks that occur when heavy trains take off, when switching the operation modes of electric locomotive engines, etc.

At the end of the forecast delay time implemented as subroutine 22, the current value with the setpoint value cut by 20% in subroutine 25 is re-checked. If the current exceeds the specified value and at the same time the complex resistance is reduced by 20% to the lower side of the setpoint value in subroutine 26, a command is generated to disconnect the feeder with arrangement of the set delay in subroutine 30.

If the current of the setpoint in the comparator 17 is not exceeded, the value of the complex resistance supplied from the subroutine 12 is compared. If the resistance exceeds the setpoint, a setpoint resistance correction signal is generated in block 18. The plurality of subroutines 11, 17, 18 form an adaptive resistance protection identification loop. Subroutine 21 evaluates the derivative of complex resistance and determines the forecast time of resistance reduction to a value less than the setpoint value by 20%. The “desensitization” of the resistance setpoint (by 20% to the lower side) is connected with the need to offset from starting currents of electric locomotives. The analysis of complex resistance derivative at the corresponding sign makes it possible to increase the selectivity of protection at recognition of modes that occur when heavy trains take off, when switching the operation modes of electric locomotive engines, etc.

At the end of the forecast delay time implemented as subroutine 22, the current value with the setpoint value cut by 20% in subroutine 25 is re-checked. If the complex resistance of the cut-off
setpoint value is not exceeded and the current of the cut-off value is simultaneously exceeded by 20% to the higher side of the setpoint value in block 25, a command is generated to disconnect the feeder with arrangement of the set delay in subroutine 30. The plurality of subroutines 20, 21, 22, 23 form a loop of adaptive parametric protection identification by current derivative and complex resistance.

The command to disconnect the feeder is also supplied if the logic element 27 generates value “1”. This event occurs provided three conditions are fulfilled: the argument of complex resistance of the traction network module exceeds the value of the setpoint when closing the program key “Mirror Zone”, which increases the actuation zone due to addition of symmetrical actuation zones; absence of information from subroutine for generation of templates of electrical parameters of emergency modes and generation of sets of setpoints; effect of complex resistance of smaller value of the setpoint cut down by 20% in subroutine 26.

An important element of the proposed system, unlike [7], is the software-level subroutine 15 for generating templates of electrical parameters of emergency modes and generating the sets of setpoints. This subroutine forms an element of system learning. The essence of subroutine is to process information on the current train situation (traffic schedule, train coordinates, train weights, locomotive types, driving modes) received via external digital communication channel and to compare this information with voltage and current oscillograms, as well as change graphs of complex resistance, current derivative and impedance derivative. In process of operation of the protection device information on the change of electric parameters depending on train movement schedule, train weight, locomotive movement modes, individual features of track profile on a protected section is recorded. During processing of statistical information, templates of change of electric parameters are formed, on the basis of which sets of setpoints are developed. In case of frequent false actions of the protection device at repeated train and emergency situations, the user can analyze the information, find the reasons for actions, form sets of setpoints and templates of electrical parameters of emergency modes.

System training related to information accumulation contributes to significant increase of selectivity of remote protection device of contact system feeders and elimination of overlapping between actuation zone of normal and emergency modes of reserve operation stages. In case there is no information on external digital channel concerning current train situation, subroutine 15 performs the role of a device that stores the sets of electric parameters setpoints.

It shall be noted that a significant disadvantage of digital filters functioning as part of microprocessor protection units is the increased error of measurement of the initial phase of the first harmonic of current and voltage related to frequency deviation of the monitored signal from the nominal one. In case of signal deviation, the algorithms of digital filters change the number of samples both within integer and non-integral numbers. This fact actually leads to an increase in the error in determining the phase of the useful signal.

The authors have achieved a significant reduction of this error by introducing additional filtering modules into a standard protection unit and extracting the first harmonic based on AFC circuits (Figure 1, block 3 and 4).

The essence of operation of additional AFC modules is presented in the form of a flow diagram (Figure 2).

The module uses current transformer 1 and voltage transformer 3 as high-voltage inputs, the measuring outputs of which are connected to inputs of galvanic isolation and normalization units of current 2 and voltage 4. Signals from the output of measuring transformers of current and voltage are supplied to low frequencies filters 5 and 8 to exclude higher harmonics and reduce the error of the first harmonic extraction. In parallel, the signals from the measuring transformers are rectified by means of full-wave rectifiers 6 and 7.

From filter outputs the measured current and voltage signals are supplied to inputs of automatic frequency control circuits 9 and 10, at the output of which, when working together with pulse converters 12 and 15, the control signals are generated, the front and rear edges of which coincide in phase with the measured signals at their transition through zero values. The control signals control the operation of transistor switches of quasi-resonance inverters 13 and 14. Supply voltages proportional
to amplitude values of current and voltage at the output of measuring transformers 2 and 4 are supplied to transistor switches of inverters 13 and 14 for generation of the first harmonics of measured signals.

In order to increase the reliability of operation, backup circuits bypassing the AFC are provided. In case of failure of PLL circuit, pulse converter or inverter, the control signals are supplied from microcontroller to electronic switches 11 and 16, which implement bypass circuits. From the outputs of inverters 13 and 14 the selected first harmonics of current and voltage are supplied to the inputs of ADC 17 and 18 and further from outputs of ADC to microcontroller PCM 19.

![Figure 2. Flow diagram of additional modules for filtration and extraction of the first harmonic on the basis of AFC circuits as part of the standard DPA-27.5-CNF protection unit.](image)

4. Conclusion
The simulation of the operation of the microprocessor protection system of contact network feeders using adaptive parametric identification methods in application packages confirmed the correctness and effectiveness of the proposed software and technical solutions related to modernization of the operation of existing standard DPA-27.5-CNF protection units. The results show that when using the proposed protection system, the number of false activations decreased in comparison with the operation of identical protection [7] by 3-5% at smooth change of electric parameters and by 15-17% in modes related to short-term dynamic changes of current and resistance.

In parallel, the error of measurement of initial phases of the first harmonic of current and voltage was estimated by standard digital filters and taking into account additional modules of filtration and extraction of the first harmonic on the basis of AFC circuits. In the second option, the measurement error decreased by 7-9%.

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