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Microprocessor Protection Relay Based on Amplitude-Phase Measurements of Signals

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***Abstract*—Microprocessor-based relay protection devices enable efficient operation of the electrical infrastructure of high voltage power lines and substations under emergency conditions. This is achieved by using high-speed fault detection algorithms and advanced electronic components. The paper deals with the elaboration of a such algorithm which novelty lies in the fact that it is based on amplitude-phase measurements of asymmetrical components of current and voltage signals, which detects accidents with symmetrical and asymmetric overloads significantly faster. The algorithm is implemented in microprocessor protection in the LIRA device.**

***Keywords*— Relay protection; microcontroller; amplitud-phase measurements; alarm waveforms.**

I. INTRODUCTION

Microprocessor protection relays (MPR) is a relay protection device, the control part of which is implemented on the basis of microprocessor elements (microcontroller).

Currently, the development of MPR are the main direction of development of relay protection [1], [2]. In addition to the main function - emergency shutdown of power systems, its have additional functions in comparison with other types of relay protection devices (for example, electromechanical relays), that is - emergency registering.

MPR have the following advantages:

- Improved performances of speed, sensitivity and reliability in comparison with relay protection devices based on electromechanical relays.
- The presence of many service functions, such as: self-diagnostics, registration and oscillography of signals (Fig. 1. [3]), the ability to integrate MP RPA into the SCADA of an energy facility, etc.

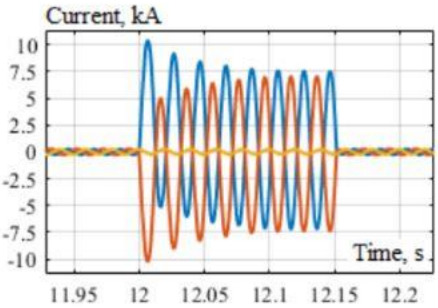

Figure 1. Emergency oscillograms of three-phase currents.

To make decisions about the appearance of an emergency mode, the MPR compares the measured and calculated values with the settings-threshold emergency levels (Fig. 2. [4])

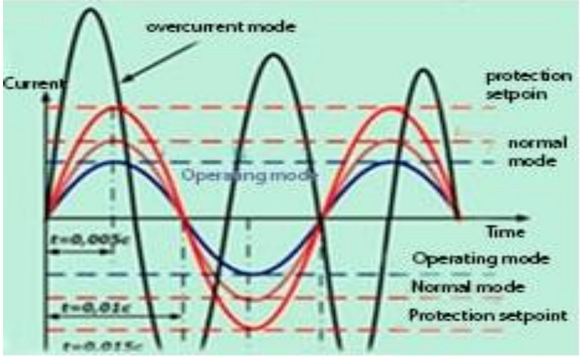

Figure 2. Detection of emergency mode

The main influence on the speed of the measuring elements of microprocessor protection of electrical installations is exerted by two factors. The first of them is associated with the appearance of damage in the measured signals of aperiodic and harmonic components due to transients and the nonlinearity of the elements of the electrical installation. The second one is due to the inertia of information processing algorithms, in particular analog and digital filtering. This leads to the fact that the time of signal establishment at the output of the measuring body is delayed to unacceptable values. This in some cases makes the high-speed protection of electrical equipment *ineffective*. There are known methods for determining the emergency mode based on the calculation of the effective values of currents and voltages, as well as the fast Furie transform (FFT). However, the fault detection time is from one half cycle to one cycle, which requires high performance processors.

The main tasks in the development of the MPR are to ensure high speed when detecting emergency modes and reliability of operation, which should be provided by fault tolerance and by ability to quickly replace of failed devices. To solve these problems, a simple high-speed ***MPR LIRA*** (*Local Integrated Relay Advanced*) was designed and manufactured.

II. MAIN PART

A. *Theoretical background*

The *LIRA* device uses an amplitude-phase method of calculating values to make a decision about the occurrence of an accident. Unlike the known methods for calculating the effective (*root mean square, r.m.s.)* values of currents and voltages for a quarter (0-45°) of the signal period, the calculation of instantaneous values of the signal amplitudes at points with phases i + 30° is used (Fig. 3).

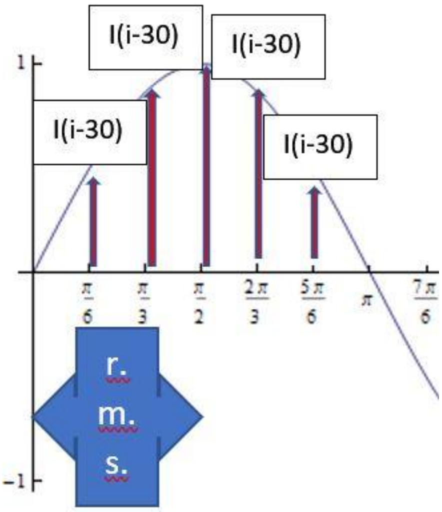

Figure 3. Amplitude phase measurements

This allows to make a decision about the occurrence of an alarm during 1/24 of the period (15°) in comparison with the measurement of the effective values of currents and voltages for half a period. The measured values are divided into two groups: *direct* measurements and *calculated* measurements. The first group includes input signals processed directly by the ADC, and the second group includes signals processed by the processor unit.

To obtain instantaneous signal values, the measurement channels are scanned by a 10-bit ADC. When the device is started, measurements are made at a frequency of 1200 Hz.

To detect accidents (such as *Line-Line, Line-Phase, Phase-Phase, Line-Ground*), symmetrical components are calculated on the basis of asymmetric decomposition system with three symmetrical components - direct (ABC_1), reverse (ABC_2) and zero (ABC_0) sequences for calculating the modes of a three-phase asymmetric network with short circuits [4], [5].

The essence of the method of symmetrical components is that any asymmetric three-phase system of current or voltage vectors can be replaced by the sum of three symmetrical systems:

$$\begin{aligned} \dot{A} &= \dot{A}_1 + \dot{A}_2 + \dot{A}_0 \\ \dot{B} &= \dot{B}_1 + \dot{B}_2 + \dot{B}_0 = \underline{a}^2\dot{A}_1 + \underline{a}\dot{A}_2 + \dot{A}_0 \\ \dot{C} &= \dot{C}_1 + \dot{C}_2 + \dot{C}_0 = \underline{a}\dot{A}_1 + \underline{a}^2\dot{A}_2 + \dot{A}_0 \end{aligned} \qquad (1)$$

The components of inverse sequence $3I_2$, $3U_2$ appear when any asymmetry occurs in the network: a single-phase or two-phase short circuit, phase breakdown, load unbalance. The components of the zero sequence $3I_0$, 3Uo occur during ground faults (one or two) or when one or two phases are broken.

The measurement frequency is adjusted so that there are exactly 24 measurements per period of the measured signal (15° between measurements).

B. *Calculation formulas*

For comparison with the settings, the values of the corresponding parameters are calculated every 10ms using the formulas.

The effective values of phase currents and voltages (I_{abc},U_{abc}), as well as voltages $3U_0$ are calculated by the formula :

$$(I_{abc}, U_{abc}, 3U_0) = \sqrt{\sum X_i^2/12} \qquad (1)$$

where X_i is the instantaneous value of the measured signal.

The effective current $3I_0$ is calculated by formula:

$$3I_0 = \sqrt{\sum(I_{ai} + I_{bi} + I_{ci})^2/12} \qquad (2)$$

where I_{ai} is the instantaneous value of the current (voltage) of phase ***a***;

I_{bi} is the instantaneous value of the current (voltage) of phase ***b***;

I_{ci} is the instantaneous value of the current (voltage) of phase ***c***.

The effective current $3I_2$ and voltage $3U_2$ are calculated by the formula:

$$3X_2 = \sqrt{\sum 3X_{2i}^2/12} \tag{3}$$

where: $3X_2$ - effective current $3I_2$ (voltage $3U_2$);
$3X_{2i}$ - instantaneous value of current $3I_2$ (voltage $3U_2$), calculated by the formula:

$$3X_{2i} = \sqrt{3(X_{ci} - X_{bi}) + X_{a(i-30^0)} + X_{b(i-30^0)} - 2X_{c(i-30^0)}} \tag{4}$$

where X_{ci} is the instantaneous value of the current (voltage) of phase ***c***;
X_{bi} is the instantaneous value of the current (voltage) of phase ***b***;
$X_{a(i-30^\circ)}$ is the instantaneous value of the current (voltage) of phase ***a*** 1/12 of the period ago;
$X_{b(i-30^\circ)}$ - instantaneous value of the current (voltage) of phase ***b*** 1/12 of the period ago;
$X_{c(i-30^\circ)}$ - instantaneous value of the current (voltage) of the phase ***c*** 1/12 of the period ago.

For accurately determining of the phase shift, every minute automatic frequency adjustment and hardware phase 0° detector are used.

C. Practical implementation

Digital processing in MPR LIRA [6] is carried out on the basis of an industrial microcontroller INTEL **87C196CA**. The device was developed in collaboration with the company SA Sandrologic Chishinau(www.sandrologic.md).The 87C196CA is based on Intel's MCS 96 16-bit microcontroller architecture and is manufactured with Intel's CHMOS process. The scheme for connecting the LIRA device to the measuring and executive circuits is shown in Fig.4. [5].

MPR LIRA performs the following functions:

- measurement of effective values of currents, voltages and then their transfer every 15 seconds to the SCADA supervisory control system;

- measurements and calculation of emergency values of currents and voltages;

- in the event of an accident in the network, an emergency oscillogram is recorded in the flash memory.

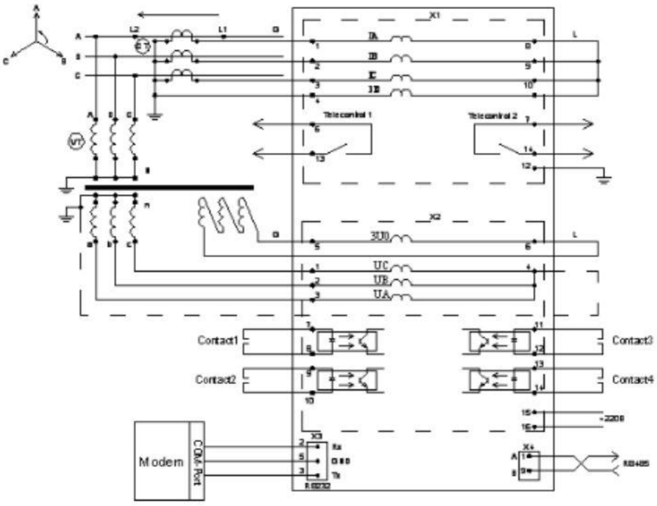

Figure 4. Scheme of connection to the measuring and executive circuits

To increase the speed of values calculation according to formulas (1)-(4) tabular methods are used.

The fault tolerance of the device is provided by Error Correcting Coding (ECC) methods based on the Hamming code for restoring information in the flash memory of programs in case of its failure. This allows to ensure long-term operation of the device at remote sites. To implement ECC, a hardware encoder-decoder based on the ALTERA MAX V FPGA is used.

The LIRA uses *alarm setpoints* for selecting the operating modes, beyond which the device recognizes the measured values as an alarm situation.

The alarm setpoints are set by the user as "trip" and "return" thresholds as valid secondary quantities

If the effective values of I_a, I_b, I_c, $3I_2$, $3U_2$, $3I_0$, $3U_0$ exceed the specified thresholds (settings), then an accident is recorded in the line.

An example of settings is presented in Table 1.

TABLE I. ALARM SETTINGS

Values	***Direction***	***Trigger***	***Processing***
I_{abc}	higher	5.25A	measurement
U_{abc}	higher	67.0V	measurement
U_{abc}	lower	48.0V	measurement
$3I_0$	higher	0.8A	calculation
$3U_0$	higher	15.0V	dimension
$3I_2$	higher	0.8A	calculation
$3U_2$	higher	15.0V	calculation
freq.	lower	49.0Hz	measurement

Alarm waveforms. An oscillogram of the instantaneous values of currents and voltages before the accident (10 periods) and after the occurrence of the accident (30 periods) is recorded in the flash memory.

In this case, an alarm is recorded for I_a, I_b, I_c, $3I_2$, $3U_2$, $3I_0$, $3U_0$, U_a, U_b, U_c. For each alarm, the following parameters are recorded: start time, end time, emergency settings flags (Fig. 5).

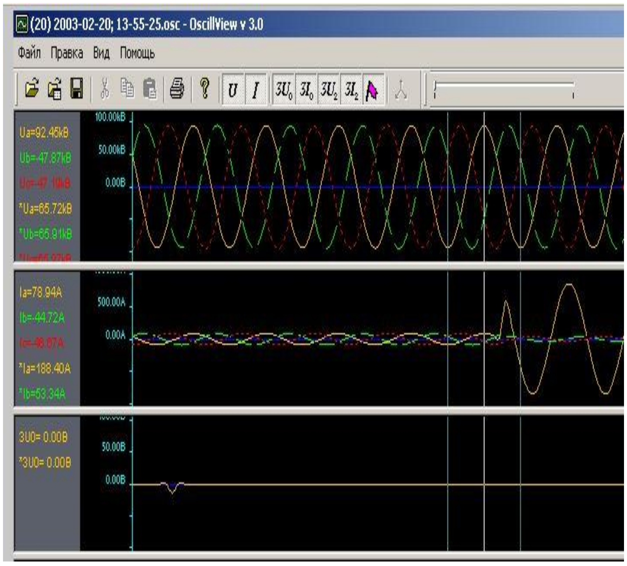

Figure 5. Alarm waveform of the LIRA device

LIRA devices are installed in HV grid PM objects, shown in Fig. 5 (with permission Sandrologic). During the testing of these devices, 12 accidents were recorded due to overcurrent, which completely coincided with the results detected by standard relay protection devices (electromechanical relays). There were no device failures. Pilot operation confirmed the high reliability and efficiency of the developed device.

Figure 5. LIRA device in a 110 kV substation

III. CONCLUSION

As a result of carried out research, the following conclusions can be drawn:

1. Amplitude-phase measurements of instantaneous values of three-phase currents and voltages ***I_{abc}, U_{abc}, $3I_o$, $3U_o$, $3I_2$, $3U_2$*** *allow to quickly (1/24 of the period) detect accidents with symmetrical and asymmetric overloads.*

2. The proposed algorithm ***is the first to be implemented*** on a microcontroller with standard architecture without the use of digital signal processors.

3. The carried out and observed Pilot operation of LIRA devices confirmed the reliability of accident detection algorithms and applied design solutions.

4. During the testing of these devices, 12 accidents were recorded due to overcurrent, which completely coincided with the results detected by standard relay protection devices (electromechanical relays).

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