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Digital Protection Relay for 22 kV Power Line Model with Partial Power Quality Measurement

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***Abstract* — The paper deals with the function and structure of a digital protection relay (DPR) used in 22 kV power lines. It contains the description of the relay's software and hardware and its realization. The device is designed for the three-phase 22 kV power line model. DPR is created for the microcontroller MCF51EM256. There were also algorithms designed for partial power quality (PQ) measurement for this microcontroller. Designed algorithm is programmed and debugged using the demo kit of the intelligent smart meter DEMOEM where this type of microcontroller has been used. The proper function of the created protection relay is verified by real model tests.**

Keywords* — *digital protection, power quality, THD, harmonics, power network analyzator

I. INTRODUCTION

With the increasing number of new computer technologies, digital protection relays are improved as well. They are becoming more spread and affordable. Digital protection relays can also perform several other tasks and thus they contribute to monitoring, control and operating of the electrical power system and its components in real-time [1].

Digital protections play a very important role in every electrical power system. During normal fault-free operating condition they are useless but when a system failure or abnormal condition occurs they are vital. If an electrical protection device is designed properly only the affected power line section is disconnected during a system fault and the rest of the system equipment can continue to operate independently [1].

The fundamental parts of this type of protection relays are digital circuits. All or some of the variables within these devices are displayed and processed using discontinuous (discrete) values. Individual data are displayed by combinations of log "0" and log "1". The digital device is able to processed the complex information about the entire object. In state space P the vector x(t) can be monitored in all n directions [1].

Technical progress in the areas of transformation, production, transportation and consumption of electricity, along with operating processes to support the market of this commodity raise questions about the quality of its delivery.

The result of this progress and effort to produce "green energy" is the introduction of renewable electrical energy sources and other devices used for production or consumption of electrical energy. (e.g. static frequency converters (inverters), cycloconverters, inverter cascades, induction motors and others). It is proved that these devices adversely affect the ideal sine in electrical power system, or eventually may have an indirect impact on short-term or long-term interruption of the supply. At electricity buyers, this fact can cause incorrect operation of devices and it can even cause damage to these devices in extreme cases. The issue of power quality is a matter of technical solutions and legislative measures focused on adhering to the prescribed quality as the obligation of the participating entities carrying out the electricity supply [2], [3], [5], [8].

In this paper, attention is paid to creation of the DPR device, which on the one had performs the classic protection functions to the model and on the other hand makes the basic assessment of PQ in the network.

II. HARMONICS

Voltage or current harmonics are voltages or currents with sinusoidal waveform and a frequency that is an integer multiple of the fundamental frequency at which a network is designed to operate. There may not be only harmonics with an integer multiple of the fundamental frequency in a network but harmonics whose frequency is not an integer multiple can also occur. These are called interharmonics and can be generated by various devices, e.g. static frequency converters (inverters), cycloconverters, inverter cascades, induction motors, arc welders or arc furnaces. The major negative effect of current harmonics is that the RMS value of a non-sinusoidal current is higher than the RMS of its fundamental component at which the equipment is designed [7], [6].

Harmful effects of harmonics can be divided as follows:

- Short-term – are associated with failure and malfunction or decreasing the quality of equipment operation caused by incorrect zero-crossing detection.
- Long-term – are essentially thermal effects. These occur after a time period of more than 10 minutes.

The most severe negative effects of harmonics in the field of electroenergetics are [1], [7]:

- Improper function of control devices.

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- Additional power losses in capacitors and rotating machines.
- Malfunction of telecontrol signals and other network signalization devices or protection relays.
- Occurrence of undesirable resonances.

The RMS value of a non-sinusoidal voltage waveform is expressed as follows [3]:

$$U = \sqrt{\frac{1}{T} \cdot \int_0^T \left[\sum_{h=1}^{\infty} U_h \cdot \sin\left(h\omega t + \varphi_{U_h}\right) \right]^2 d\omega t} = \sqrt{\sum_{h=1}^{\infty} U_h^2} \quad (1)$$

Similarly, the RMS value of current is:

$$I = \sqrt{\frac{1}{T} \cdot \int_0^T \left[\sum_{h=1}^{\infty} I_h \cdot \sin\left(h\omega t + \varphi_{I_h}\right) \right]^2 d\omega t} = \sqrt{\sum_{h=1}^{\infty} I_h^2} \quad (2)$$

For the voltage and current quality assessment STN EN 61000-2-4 stipulates total harmonic distortion factor (THD) as follows [3]:

$$THD_U = \sqrt{\sum_{h=2}^{40} u_h^2} \quad \text{, where} \quad u_h = \frac{U_h}{U_1}, \quad (3)$$

$$THD_I = \sqrt{\sum_{h=2}^{40} i_h^2} \quad \text{, where} \quad i_h = \frac{I_h}{I_1}, \quad (4)$$

where: U_1 and I_1 is the voltage and current fundamental component RMS value of a non-sinusoidal waveform, respectively.

U_h and I_h for h = 2, 3, 4,... are the RMS values of the harmonics [3].

An example of the superposition of odd-order harmonics is in Fig. 1. It shows the generation of a rectangular waveform signal caused by a rectifier harmonics which are superposed on each other [1].

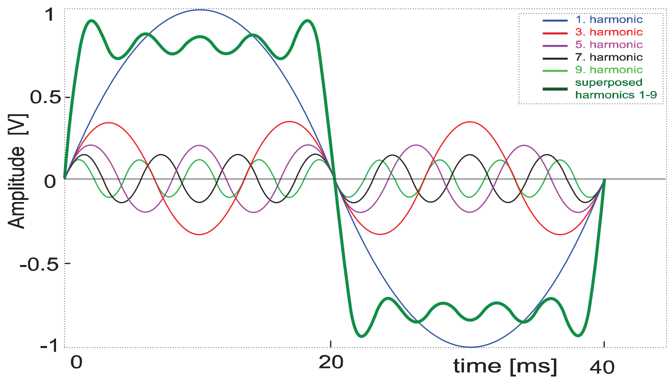

Fig. 1. The generation of a rectangular waveform on a rectifier

III. THE DIGITAL PROTECTION DESIGN

For realization of the digital protection relay the digital SMART metering demo board DEMOEN is used. The hardware and software of the protection relay is designed to cooperate simultaneously. Thus the complex protection system is created and ready to be used in 22 kV power line model.

The hardware of the designed digital protection model consists of three main parts: measurement unit, controller and output power unit.

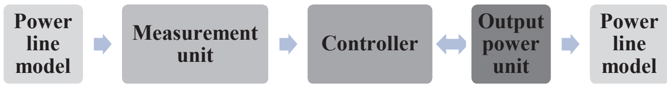

Fig. 2. The digital protection structure

A. Three-phase 22 kV power line model

Power lines are represented by RLC parameters. The conception of the model is based on an implementation of the basic passive electrical elements – resistances, capacitors and inductors and their connection in the form of π-section, which is accompanied by inductive and capacitive couplings. The earth return and its resistance was taken into a count as well. It consists of a combination of three basic single-phase π-sections connected to a common electrical ground, which is divided into two halves using the earth resistance R_0. The first two digits in the index of the capacitor label mean the numbers of phases between which the capacitor is connected and the third one indicates whether it is connected to the first half or the second one. The resistances R_1, R_2 and R_3 represent the active resistances of the phases. M_{12}, M_{13} and M_{23} are the mutual inductances between phases (Fig. 3) [9].

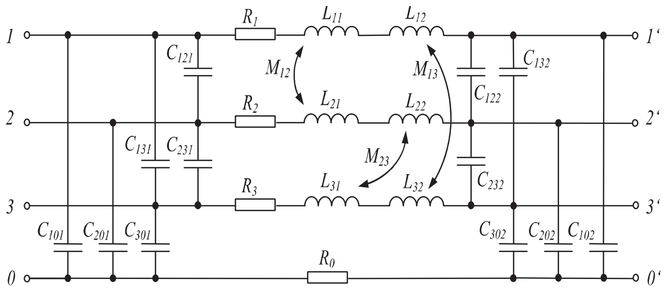

Fig. 3. Three-phase π-section connection

The transmission capabilities of π-sections lines influences mainly the resistance in the longitudinal branch and the capacitance in the transverse branch. The 22 kV network model is constructed in 1:100 scale. It consists of different modules, representing the line lengths of 2.5 km, 5 km a 10 km using AlFe 95/15 wire in a planar arrangement of conductors on concrete towers. The values of RLC parameters are shown in Table 1.

TABLE I. RLC PARAMETERS OF THE POWER LINE

R_1, R_2, R_3 ($\Omega.km^{-1}$)	L_1, L_2, L_3 ($mH.km^{-1}$)	M_{12}, M_{23} ($mH.km^{-1}$)	M_{13} ($mH.km^{-1}$)	C_{10}, C_{20}, C_{30} ($nF.km^{-1}$)	C_{12}, C_{23} ($nF.km^{-1}$)	C_{13} ($nF.km^{-1}$)
0.359	2.408	1.298	1.159	8.01	2.23	1.2

B. The measurement unit

This part of the model provides current and voltage measurements. The outputs are six low voltage analogue signals (0 ÷ 3,3 V). In order to transfer them to digital values, these signals are processed by A/D converter in the next step. The electrical scheme of the measurement unit is depicted in

Fig. 3. It is divided into two sections – current measurement (the upper part) and voltage measurement (the lower one). The currents are measured by current transducers LEM HY 10p, which convert actual currents flown through phases to corresponding output voltage signals in the range of ± 4 V. For phase voltages measurement voltage dividers are implemented. Since the controller is fed by the voltage of 0 ÷ 3,3 V it is able to process only positive voltage signals. Therefore, some DC offset must be added to the output signals so that they can be processed by the controller. This is executed by several operational amplifiers in the right hand side of the scheme. The voltage signals are superimposed by +1,65 V DC offset in the first step to ensure all the signals range from 0 to 3,3 V with +1,65 V DC as the mean value. Next, antialiasing filters are applied to reduce signal noise and ripple. The analogue signals obtained in this form are suitable for A/D converter processing and some other devices as well (e.g. data acquisition cards).

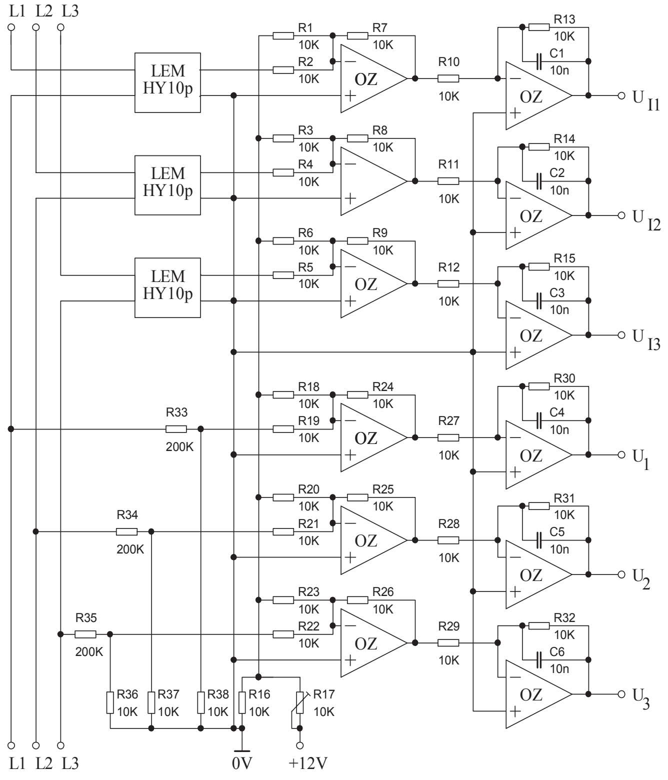

Fig. 4. The electrical scheme of the measurement unit

C. The Controller

The core of the control unit is SMART metering demo board DEMOEM with microcontroller MCF51EM256. For this microprocessor the following algorithms are implemented: overcurrent protection (instantaneous and time overcurrent), line distance protection, earth-fault directional protection for earth-faults detection in the networks with isolated neutral point and partial PQ measurement.

From automatic functions autoreclosing was integrated. The communication with the actuator is done using serial port RS232, which provides monitoring of the individual protections statuses, autoreclosing, power circuit breaker and all the measured variables.

Designing the measurement algorithm is based on already created libraries and pre-programmed algorithms which are contained in the DEMOEM software [4]. Used MCF51EM256 microcontroller contains four 16-bit A/D converters, whose task is to change analog values to discrete values, so that they could be processed by the microcontroller. In our case we used three A/D converters for three voltage signals and three current signals measurements [4]. Each converter uses multiplexer for measurement of two channels (voltage and current). Individual samples are saved in the memory (buffer) and after sampling of an entire period, they are used for calculation of RMS values from measured signals.

The structure of designed algorithm starts with the main function of the program ***main()***, which includes the initialization of individual peripherals. The initialization of peripherals is shown in the part of the source code:

MCU_init(); // initialization of microprocessor registers,
vfnLCD_Init(); // initialization of LCD,
sampling_init(); // initialization of sampling frequency, whose value is 12 800 samples per second, which means 256 samples per period.

A part of the main function main() is an endless cycle, which consists of functions listed in the following example of the source code:

ptr_next_task(); // call of current function for displaying on LCD (displaying one out of calculated parameters with function Measurements()),

Measurements();// function for parameters calculation.

The function *Measurements()* contains algorithms for calculation of effective values of voltage, current, active, reactive and apparent power, power factor, THD for each phase separately. As an example, there is shown the calculation of phase parameters in the function Measurements() in the following part of the source code [4]:

Calculation of effective values of voltage, current and power:

Power_Calc(&Vec6[0], &Vec3[0], &DPower1[i1]), where:

&Vec6[0] is an address of the saved samples of voltage signal,

&Vec3[0] is an address of the saved samples of current,

&DPower1[i1] is an address of structure for the results listing (U, I, P).

Calculation of complex value for the 1^{st} harmonic of voltage:

DDFT_u1[i1] = DFT(&Vec6[0]);

Calculation of complex value for the 1^{st} harmonic of current:

DDFT_i1[i1] = DFT(&Vec3[0]);

Individual calculations are repeated 8 times and subsequently the average value, which is obtained carrying out the previous steps, is calculated according to the formula (3.1).

$$X_{AVG} = \sum_{i=0}^{7} X[i] \qquad (5)$$

The next part of the code express:

Calculation of average value out of calculated effective values of voltage, current and power:

Average(&DPower1[0], &Power1);

Calculation of average complex value for the 1st harmonic of voltage:

DFT_u1 = DFT_Average(&DDFT_u1[0]);

Calculation of average complex value for the 1st harmonic of current:

DFT_i1 = DFT_Average(&DDFT_i1[0]);

Absolute effective values for the 1st harmonic of voltage and current are calculated from average complex values. These calculations are performed in the following lines of the code part:

RMS_DFT_u1 = RMS_DFT_calc(DFT_u1);
// calculation of absolute effective value U,

RMS_DFT_i1 = RMS_DFT_calc(DFT_i1);
// calculation of absolute effective value I.

The factor of harmonic distortion for voltage (THD_U) and current (THD_I) is subsequently calculated, what is shown in the following part of the source code:

THD_u1 = THD_calc(Power1.Vrms, RMS_DFT_u1);
// calculation of THD_U,

THD_i1 = THD_calc(Power1.Irms, RMS_DFT_i1);
// calculation of THD_I.

Algorithm for the calculation of total harmonic distortion THD was designed according to these formulae:

$$THD_U = \frac{1}{U_1} \cdot \sqrt{U - U_1} \cdot 100\, ; \; THD_I = \frac{1}{I_1} \cdot \sqrt{I - I_1} \cdot 100 \qquad (6)$$

where U, I are values of the total effective value of voltage and current for one phase,

U1, I1 – absolute effective values for the 1st harmonic of voltage and current.

Absolute effective values for the 1st harmonic of voltage and current were obtained from average complex values which were obtained from discrete Fourier transformation. This is calculated according to the following formulae:

$$U_1 = \sqrt{\frac{U_{real}^2 + U_{imag}^2}{2}}, \qquad I_1 = \sqrt{\frac{I_{real}^2 + I_{imag}^2}{2}} \qquad (7)$$

One of the basic protections is overcurrent protection. This type of the protection has two main stages. The first one reacts on the overcurrent and second one reacts on the short circuit current. The difference between these two stages are starting current and tripping time. The possibility how to adjust a nondirectional overcurrent protection is as follows:

OverLevel_I *(Val_I, strVal_I, endVal_I, tripTime_I, prtIndex_I);*

Where *Val_I* – measured phase currents,
strVal_I – starting current value,
endVal_I – holding current value,
tripTime_I – ripping time,
prtIndex_I – protection stage index.

According to the algorithm, RMS value of the current is computed instantly and compared with the desired value. Similarly, phase voltages can be monitored as well but only for signalization in the case of voltage sag or power supply loss.

The algorithm of the earth-fault directional protection is adjusted in such a way that it analyses and compares tree variables – voltage and current zero sequence and their phase angle. The phase angle is computed on the base of signal zero crossing and in the case of sampling frequency of 256 samples per second the accuracy is $\Delta\varphi = 1{,}4°$. The algorithm analyses whether the following three conditions are fulfilled at the same time:

1) $U_0 > 40$ % of U_N
2) $I_0 > 1 \div 4$ % of U_N, 0,5 % step size (depending on the power line length)
3) $P_0 > 0 \Rightarrow \varphi$ □ < – 90° , 90° > (power flows from the source)

The distance protection algorithm evaluates the magnitude of a fault loop. For the algorithm circle shape impedance diagram was used with the center in the origin of R-X axis system. In the protection, there are three stages of the starting impedance values and the corresponding tripping times.

Every digital protection includes autoreclosing function. This function is called every time when any of the protection algorithms detects a fault. In the algorithm the potential-free time and blocking time is adjusted.

The algorithm is implemented into the microprocessor memory and thus the control unit is created and it is able to control the entire protection device.

D. The output power unit

Fig. 5. shows the electrical scheme of the power section that is controlled by a bistable flip-flop circuit. The trip signal enters the set input of this circuit and at the reset input the control and interlocking of autoreslosing is brought. The essential power component of the output unit is a relay, which provides disconnecting of the power line section from the power supply and guarantees a secure galvanic isolation between the electronic equipment and the power circuit.

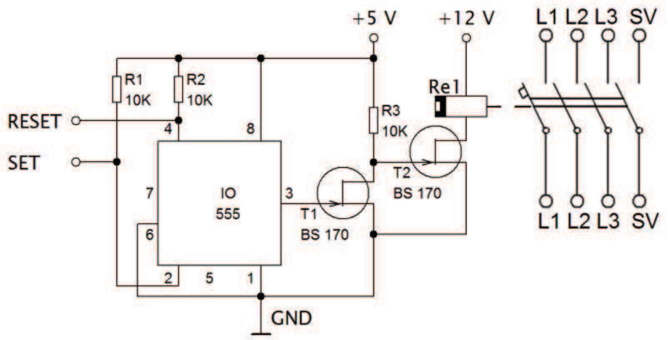

Fig. 5. The output power unit scheme

IV. MEASUREMENTS

In order to prove the correct function of the device, it was necessary to perform some tests. One of these tests is to investigate the output unit reaction on the trip signal, autoreclosing and blocking time. Fig. 4 shows the time-base principle of the digital protection operation. Three different time values were measured – delay time, potential-free time and blocking time of autoreclosing. The acquired times are compared with their preset values in Tab. 1.

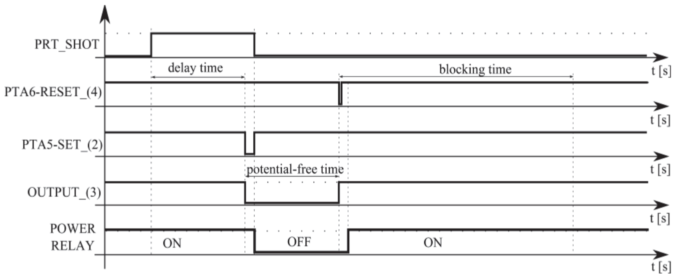

Fig. 6. Time-base principle of the digital protection operation

It is clear, that the timer is designed properly. Thus the implementation of the timer in the digital protection relay is possible and satisfactory.

TABLE II. MEASURED TIMES AND THEIR PRESET VALUES

Delay time		Potential-free time		Blocking time	
preset	measured	preset	measured	preset	measured
0,2 s	0,209 s	0,3 s	0,302 s	3 s	3,00 s
0,3 s	0,311 s	0,5 s	0,518 s	5 s	5,02 s
0,5 s	0,505 s	0,8 s	0,825 s	10 s	10,09 s
1 s	1,01 s	3 s	3,01 s	20 s	20,2 s

The measurement with non-sinusoidal load consisted of the rectifier connection with resistive load. There was connection of the digital protection and measurement of the power network analyzer BK-ELCOM PNA571 in the point of load. It was used for comparison of measured values outputted by the device. Scheme of measurement in 22 kV power line model is shown in Fig. 7. The measurement realization in laboratory environment is shown in Fig. 8.

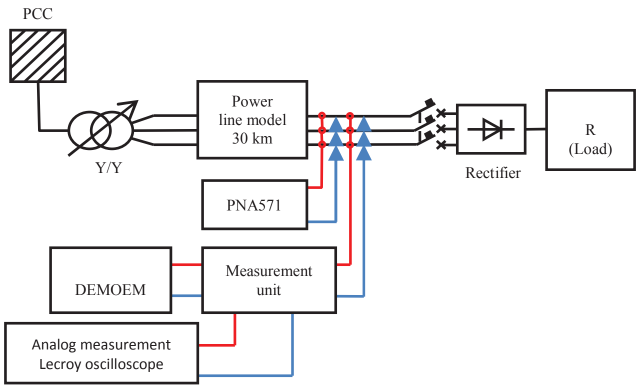

Fig. 7. Scheme of PQ measurement in 22 kV power line model

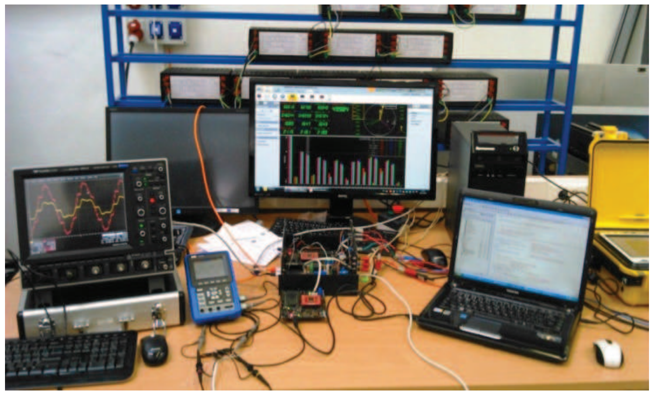

Fig. 8. Realization of the measurement

The following table shows selected measured values U, I, THDU and harmonics for phase L1. There are values of the DEMOEM with implemented algorithms in the right part of the table and the left part of the table shows values obtained from certificated device PNA.

TABLE III. MEASURED VALUES OF HARMONICS

		BK-ELCOM PNA571			**DEMOEM**		
		1	**2**	**3**	**1**	**2**	**3**
	$I_{RMS(L1)}$ **(A)**	1	1,5	2	0,98	1,47	1,97
	$U_{RMS(L1)}$ **(V)**	32,04	47,39	62,95	31,8	47,1	62,3
	$THD_{U(L1)}$ **(%)**	28,54	28,88	28,92	28,4	28,7	28,8
	Fundamental	30,73	45,44	60,01	30,2	44,9	59,3
harmonic	**3**	0,15	0,34	1,28	0,1	0,3	1,1
	5	6,36	9,52	12,11	6,1	8,9	11,8
	7	3,82	5,67	7,61	3,3	5,1	7,2

We can see that the values for individual harmonic voltage (except for little variations) are almost the same at comparison between values measured with DEMOEM and values measured with commercial device. Therefore we can state that designed algorithm for the calculation of Fourier transformation was correct.

V. Results

The created digital protection relay is primarily designated to protect 22 kV power line model but it can be employed in many other applications such as education purposes or illustration of the electric protection operation.

The algorithm was implemented to the device. This algorithm was designed to measure the voltage and current RMS, active, apparent and reactive power, the real power factor, Fourier transformation, by means of which the frequency spectra of voltage harmonics were obtained and finally the calculation of total harmonic distortion.

There were algorithms for pre over-current and short-circuit current protection, voltage protection, earth-fault relay, distance protection and also autoreclosing function out of protective functions.

Since it is a digital device, it is possible to easily modify its software and a new control algorithm or communication with other devices can be implemented. The model of digital protection is suitable for the next research and because it contains demo board, various built-in modules and functions can be used in the future.

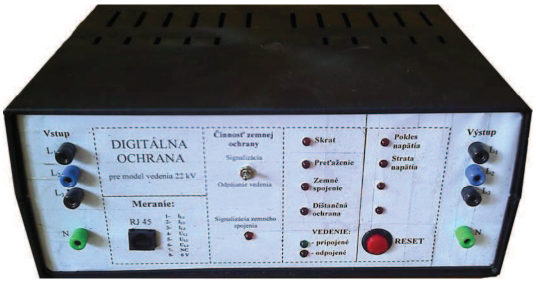

Fig. 9. Digital protecton relay

References

[1] J. Blackburn and T. Domin, "Protective relaying, Principles and Applications, " CRC Press 207, ISBN 1-57444-716-5

[2] R. C. Dugan, M. F. Mcgranaghan, S. Santoso and H. W. Beaty "Electrical Power Systems Quality, " Third Edition, The McGraw-Hill Companies, Inc., NY, USA, 2012, ISBN 978-0-070176155-0.

[3] J. Altus, M. Novák, A. Otčenášová and M. Pokorný "Elektromagnetická kompatibilita elektrizačných sústav," Žilinská univerzita v Žiline, EDIS, 2004. ISBN 80-8070-227-6.

[4] DEMOEM User Manual, [online] [cit. 15.01.2015]: http://cache.freescale.com/files/microcontrollers/doc/user_guide/DEMOEMUM.pdf

[5] P. Bilik, L. Koval and J. Hula, "Modular System for Distributed Power Quality Monitoring," In Conference proceeding of 9th International Conference on Electrical Power Quality and Utilisation EPQU2007, Barcelona (Spain), Oct. 09-11, 2007. Electrical Engineering Department TU of Catalonia, 2007, p. 769-773. ISBN 978-84-691-0057-8

[6] M. Tesařová, "Wide Area Measurement System Applications and Experience Abroad," In Proceedings of the 13th International Scientific Conference Electric Power Engineering 2012. Brno: Brno University of Technology, 2012. ISBN: 978-80-214-4514-7

[7] T. Josefova and V. Kus, "New insights into the harmonic analysis of voltage-source active rectifier," Proceedings of the 14th international scientific conference ELECTRIC POWER ENGINEERING 2013, Ostrava: VSB - Technical University of Ostrava, pp 319-324. Published: 2013, ISBN 978-80-248-2988-3.

[8] M. Kašpírek and D. Mezera, "Problems of voltage quality in low voltage distribution grids," Proceedings of the 13th International Scientific Conference ELECTRIC POWER ENGINEERING 2012, Brno University of Technology, Faculty of Electronical Engineering and Communication, Department of Electrical Power Engineering, 23-25 May 2012, Brno, ISBN 978-80-214-4514-7

[9] M. Reguľa, D. Szabó and A. Otčenášová "Voltage quality analyses in laboratory enviroment," Proceedings of the 7th International Scientific Symposium on Electrical Power Engineering ELEKTROENERGETIKA 2013, Stará Lesná, SR, 2013, 09, 18.-20., pp 300-303, ISBN 978-80-553-1441-9.