S. M. Levytskiy, Cand. Sc. (Eng.); O. O. Matienko

MICRO-PROCESSOR DEVICE FOR CONTROL OF PHASE-SHIFTING TRANSFORMER USING TWIDO CONTROLLER

The paper considers the usage of microprocessor controller TWIDO in energy supply systems with longitudinal-shifting voltage regulation. Functional and software realization of microcontroller has been elaborated. Characteristic feature of this version, as compared with already known versions is the application of PID-regulator function for definition of derivative sign of envelop reactive power. This realization enables to optimize the duration of program cycle execution.

Key words: *microcontroller, regulation.*

Introduction

Significant advantage of programmable logic controllers (PLC) application for the systems of voltage regulation is the possibility to elaborate software using the accumulated experience of design, adjustment and operation of automatic regulators. Besides, manufactured PLC possess higher flexibility in the process of control, regulation, diagnostics, than their microprocessor- based analogs, realized as ready-to-use device.

In [1] PLC is suggested to use as primary basic structure of information-measuring systems in energy branch of national economy, but there are no programming means for these units. In [2] the usage of PLC-based control facilities for energy supply systems of electrometallurgy enterprises is substantiated and proposed, but peculiarities of operation of depreciated on-load tap-changing units, including phase-shifting transformers are not taken into consideration. That is why, the problem of elaboration of PLC-base devices, intended for automatic control of the transformers remains actual.

Law of phase-shifting transformer control

In the process of using phase-shifting transformers (PST) the correction of energy supply systems operation mode must be carried out simultaneously by voltage, that stipulates the usage of joint longitudinal-transversal voltage regulation.

In [3] the system of automatic control of on-load tap changing units for transformer complex with longitudinal-transversal voltage regulation is suggested, this system operates in accordance with regulation law (1).

$$u_y(t) = k_1\left[(U_{out}(t) - U_y) - k_2(I_{load}(t) - I_{\min})\right];\ \ u_x(t) = k_3\left[(Q_{set} - Q(t)) + k_4(P(t) - P_{set})\right];$$

$$k_i = \begin{cases} \dfrac{U_{i+1}}{U_{lv}},\ if \begin{cases} u_y(t) < u_{lz.y}; \\ u_y(t\text{-}\tau) < u_{lz.y}; \\ \dfrac{dU_{out}(t)}{dt} < 0; \end{cases} \\ \dfrac{U_i}{U_{lv}},\ if\ u_{lz.y} \le u_y(t) \le u_{hz.y}; \\ \dfrac{U_{i-1}}{U_{lv}},\ if \begin{cases} u_y(t) > u_{hz.y}; \\ u_y(t\text{-}\tau) > u_{hz.y}; \\ \dfrac{dU_{out}(t)}{dt} > 0; \end{cases} \end{cases} \qquad k_j = \begin{cases} \dfrac{U_{j+1}}{U_{hv}},\ if \begin{cases} u_x(t) < u_{lz.x}; \\ u_x(t\text{-}\tau) < u_{lz.x}; \\ \dfrac{dQ(t)}{dt} > 0; \end{cases} \\ \dfrac{U_j}{U_{hv}},\ if\ u_{lz.x} \le u(t) \le u_{hz.x}; \\ \dfrac{U_{j-1}}{U_{hv}},\ if \begin{cases} u_x(t) > u_{hz.x}; \\ u_x(t\text{-}\tau) > u_{hz.x}; \\ \dfrac{dQ(t)}{dt} < 0. \end{cases} \end{cases}, \qquad (1)$$

where k_i – is transformation ratio at i^{th} winding tap of HV; U_y –is set voltage value at load taps; $U_{load}(t)$ – is real value of the voltage at loads outputs; U_i – is EMF, induced in HV winding at i^{th} tap; k_1 – is sensitivity factor of voltage regulator; k_2 – is slope factor of voltage regulation characteristic, $k_2 = 0{,}05 \cdot U_{nom} / (I_{max} - I_{min})$; I_{min} – is load current in minimum mode; $I_{load}(t)$ – is real value of load current; $dU(t)/dt$ – is a derivative of controlled voltage envelope; $u_{tz.y}$, u_{bz}, $u_{tz.x}$, $u_{bz.x}$ – are top and bottom boundaries of nonsensitivity zones, which are set proceeding from the conditions of reliability and accuracy of regulated parameter support, by longitudinal and lateral components, correspondingly; $u_y(t)$ – is the voltage at the outlet of power transformer; $u_x(t)$ – is the voltage at the outlet of phase shifting transformer (PST; U_j – is EMF, induced in feeding winding of PST at j-th tap; k_j – is transformation ratio at j-th tap of PST; Q_{set} – is set value of reactive power, determining the stability of energy supply system mode with minimum voltage deviations in energy nodes;

k_3 – is sensitivity factor of automatic control unit of TCUL PST; $dQ(t)/dt$ – is the derivative of reactive power envelope, transferred across transformer substation from PST. Structural diagram of such system of voltage regulation is shown in Fig. 1.

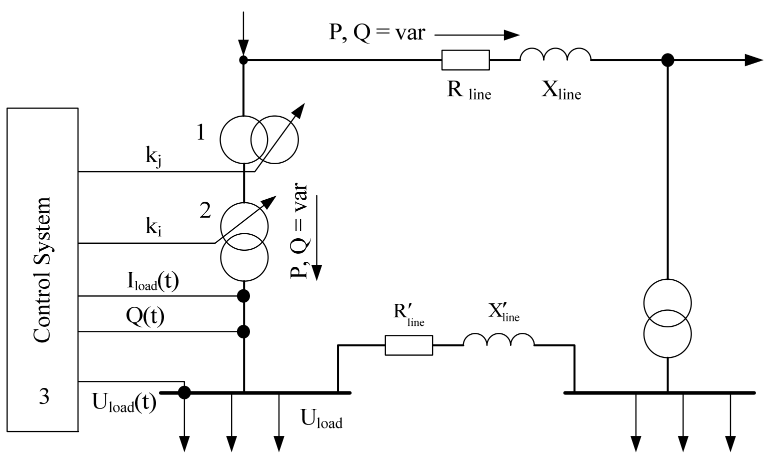

Fig. 1. Structural diagram of energy supply system with phase-shifting transformer: 1 phase-shifting– transformer , 2 – power transformer with tap changing under load, 3 – control system

Virtual model and the program of controller operation

Functional diagram of control system 3 using programmable logic controller, will have the form, shown in Fig. 2.

For organization of transformer complex control module controller *Twido TWDLMDA20DTK with diffusion transistor discrete outputs of 24 V* d.c., man-machine interface based on operator panel *XBTR410,* that enables to perform tuning of settings and nonsensitivity zone of remote *Modbus* [4]. Discrete outputs of the controller *%Q0.1 – %Q0.4*serve as output signals of control unit that switch starters TCUL electric drives in order to increase or decrease transformation ration k_i of power transformer and k_j of phase-shifting transformer correspondingly.

Basic controller has one built-on analog input, and for control system at least four inputs are required (active, reactive power, voltage and load current), that is why, in configuration of basis module we should provide expansion module of analog inputs with unified current signals 0-20 mA *TWDAMI4LT* (on 4 inputs). For matching of the signals from instrument current and voltage transformers (VT and CT correspondingly), voltage transducers and current transducers of TIT type are provided [5], as well as active and reactive power converters (APC and RPC correspondingly) of
E849-M1 type [6], having accuracy rating 0,5 and certified by manufactures as fast acting transducers.

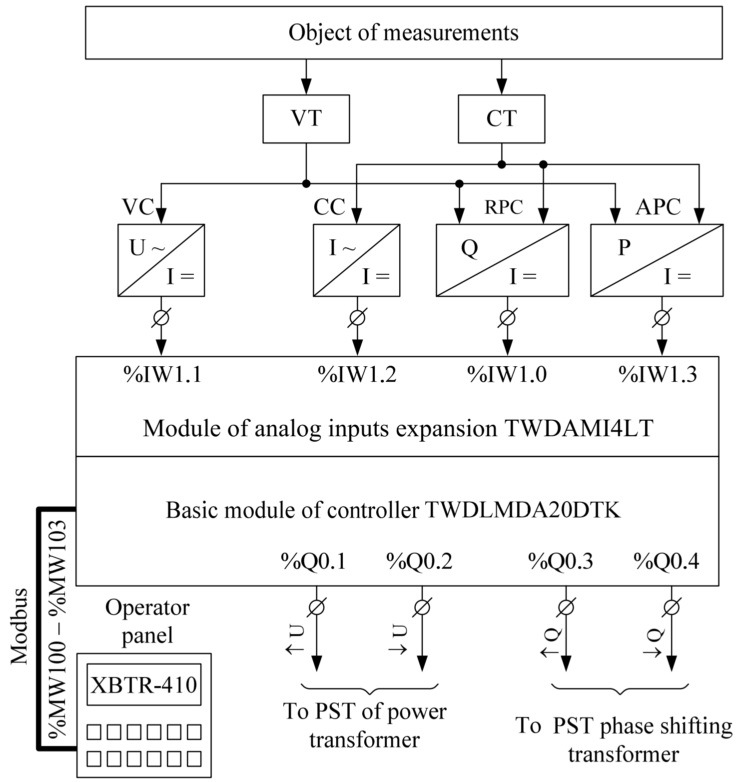

Fig. 2. Functional diagram of control system for tap-changing under load transformers

Virtual model of such control system is shown in Fig. 3.

Module of analog inputs expansion, adjusted to basic configuration of the controller, if controller program addresses it, will have internal index of variables 1, and inputs/outputs of basis module are assigned 0.

The suggested structure operates in the following way. Input *%I0.0* indicates the execution of the problem, i.e. shifts the controller in RUN operation mode. For internal bit %M1 the cycle is formed to activate this bit. The period *%M1* bit activation corresponds to pulses formation of *TCUL* electric drive circuit, and pause, corresponding to delay tome of control system τ formation(1). Memory bit of *%M5* controller performs the same function, but the duration of the pause between its activations corresponds to motion time of TCUL transform unit from one position into neighboring position, i.e. to the state of control system in switching mode.

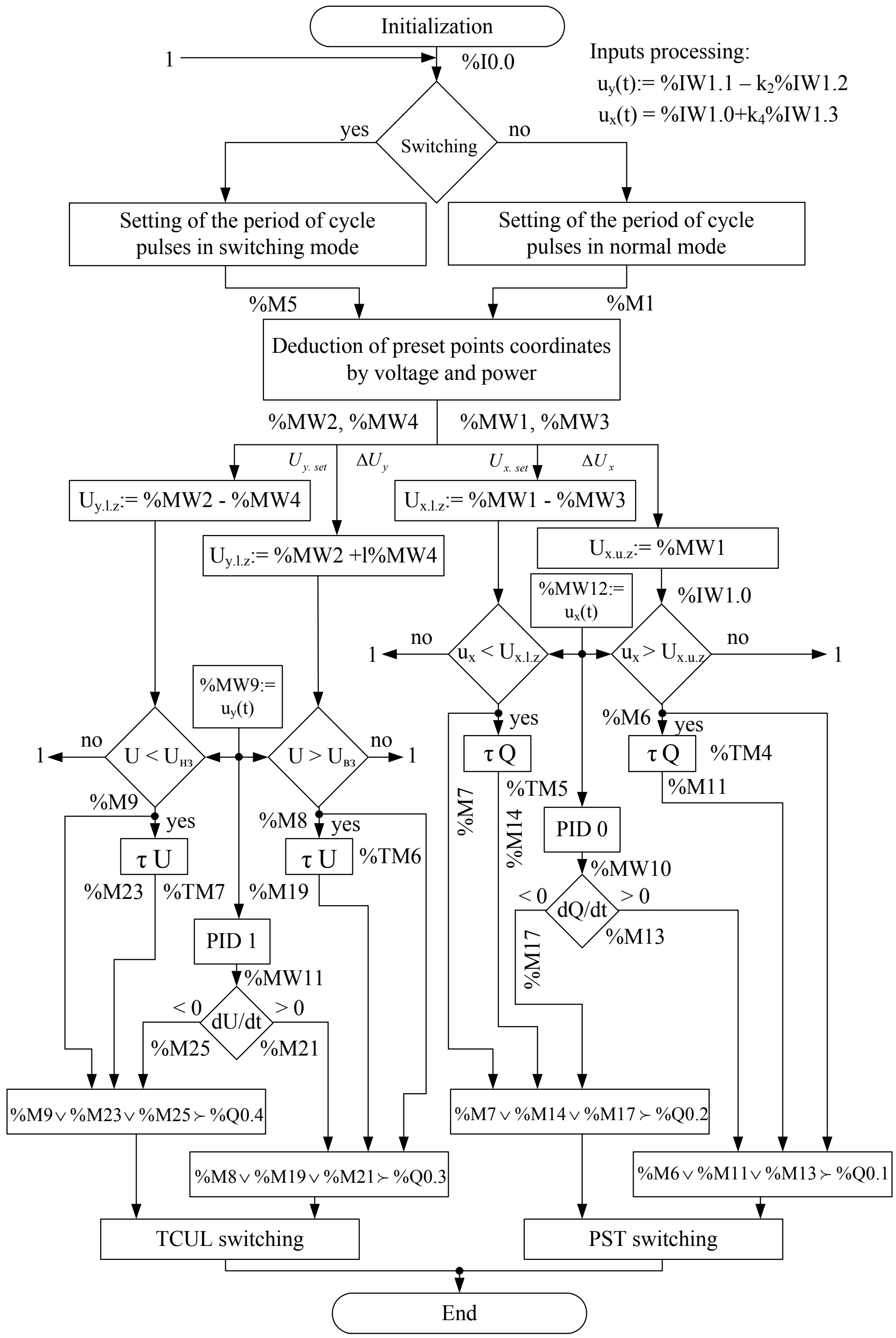

Fig. 3. Virtual model of programmable controller for the system of transformer complex control

Internal registers (words) of memory controller *%MW1* and *%MW2* by means of values *%MW100 – %MW103* introduced in operator panel are assigned regulator setting values of longitudinal and transversal voltage components at measuring unit of the regulator, and words *%MW3* and *%MW4* are assigned values of non-sensitivity zones of the regulator of longitudinal and transversal components correspondingly. The results of computation of upper and lower boundaries of deviation of transversal component of regulation law U_x are written in controller *%MW5* and *%MW6* results of calculation of longitudinal component U_y are written in words *%MW7* and *%MW8*.

Signals from transducers APC, RPC, VC and CC, arrived at expansion module inputs, are read by the programme and written in correspondingly words of the controller *%IW1.0*, *%IW1.1*, *%IW1.2* and *%IW1.3* (Fig. 2). The value of initial word *%MW0* is assigned the result of calculation of current compensation in regulation law, word *%MW9* is assigned the value, corresponding the voltage U_y at measuring unit of regulator (in accordance Fig. 3, real value of transversal component of the voltage at measuring unit of the regulator $u_x(t)$ is obtained by means of arithmetic operations according (1) with words *%IW1.0* та *%IW1.3* and is written into words *%MW12*).

Further execution of the programme by the controller is divided into two directions: formation of control signals of TCUL unit of power transformer and TCUL of PST. We will consider in details the operation of the programme, corresponding to control route of TCUL.

If the value of *%MW9* word is less than the value, written in register *%MW7* (low setting by the voltage), then bit *%M9* is activated, if this value is greater, than the content of the register *%MW8* (upper setting by voltage),then bit is activated *%M8*. Time delay τ for control signal formation is set in this channel by timers *%TM6* and *%TM7* along the channels of signals formation «Increase» and «Decrease» correspondingly. If for instance, the voltage at the terminals of load exceeds the limits of non-sensitivity zone in the direction of increase, and does not return in this zone during time τ , then *%M8* remains active during this time, and this results in activation of time *%TM6* output and bit *%M19*, connected with it.

Sign of voltage envelop derivatives is calculated by means of built-in function *PID* 1and comparison element (procedure of this function adjustment for calculation of voltage envelop derivative is described below). Derivative of voltage envelop is written by the function *PID* 1 into internal register *%MW11*, if the content of this register is positive or equal 0, then bit *%M21* is activated, and if the content is negative (or equal 0), then bit *%M25* is activated. Thus, if the voltage at the terminals of the load exceeds the value of non-sensitivity zone (bit *%M8*), and does not return in it during time τ (bit *%M19*), and does not have the trend to decrease (envelop derivative equal 0 or positive but bit *%M21*), the controller forms the switching signal for TCUL of power transformer in the direction of voltage decrease. Bits *%M21* and *%M25* are inverse, i.e., if the derivative of voltage envelop was positive, and then it became equal 0, in this case *%M21* is active, if the voltage drops , then the derivative of voltage envelop becomes negative that leads to reset of bit *%M21* and activation of bit %M25. Other channels of signals formation for TCUL switching operate in the same manner.

An important step in the process of programme development is organization of calculation frame of regulated parameter derivative. Two PID-regulators (PID 0 – for calculation of reactive power envelop derivative, *PID* 1 – for calculation of voltage envelop derivative) are configurated correspondingly. In accordance with the theory of automatic control, PID-regulator forms at its output signal, proportional to the value, duration and rate of regulated parameter deviation from preset value [7]. Hence, there is a signal at the input of PID-regulator equivalent to the difference of real value of the parameter and preset value. In our case, if set point equals 0, then at the input of PID-regulator we obtain inverse value of the parameter (for negative feedback). That is why, in the program the output signal of PID-regulator should be inverted and set zero value of amplification factor and time of integration [4].

For data exchange between programmable controller and operator panel, we should use as the set values of settings and regulator non-sensitivity zone, such user address words, which further will be connected with the values of panel data input fields. Such problem is solved by while operator panel configuration by means of the software (for instance, *XBT-L1000*). Parallely with assigning of controller words values it is necessary to match networking designation of the controller and the panel, setting the panel in master mode, and controller-in slave mode with corresponding address in the network.

Example. Programme of controller operation, is developed in *TwidoSoft* environment in *List Instruction* language in accordance with the suggested virtual structure (Fig. 3).

```
LD %I0.0.0
ANDN %M4
S %M0
BLK %TM0
LD %M0
IN
OUT_BLK
LD Q
S %M1
END_BLK
BLK %TM1
LD %M1
IN
OUT_BLK
LD Q
R %M0
R %M1
END_BLK
LD %Q0.0.1
OR %Q0.0.2
OR %Q0.0.3
OR %Q0.0.4
S %M4
LD %I0.0.1
R %M4
LD %M4
S %M5
BLK %TM2
LD %M5
IN
OUT_BLK
LD Q
S %M2
END_BLK
BLK %TM1
LD %M2
IN
OUT_BLK
LD Q
R %M5
R %M2
END_BLK
LD %M1
OR %M2
ST %M3
LD %I0.0.0
[%MW1:=%MW100]
LD %I0.0.0
[%MW2:=%MW101]
LD %I0.0.0
[%MW3:=%MW102]
LD %I0.0.0
[%MW4:=%MW103]
LD %I0.0.0
[%MW5:=%MW1]
LD %I0.0.0
[%MW6:=%MW1-%MW3]
LD %I0.0.0
[%MW7:=%MW2+%MW4]
LD %I0.0.0
[%MW8:=%MW2-%MW4]
LD [%IW0.1.0>
%MW5]
ST %M6
LD [%IW0.1.0<
%MW6]
ST %M7
LD %I0.0.0
[%MW0:=%IW0.1.2 /
10]
LD %I0.0.0
[%MW12:=%IW0.1.0+
0.2%IW0.1.3]
[%MW9:=%IW0.1.1
-%MW0]
LD [%MW9>%MW7]
ST %M8
LD [%MW9<%MW8]
ST %M9
LD %I0.0.0
[PID 0]
LD %I0.0.0
[PID 1]
LD %I0.0.0
[%MW12:=%MW10*%
KW1]
LD %I0.0.0
[%MW13:=%MW11*%
KW1]
LD [%MW12>=0]
AND %M6
ST %M12
BLK %TM4
LD %M6
IN
OUT_BLK
LD Q
ST %M10
END_BLK
LD %M10
AND %M3
ST %M11
LD %M12
ANDN %M11
S %M13
LD %M7
R %M13
LD %M13
AND %M6
AND %M11
ANDN %I0.0.2
ST %Q0.0.1
LD [%MW12<=0]
AND %M7
ST %M16
BLK %TM5
LD %M7
IN
OUT_BLK
LD Q
ST %M14
END_BLK
LD %M14
AND %M3
ST %M15
LD %M16
ANDN %M15
S %M17
LD %M6
R %M17
LD %M17
AND %M7
AND %M15
ANDN %I0.0.2
ST %Q0.0.2
BLK %TM6
LD %M8
IN
OUT_BLK
LD Q
ST %M18
END_BLK
LD %M18
AND %M3
ST %M19
LD [%MW13>=0]
AND %M8
ST %M20
LD %M20
ANDN %M19
S %M21
LD %M9
R %M21
LD %M21
AND %M8
AND %M19
ANDN %I0.0.2
ST %Q0.0.3
BLK %TM7
LD %M9
IN
OUT_BLK
LD Q
ST %M22
END_BLK
LD %M22
AND %M3
ST %M23
LD [%MW13<=0]
AND %M9
ST %M24
LD %M24
ANDN %M23
S %M25
LD %M8
R %M25
LD %M25
AND %M23
AND %M9
ANDN %I0.0.2
ST %Q0.0.4
LD %I0.0.2
ST %Q0.0.5
LD %M3
ST %Q0.0.6
END
```

Tables of tuning parameter *PID* 0 and *PID* 1 are given below.

```
PID 0: configured
+-----------------------------+-GENERAL-----------------------------+
|Operating mode: PID          |                                     |
|PID Status: Inhibit          |                                     |
+-----------------------------+-INPUT-------------+-----------------+
|Current value: %IW1.0        |                   |                 |
|Conversion: Inhibit          | Min:              | Max:            |
|Alarms: Allow                | Low: 5            | Output:  %Q0.7  |
|                             | High: 95          | Output:  %Q0.8  |
+-----------------------------+-PID---------------+-----------------+
|Setpoint:          0         |                   |                 |
|Kp: %KW0                     | Ti: 0             | Td:  10         |
|Sampling period:  20         |                   |                 |
+-----------------------------+-AT----------------+-----------------+
|AT mode: Inhibit             | Limit:            | Output:         |
+-----------------------------+-OUTPUT------------+-----------------+
|Action: Invert               |                   |                 |
|Thresholds: Allow            | Min: %KW2         | Max: %KW3       |
|Manual mode: Inhibit         | Output:           |                 |
|Digital output: %MW10        |                   |                 |
|PWM: Inhibit                 | Period:           | Output:         |
+-----------------------------+-------------------+-----------------+
```

Fig. 4. Window of contour tuning parameters of PID-regulator PID 0

Current value of measured parameter of the selected PID-regulator is marked in the program of external variables of the controller by word *%IW1.0,* in the same row the range of input word variation is indicated form 5 to 95 technological units. If the measured parameter decreases, outside the selected range operation of discrete output *%Q0.7* is tuned to inform the dispatcher about critical drop of the parameter, in the same manner operation of discrete output *%Q0.8* is tuned if the parameter increases its value outside the range. If selected value of signal conversion indicates that the signal from measuring port *%IW1.0* arrives to the input of PID-regulator without any changes (multiplication by the coefficient, zero shift, etc.).

Since PID function is used in the device for calculation of the derivative, then the value of parameter setting, setpoint and *Ti* are set to equal 0, and the value of amplification factor of the regulator is assumed to be equal 1 and is set by the internal constant *%KW0*.

Auto-tuning of the selected PID regulator enables to perform automatic tuning of regulator parameters in accordance with the set range of input signal variation and output performance. For activation AT function we should choose not simply *PID* operation mode but *PID+AT* mode, in case of PID-regulator configuration.

In the output of PID-regulator inverse output action is set to obtain the correct value of the derivative. It is requirement of control system operation algorithm, since the differential form the measured parameter is taken in the channel of negative feedback, that is why to obtain the direct value of the derivative, output signal of PID-regulator, channel is to be inversed. Digital output, that carries information regarding the value of derivative, is written into internal word of the controller *%MW10* and further is used by the program according to virtual structure of the controller (Fig. 4).

Conclusions

Functional and program realization of microprocessor unit intended for the control of transformer complex for longitudinal-transversal regulation of the voltage, based on serial microprocessor controller is developed. The given structure differs from the known ones as it uses the function of PID-regulator for determination of the sign of reactive power derivative envelop and enables to optimize the time of program cycle execution as well as to improve the flexibility of control system at the expense of application of controller manufactured modules and adapted software.

REFERENCES

1. Чичёв С. И. Информационно-измерительная система центра управления электрических сетей / С. И. Чичёв, В. Ф. Калинин, Е. И. Глинкин. – М.: Машиностроение. – 2009. – 176 с. – ISBN 978-5-94275-506-5.
2. Труфанов И. Д. Научные основы разрешения инновационных проблем идентификации в системах автоматизации процессов электрометалургии стали и сплавов / И. Д. Труфанов, А. П. Лютый и др. // Восточно-европейский журнал передовых технологий. – 2010. – № 3/10(45). – С. 8 – 23.
3. Грабко В. В. Система регулювання напруги електричної мережі за умови обмеженого споживання реактивної енергії / В. В. Грабко, С. М. Левицький. // Збірник наукових праць Дніпродзержинського державного технічного університету (технічні науки). Тематичний випуск «Проблеми автоматизованого електроприводу. Теорія й практика». – 2007. – С. 536 – 538.
4. Twido. Программируемые контроллеры. Справочное руководство по программному обеспечению. – Schneider Electric. – Telemecanique. – TWDUSE10AF ver 2.1 – 2004. – 478 с.
5. Аналоговые измерительные преобразователи переменного тока и напряжения переменного тока TIT. – Vertesz electronics. – TIT_02VSD. – 2008. – 2 с. – [Електронний ресурс] – Режим доступу до каталогу: – http://www.vertesz.ru/product/pdf/TIT.pdf
6. Преобразователь измерительный активной и реактивной мощности трехфазного тока типа Е849-М1 / Описание. – ИТЦ "ЛаборКомплектСервис". [Електронний ресурс]. – Режим доступу до каталогу: http://www.measurement.ru/gk/electro/04/02/026.htm
7. Astrom Kristofer J. PID Controllers: Theory, Design, and Tuning, 2nd Edition / K. J. Astrom, T. Hagglund. – ISA, Research Triangle Park, NC, USA. – 1995. – 456 p.

Levytskiy Serghiy – Assistant Professor, Chair of Electromechanical Systems of Automation in Industry and Transport, tel. +38 (0432) 598-167 leviserg@rambler.ru

Matienko Oleg –Student, Department of Electromechanics Energy Consumption and Energy Management.
Vinnytsia National Technical University.