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Automatic control system for power grid voltage stabilization

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Abstract

Significant growth of power plants unit capacity, large extent of power grids, presence of weak interconnections and uneven load schedule increase are the development features of power industry, that necessitate an improvement of energy facilities automatic control systems (ACS). Operating experience of electric power facilities microprocessor automatic control systems showed their advantages in comparison with the devices made from discrete components, for both service functions and reliability. A microprocessor control system in a combination with a static VAR compensator has been designed to regulate and stabilize voltage in an electric power system at a predetermined level. The ACS usage also leads to a reduce of power losses in the stabilized electric power system and an improvement in electrical load operations.

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Keywords: controlled electromagnetic reactors, electric power industry, microprocessor, control system.

1. Introduction

An automatic control unit (ACU) with a built-in microcomputer provides an opportunity to implement more sophisticated control algorithms, compared to discrete-components solutions. Storing of control programs into a reprogrammable read-only memory (PROM) allows to perform control logic changes during the operating process in accordance with the power system development and to adapt control logic to the individual characteristics of the specific electrical circuitry. The use of embedded microcomputers in the automatic control of electric power facilities

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allows to reduce the damage caused by electrical and power equipment failures, and to improve the quality of the generated electricity.

A phase-controlling microprocessor control system for a silicon controlled rectifier (SCR)-controlled shunt reactor (CR) has been designed, manufactured and tested. The electromagnetic circuits of such CRs has been examined and explored in[1]. One of the purposes of CR – to perform as a controller of a static var compensator (SVC), which is used in distribution networks (Figure 1 a, b.). Since a voltage loss compensation of reactive power in the network are reduced, under certain conditions, the SVC is not only used to balance the reactive power, but also as a means to regulate and stabilize voltage at the point of installation. This is achieved by adjusting the intake and dispensing of reactive power compensator by applying of the control action to the SCRs in accordance with the current system variables. The ACS usage also leads to a reduce of power losses in the stabilized electric power system and an improvement in electrical load operations.

The implemented microprocessor control system is based on a single-chip microcomputer KR1816VE51[2]. The control algorithm has been written and the corresponding control assembler program has been developed. The control of a CR is performed automatically by comparing the nominal line voltage with the voltage measured at the point of the reactor installation[3,4]. The purpose of the automatic control is to maintain line voltage at a predetermined level.

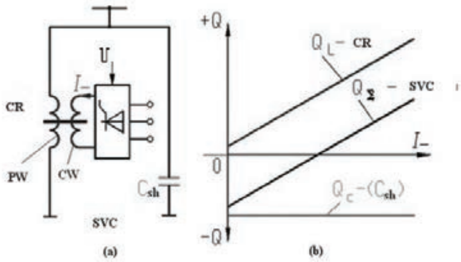

Fig. 1. Schematic diagram of the CR based SVC (a); SVC characteristic $Q = f(I_-)$ (b)

2. Structure and operating principle of the ACS

The objective of the ACS action is to stabilize the distribution network voltage at the point of the installation at the rated voltage level with a given accuracy of approximately ± 1%. This is accomplished by changing the bias current of the combined controlled reactors and reactors-transformers. If the voltage is below the set point, the bias current should be reduced until the controlled voltage reaches the set point and vice versa. The ACS consists of the control unit, power unit and a source of a stabilized DC +5 V, +15 V and -15 V voltage. Figure 2 shows a functional diagram of the ACS.

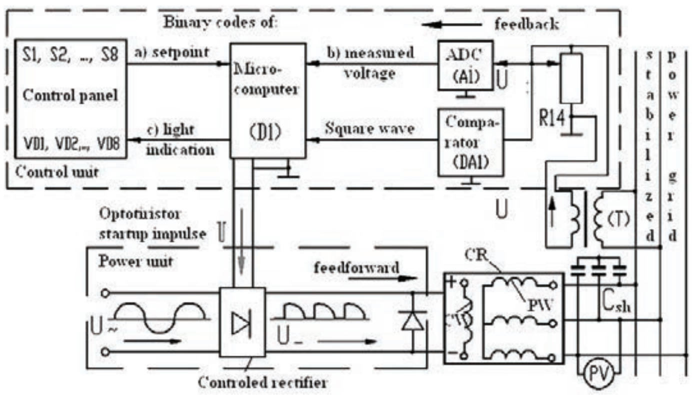

Fig. 2. Functional diagram of ACS

The dimensions of the control unit are 260x180x40 mm, weight – less than 1 kg.

The control action is carried out using the SCRs, placed in the shoulders of the bridged control rectifier, which feeds the reactor control winding (CW). Also, a galvanic isolation between low-current and high-current circuits is also performed by these opto-SCRs.

The ACS principle of operation is as follows. The stabilized distributed network voltage is supplied to the ADC A1 (F7077M/2) through the voltage transformer T, where it is converted into a digital binary code that is compared by the processor with a digital binary code of the set point, programmed using the CU front panel switches (Figure 2). If those codes are not equal, the sign of the mismatch is determined and the angle of opening of SCRs is varied correspondingly every half cycle, which leads to a change in the constant component of the current flowing in the reactor and a change in power supply voltage being stabilized.

The control software consists of a main program and six sub-routines: timer interrupt service routine, SQRT, SHR, DIV, SHL and MUL.

The timer interrupt sub-routine operates in two modes: mode "0" or "1", which are defined by a sign, ie 0x08 bit value in the data memory. If that bit is set to "0", then the subroutine works in #0 mode, and if "1", then in the #1 mode. In #0 mode it starts SCRs start pulse, the duration of this pulse is preset to 200 microseconds, and in #1 mode, the SCRs start pulse is terminated.

3. The ACS control logic

The automatic control system works as follows: 1) the S9 switch "Reset-Operation" is set to "Reset"; 2) the control unit is powered on; 3) the power unit is connected to AC power; 4) the set point is programmed using the S1-S8 switches; 5) the microcomputer (D1) starts the control program.

As a result, the target voltage at the point of the CR installation is being established. The actual voltage is displayed on the PV voltmeter (Figure 2).

The control program workflow is controlled by the input voltage U_{in} polarity: during the positive half-cycle, the measurement part is performed: accumulation of the sum of squares of the instantaneous measured voltage values and counting of the number of measurement cycles, and during each negative half-cycle - processing of the results of these measurements, analysis and correction of the current value of the SCR ON delay code.

At the start of the program sets up stack address, memory data bank number and prepares timer interrupt, which is a part of the D1 microcomputer. The program then analyzes the state of the output of the DA1 comparator (554SAZ). If there's an "1" on that output, then a negative half-wave voltage U_{in} is assumed to be applied to the ADC A1 input (Figure 3 a, b). After preparations of the first measurement cycle, the program waits for a positive half-cycle to start.

3.1. The ACS workflow in the positive half-cycle

- At the beginning of the positive half-cycle, the timer T is set up by the SCR ON delay code and started. The SCR ON delay code value is automatically set in a predetermined range from 0x38 to 0xEC. With the increase of that code, the SCR ON delay itself is reduced and (as the SCR goes to ON state with the trigger of the timer) the SCR remains more time in ON state and transmits more power to the load. The SCR ON delay ranges from 1 to 9 ms from the start of half-cycle of the U_{in} voltage. The timer after its actuation works in the #0 mode, increasing its counter every 48 microseconds (assuming the frequency is 8 MHz).
- The sum of the squares for instantaneous values of the U_{in} and the number of cycles counter (the number of samples) is computed.

3.2. The ACS negative half-cycle workflow

- At the beginning of the negative half cycle the timer is programmed using the SCR ON delay code and started;

The following steps are also performed: a) a binary code corresponding to the voltage U_{avg} is calculated; b) a square of the set point binary code (U_e reference voltage) is calculated; c) the codes of the U_{avg} and U_e^2 are compared and the control action is calculated from the result that is, SCR ON delay code is adjusted (decremented or incremented).

If $U_{avg} > U_e{}^2$, the bias current should be increased, so the program increases the value of the current SCR ON delay code by 1 (the SCR ON delay itself is decreased).

If $U_{avg} < U_e{}^2$, the bias current should be reduced, so the program decreases the value of the current SCR ON delay code by 1 (the SCR ON delay itself is increased).

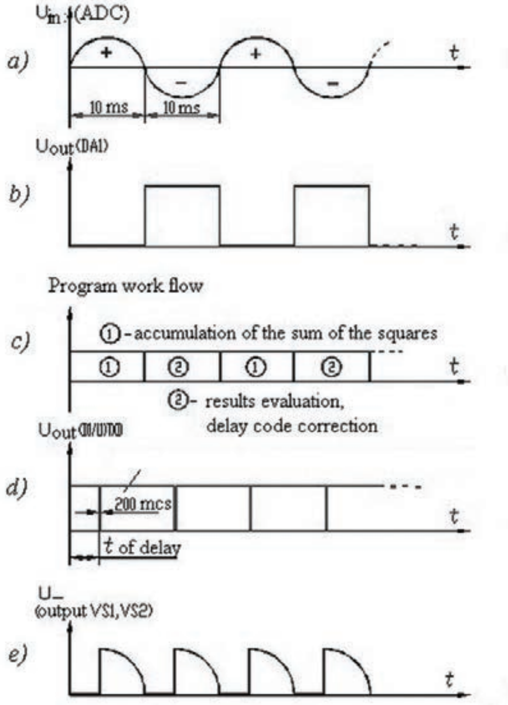

Fig. 3. The ACS workflow timing diagram

Figure 3 shows the ACS workflow timing diagram, and Figure 4 - its stabilization characteristic.

The voltage U_{in} could be stabilized in the range from $U_{in\min}$ to $U_{in\max}$ (the stabilization zone), because in this range, in accordance with the current-voltage characteristics of the reactor, the change in voltage U_{in} on the ADC input A1 is fully compensated by the corresponding bias current I_2 flowing through the reactor control winding. This current is controlled by the ACS by changing of the SCR ON delay code.

If the U_{in} is outside the stabilization zone, it's possible to enter the stabilization zone, by changing of the input voltage U_{in} by the voltage divider R14, or changing of the set point using the code switches S1-S8. After about 1-2 seconds, the system enters the stabilization mode.

4. The results of experiments

The prototype of the managed combined reactor was produced according to the electromagnetic circuit in Figure 5 as in[5]. The active portion of the reactor consists of three identical modules, characterized by the following basic information: the number of the magnetically disconnected planar cores - 3; the number of rods in a core - 4; the length of the rod - $10.10^{-2}\,m$; cross sectional area of the rod - $10.10^{-4}\,m^2$; magnetic material - steel 3413, $0{,}35.10^{-3}\,m$; coupling rods and yokes - laminated overlap; the number of turns in the coils of a three-phase work winding - $W_{ebs} = 142, W_m = 82$; the number of turns in the control winding coil - $W_o = 197$; the number of effective turns of the windings coils - 2; wire diameter - $1{,}32.10^{-6}\,m^2$.

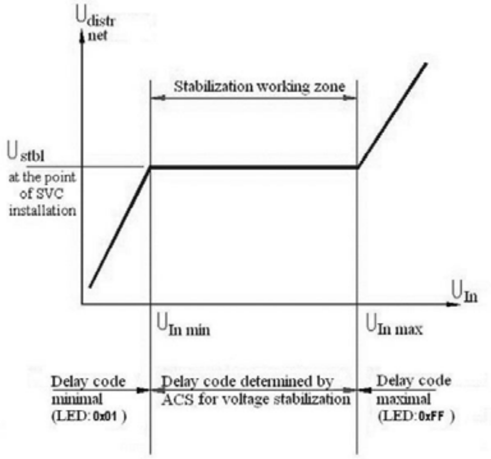

Figure 4. Characteristics of the ACS operation

Tests were conducted with and without bridges connecting terminals a, b, c of the control winding. With open terminals a, b, c, this winding has three parallel branches, and if the terminals are closed - six branches. Furthermore, during the research, control winding coils were connected in opposite-serial mode, there's no parallel branches in control winding in that case. If the terminals a, b, c are open, a free magnetization mode at 4 and 8th harmonics of the magnetic field (SN_4_8) is entered, and id the terminals are closed - a free magnetization mode at 2, 4, 8 and 10th harmonics of the magnetic field (SN_2_4_8_10) is used. With opposite-serial CW coils connection (without parallel branches) the mode of forced magnetization (FM) at all higher harmonics of the magnetic field is entered.

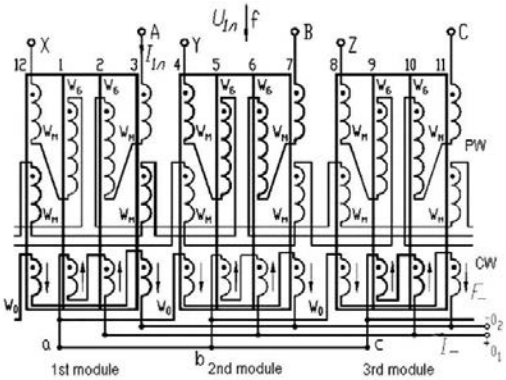

Fig. 5. Electromagnetic scheme of the combined controlled reactor (CCR)

Figure 6 shows the current-voltage characteristics of the reactor $U_{1L} = f(I_{1L}, I_2)$ for the FM, SN_4_8 and SN_2_4_8_10 modes. As it follows from the experimental dependences at $U_{1L} = 380V$ and a current bias $I_{\_} = 6A$, reactor control range in SN_2_4_8_10 mode is by ~35% more than in the HV mode and by ~21% more than in SN_4_8 mode. SN_2_4_8_10 mode stands out not only because of the increased control range of I_{1L} current, but also because of the shape of its improved curve.

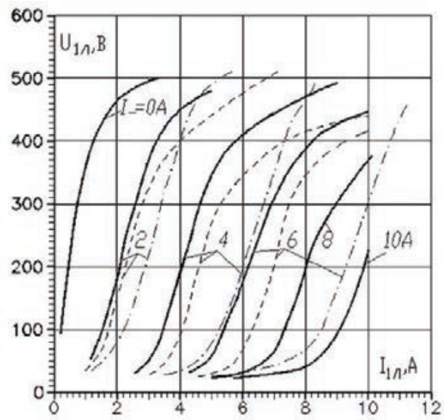

Fig. 6. The current-voltage characteristics of the reactor in the conditions of magnetization;
----- forced magnetization; - - - - free magnetization at 4 and 8th harmonics of the field; -.-.- free magnetization at 2, 4 and 8, the 10th harmonic of the field

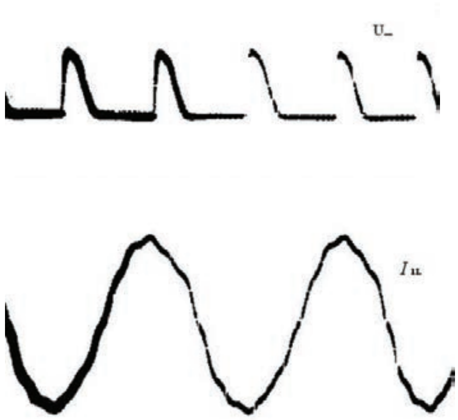

Fig. 7. The waveforms of operating winding current I_{1L} , and rectified voltage $U_{\_}$ suppling control winding at SCR opening angle ~ 120º

The reactor has been tested with a designed and manufactured mains voltage stabilization microprocessor ACS (figure 2). During the experiments, a DC voltage has been applied to the control coil. The magnitude of the rectified voltage has been automatically adjusted by changing the SCR TO325-12,5 included in the bridge, opening angle. Figure 7 shows the current waveform I_{1L} flowing in the reactor working coil WC, and the rectified voltage $U_{\_}$, applied to the control winding at the value of the stabilized voltage U_{1L} of 220V. In that case, the WC current was 4A, the bias current - 8,3A and SCR opening angle - ~120°.

5. Conclusion

1. The microprocessor control system in a combination with the static VAR compensator has been designed to regulate and stabilize voltage in an electric power system at the point of installation at a predetermined level. The power losses are also reduced along with the voltage stabilization in the electric power system and electrical load operation is improved.
2. The effectiveness of the developed hardware and software is defined by voltage stabilization steadiness at the point of SVC installation, speed of SVC reaction and others.

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