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CONTROLLER FUNCTIONS FOR ADAPTIVE COMPENSATION SYSTEM REACTIVE POWER

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Abstract

The article is devoted to the construction of a controller algorithm as part of an adaptive reactive power compensation system.

To construct the structure of a system with a controller, a reactive power compensator circuit with an analog calculation of the capacitance of capacitors was selected.

The article reflects the following questions:

– the compensator of reactive power on urban electric networks by the automatic control system is presented, which made it possible to build a model in terms of the theory of automatic control;
– a graphical information model of the reactive power compensator with analog calculation of the capacitance of the capacitors is shown;
– a set of system parameters is selected for control and optimization by software;
– selected the numerical values of the parameters of the elements for building the model.

Keywords: controller algorithm, adaptive control system, reactive power compensation.

ФУНКЦИИ КОНТРОЛЛЕРА ДЛЯ АДАПТИВНОЙ СИСТЕМЫ КОМПЕНСАЦИИ РЕАКТИВНОЙ МОЩНОСТИ

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Реферат

Статья посвящена построению алгоритма контроллера в составе адаптивной системы компенсации реактивной мощности. Для построения структуры системы с контроллером была выбрана схема компенсатора реактивной мощности с аналоговым расчетом емкости конденсаторов. В статье отражены следующие вопросы:

– представлен компенсатор реактивной мощности на городских электрических сетях системой автоматического управления, что позволило построить модель с точки зрения теории автоматического управления;
– показана графическая информационная модель компенсатора реактивной мощности с аналоговым расчетом емкости конденсаторов;
– набор системных параметров выбирается для управления и оптимизации с помощью программного обеспечения;
– выбраны числовые значения параметров элементов для построения модели.

Ключевые слова: алгоритм контроллера, адаптивная система управления, компенсация реактивной мощности.

Introduction

The representation of a reactive power compensator on urban electrical networks by an automatic control system allows us to build a model of a reactive power compensator in terms of the theory of automatic control. To create a model, you can use the entire arsenal of software tools created for the study of automatic control systems (Matlab, Simulink, etc.).

Controller in the structure of an analog automatic control system

The reactive power compensator model will make it possible to investigate the inductive power compensation errors caused by a number of approximations adopted for constructing schemes for calculating the value of the compensating capacitance. First, this is the representation of the values of trigonometric functions $f = tg\ (\varphi)$ by the linear dependence $f = \varphi$ when expressing φ in radians for small values of the phase difference angle. Secondly, it is quantization according to the signal level by an analog-to-digital converter and, accordingly, a stepwise connection of the capacities of the compensating battery.

The model is based on the structural diagram of the reactive power compensator with analog determination of the capacitance to compensate for the inductive load [1]. The model avoids programmatic computation of $f = tg\ (\varphi)$ values. The last operation uses a rather complex algorithm of computational mathematics, which requires a significant time interval for implementation. In the structure of the automatic control system, this is represented as a pure delay link that degrades the quality indicators of the automatic control system.

The proposed block diagram of a reactive power compensator with a microprocessor-based controller included in the control loop is shown in Fig. 1.

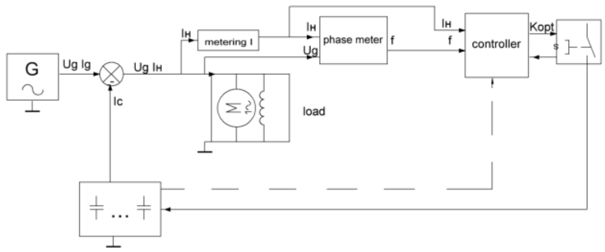

Figure 1 – Structural scheme

The controller only performs functions that require several cyclesoperation of the processor and does not introduce a significant signal delay into the automatic control system loop.

Generator *G* supplies the system load with sinusoidal voltage 220V 50Hz. The signals *Ug, Ig* are fed to the input of the comparison element. In this case, the comparison element performs the functions of vector algebra, creating vector sums of complexes of currents. The load changes the parameters of the current signal to *Iн = Ig –Ic*, where the capacitor current is created from the resonance condition of the currents of the inductive load and compensating capacitors.

The current meter generates a signal *Iн*, which with the signal *Ug* is fed to the phase meter, at the output of which the voltage *f* is proportional to the phase difference between the supply voltage and the load current.

The controller takes over the functions of a multiplier, amplifier and analog-to-digital converter. The multiplier unit multiplies the current and

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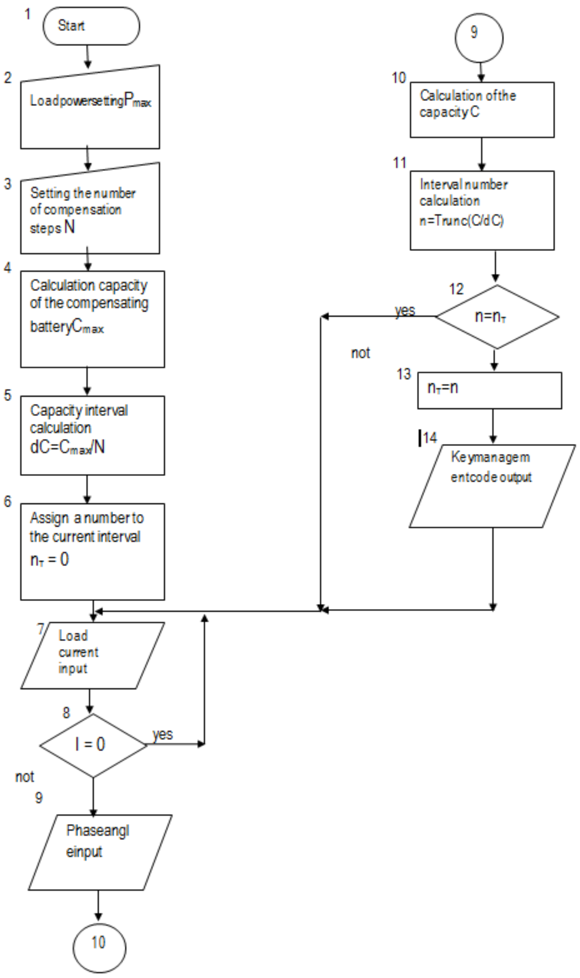
phase difference signals according to the formula for calculating the capacitance of the capacitors. Signal C at the output of the block determines the compensating capacitance. The amplifier scales the signal to the level required by the analog-to-digital converter to generate the code K for controlling the switching keys of the capacitors of the compensating battery.

The main stages of forming the control code are presented by the block diagram of the controller algorithm.

Switching in accordance with the K code will lead to an uneven load on the keys and operating capacitors, which will significantly reduce the reliability of the elements. In addition, with limited durability of elements, it is important to monitor their condition and take it into account when controlling commutation. For this purpose, a microprocessor controller was introduced into the control loop. The functions of the controller consist in analyzing the state of the triacs of the switch and capacitors, choosing the switching algorithm according to many criteria and informing about the loss of the device's performance. The *Kopt* key control signal is generated at the output of the controller.



Block functions:

Block 2. Setting the load power. The load power determines the maximum current drawn from the network. The value of this current is used to calculate the total capacity of the compensating battery.

Block 3. Setting the number of compensation steps. The capacitor for compensation of inductive load is connected in steps. The number of stages is determined from economic and design requirements, as well as requirements for compensation accuracy. The seven-stage compensator can be realized with three capacitors controlled by a three-bit binary code.

Block 4. Calculation of the full capacity of the compensating battery. The initial data for the calculation are the maximum load current, determined by the power of the consumer and the voltage of the supply network, and the maximum angle of phase shift of voltage and current. This angle is selected from the statistically established one in real networks.

$$Cos\varphi_{max}=0{,}65;\ \ \varphi_{max}\approx 50^{o}\approx 0{,}87\,rad.$$

Block 5. Calculation of the capacity interval. The capacity interval is determined by the total battery capacity and the number of control steps.

Block 6. Assigning the number of the current interval to the value zero. The number of the current interval is a multiplier with the capacity of the capacitor bank stage to determine the current compensation capacity. The current interval number is a binary discrete code for controlling the keys of the capacitor bank.

Block 7. Input of load current. The load current is obtained in the form of an analog signal by rectifying the output of the measuring current transformer. Input to the controller is made through the analog-to-digital converter block.

Block 9. Entering the phase angle. The phase angle is measured by a phase meter as an analog signal. Input to the controller is made through the analog-to-digital converter block.

Block 10. Calculation of the capacity of compensation. The initial data for the calculation are the load current and the phase angle of the voltage and current.

Block 11. Calculation of the number of the capacitance interval of the capacitor bank. The interval number is calculated as an integer part from dividing the calculated capacitance of the capacitor by the capacity of the section interval.

Block 12. Analysis: has the interval changed?

Block 13. Assigning a new value to the current interval number.

Block 14. Output of the number of the capacitor interval for controlling the switching keys of the capacitor bank.

Switching in accordance with the *K* code will lead to an uneven load on the keys and operating capacitors, which will significantly reduce the reliability of the elements. In addition, with limited durability of elements, it is important to monitor their condition and take it into account when controlling commutation. For this purpose, a microprocessor controller was introduced into the control loop. The functions of the controller consist in analyzing the state of the triacs of the switch and capacitors, choosing the switching algorithm according to many criteria and informing about the loss of the device's performance. The *Kopt* key control signal is generated at the output of the controller.

The switch block creates an electrical circuit for the current through the block of compensating capacitors.

The peculiarities of the functioning of the automatic control system of the reactive power compensator are determined by the random nature of the formation of the inductive component of the load. This uncertainty leads to uneven use of switch keys and capacitors of the compensating battery. Due to unevenness, the likelihood of loss of performance of the elements increases.

In such a situation, it is necessary to monitor the state of the switches and capacitors and ensure the uniformity of the load on the elements.

The random nature of the load forces us to build complex deterministic algorithms to ensure a uniform load of workable elements, which do not always give reliable error-free results. The task can be attributed to the synthesis of adaptive control systems. Adaptability involves tuning the system parameters to the optimal operating mode under conditions of random load changes and disturbing influences. This problem can be solved using a microprocessor controller in the loop of an automatic control system with an algorithm for generating commands according to artificial intelligence algorithms.

The controller performs a number of functions:

- control of the state of the key and accounting for the statistics of commutations;
- ensuring uniform loading of efficient capacitors and switches;
- assessment of the performance of the elements;
- taking into account the temperature of the capacitors;
- calculation of the priorities of elements to form the control code;
- informing the operator about the loss of system performance.

Parameters of elements for accounting for operability:

- key state i - Ki = 1 *(closed) or 0 (open);*
- the number of commands to close the key i - ki, i = 1 ... 7;
- the number of closures of the key i - sii = 1 ... 7;
- the average number of key closures i - $Scp = \Sigma si / 7$;
- the state of the capacitor Ci = 1 $(Uc \neq 0)$ or 0 $(Uc = 0)$ at Ki = 1;
- condenser temperature Ti = 1 $(toC<Tmax)$ *or 0* $(to>Tmax)$;

The main design ratios for choosing the numerical values of the model parameters are based on the following network parameters.

Maximum load current I_{Hmax} = 50 *A*. Power consumed in the network P_{Hmax} = 11 *kW*.

The number of control steps n = 7. The maximum error of the stepwise connection of the compensating power is 14%.

Maximum compensated phase shift of voltage and current

φ = 0.5 *rad* ($\varphi \approx 30^{o}$). In this case, $tg\varphi$ = 0.55. In this case, the error of the asymptotic representation is 10%.

To calculate the capacity of the capacitor bank, the following ratio is used.

$$C = 15\, I_H \varphi \; (\mu F)$$

The capacity of the capacitor bank is C = 15 * 50 * 0.55 = 412 μF. Then the capacity of one stage (capacitor) of the battery $C1$ = 412/7 = 58.9 ≈ 60 μF.

The main parameter for choosing capacitors is the value of the compensated reactive power Pc (var). This power can be calculated from the current in the compensating battery. From the vector diagram for the mode of full compensation of inductive power, Ic / I = $tg\varphi$ follows, where Ic is the capacitor current, I is the total current of the supply network, φ is the phase shift of the voltage and current in the network without reactive power compensation. For the maximum current I = 50 A *and* $\varphi = 30^{o}$ Ic = 50 * 0.55 = 27.3 A.

Compensation battery power at capacity C = 420 μF

$$Pc = Ic2 * Xc = Ic2 / 2\pi fC =$$
$$= 27.32 / (2\pi * 50 * 420 * 10\text{-}6) = 5650 \; (var).$$

Power per capacitor of one compensation stage

$$Pc1 = Pc / 7 = 0.8 \; (kvar).$$

The parameters of the signals of electronic elements in the structure of the ACS are determined by the choice of the element base for the implementation of circuits.

Conclusion

Analysis of the variety of control methods for reactive power compensation allows us to draw the following conclusions.

1. All methods are based on an indirect estimate of the value of the reactive power and do not provide the required cos φ of the network.
2. Assessment of the compensated power requires the study of specific characteristics of the load and technology of production processes.
3. Compensation control schemes require an individual approach to design and commissioning for a specific situation.
4. Circuits of control devices of compensators are not distinguished by simplicity and reliability.

Based on these conclusions, it can be concluded that the above disadvantages can be eliminated by using automatic control of reactive power compensation based on measuring the reactive power in the load or electrical parameters of the load, which can be used to calculate the value of the compensated reactive power.

Such a compensator must be built using a micro-processor controller to control the commutation of the compensating capacitors of the sectional battery.

To calculate the current capacity of the compensating capacitor, the value of the load current measured by the current transformer and the phase angle of the voltage and current from the electronic phase meter are used.

The control algorithm is developed in the form of a block diagram, which is the basis for programming the controller. The algorithm provides for the ability to vary the maximum load power and the number of capacitor bank sections. This uses the minimum number of I / O ports.

When choosing a controller, it is necessary to take into account the requirements of the algorithm, the shape of the input and output signals, the power requirements and the cost.

To build a model, a block diagram of a discrete automatic control system was obtained with the possibility of optimizing the parameters of elements to ensure a uniform load and taking into account the operability of the components.

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