AUTOMATIC AC COMPENSATOR WITH ASTATIC-STATIC BALANCING

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Two phase-sensitive balancing channels are used in existing automatic ac rectangular-coordinate compensators for balancing out both components of the measured voltage. Each channel consists of an amplifier, phase-shifting device, actuating members, recording and compensating elements [1].

Phase-sensitive elements used in the compensator are based on the principle of separate balancing, and are suitable for producing complex ac compensators with a single actuating member and a single recording device. This principle is used in single slide-wire ac compensators with manual balancing, in which the measured voltage components are compensated alternately [2-4]. The current from the voltage source which flows in the measuring circuit during the compensation of one of the components is due to the uncompensated quadrature component of the measured voltage. A null detector with a large impedance [3] is used in order to reduce to the minimum the errors produced by this current. However, the use of amplifiers with a large input impedance in ac compensation circuits leads to supplementary errors due to leakage currents, especially in the case of narrow-range compensators.

The authors of this article have developed an automatic ac single slide-wire compensator (Fig. 1) free from the above deficiencies. The compensator is suitable for measuring alternately with high precision both components of the measured voltage by means of a single balancing channel (a single electronic amplifier, a single actuating member and a single recording device). The high precision of measurement is attained by simultaneous compensation of both voltage components. One of the components is compensated astatically with high precision by means of an actuating motor and a slide wire, and the other component is compensated statically by means of negative feedback provided from the output of the preamplifier unit (PAU). Having recorded the voltage component measured on the slide-wire scale, the phase of the balancing-channel reference and compensating voltages is switched by 90°, and the second voltage component is measured in a similar manner.

In the cases when according to the given conditions the same precision is not required in measuring both voltage components, the measurement is simplified and it is carried out without switching the compensating voltage. The component which is required to be measured with precision is read on the slide-wire scale, and the other component on the scale of the indicating instrument which is connected to the feedback circuit of the electronic static compensator.

Let us assume that at instant t = 0 the compensator input is fed with measured voltage $U_m$, switch S is in position a, and slide-wire cursor $R_s$ is at the middle point (on the zero mark). Then $U_k = 0$, and voltage $\Delta U = U_m$ is fed to the PAU input. Voltage $\Delta U$ is amplified by the PAU and fed to the primary winding of output transformer T. Resistors $r_k$ and $r'_k$ are connected across this transformer's secondary winding which feeds the voltage to the input of the push-pull phase-sensitive detector PD.

A current flows through resistors $r_k$ and $r'_k$ in both half periods of the output voltage, producing across them an alternating voltage $U_k$, which is fed to the input of the amplifier, thus providing a negative feedback. This produces a compensation of voltage $U_m$ by voltage $U_k$.

The difference voltage $\Delta U = U_m - U_k$, which is fed to the input of the amplifier, is determined by the system's feedback ratio.

Thus, the automatic compensator's measuring circuit provides a static compensation of the measured voltage $U_m$, and the amplifier input is fed with an unbalance voltage $\Delta U$. 

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Difference voltage $\Delta U$ produces across resistor $R_d$, which is connected to the output of the phase-sensitive detector, a direct voltage proportional to the inphase component of voltage $\Delta U$ (since the transistors of the phase-sensitive rectifier are commutated by a voltage which is in phase with $U_k$). This direct voltage is fed to modulator $M$, where it is converted into a mains-frequency alternating voltage, and transmitted through amplifier $A$ to the actuating motor $AM$. The motor displaces the slide-wire cursor, thus applying voltage $U_k$ to the measuring circuit. The difference voltage at the input of the amplifier will then be determined by the expression

$$\Delta \hat{U} = \hat{U}_m - \hat{U}_k' - \hat{U}_k.$$ (1)

The application of voltage $U_k$, which is in phase with vector $U_1$ (with switch $S$ in position $a$) rotates vector $U_k'$ (as shown in Fig. 2a), tending to superpose it on vector $jU_1$. When vector $U_k'$ coincides with vector $jU_1$ the voltage at the output of the phase-sensitive detector becomes zero and the actuating motor stops. It will be seen from the vector diagram of Fig. 2a that the balancing will continue until the compensating voltage $U_k$ becomes equal to the measured voltage $U_m$ component which coincides with vector $U_1$ (i.e., $U_1 = U_kx$), which is registered by the reading device.

At the end of balancing $\hat{U}_m = \hat{U}_k + \hat{U}_k'$, i.e., the measured voltage is completely compensated, and the reading device registers the value of only one measured voltage component.

When switch $S$ is thrown to position $b$, the phase of the compensating voltage $U_k$ and the reference voltage across the phase-sensitive detector is changed by means of the phase-shifting device $Ph$ (see Fig. 1) by $90^\circ$, and thus made to coincide with vector $jU_1$. Balancing is carried out in a manner similar to that described above, and is accomplished at the instant when the compensating voltage $U_k$ coincides with vector $U_1$. The reading of the indicating device will then be proportional to the measured voltage second component $U_ky$.

The precision of the automatic compensator is determined by the sensitivity of the balancing channel to the measured voltage component which is being balanced at the time. However, it is also necessary to meet certain supplementary conditions, otherwise the quadrature signal, which is compensated statically, will provide an additional error.

Let us assume that the PAU in an open condition shifts the phase of the input signal by angle $\varphi$. In the presence of a negative feedback this shift is reduced to angle $\alpha$, evaluated from [5]:

$$\alpha = \arcsin \left( \frac{\sin \varphi}{\sqrt{1 + (\kappa \beta)^2 + 2\kappa \beta \cos \varphi}} \right),$$ (2)

where $\kappa$ is the gain of the PAU in an open condition, $\beta$ is the feedback transfer constant of the PAU.

The balancing is carried out in a similar manner to the above-mentioned simplified case when $\varphi = 0$. Voltage $U_k'$ compensates $U_m$ and, therefore, the voltage at the input of the PAU is changed (Fig. 2b):

$$\Delta \hat{U} = \hat{U}_m - \hat{U}_k'.$$

A certain relationship is constantly maintained between $\Delta U$, $U_m$ and $U_k'$ [5]. The voltage at the output of the phase detector is proportional to the PAU signal component which coincides in phase with vector $U_1$. This voltage can be evaluated as:

$$U_{R_d} = \frac{U_k'}{\beta} \cdot \kappa_{PD} \cos (\psi - \alpha),$$ (3)