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MEASURING CHANNEL FOR UNITS OF REACTIVE POWER DYNAMIC COMPENSATION

Structural diagrams of fast acting measuring channel for units of reactive power dynamic compensation, based on integration of instantaneous powers on sliding time interval, that equals half cycle of supply voltage, using time delays during one of the orthogonal components of instantaneous power are suggested.

Key words: *distributive electric grids, quality of electric energy, reactive power, dynamic compensation.*

Introduction

Application of units of reactive power dynamic compensation in electric grids simultaneously provides optimization of certain parameters of electric energy quality (steady state deviation, oscillations voltages asymmetry) and requires improvement of their information support. Creation of fast-acting measuring channels of the parameters, characterizing the asymmetry of electric three-phase loading is the most complex problem. In particular, it concerns measuring channels of static thyristor compensators (STC), voltage inverter-based static compensators, intended for dynamic compensation of reactive power, voltages and currents balancing in the connection nodes of fast-changing loads of consumers, requiring regulation with time delay that does not exceed half cycle of supply voltage.

Substantiation of the results

Analysis of asymmetric modes of three-phase electric grids of 6, 10, 35 KV with isolated neutral is performed using complex total power and complex rated power of reverse sequence

$$\underline{S} = 3\left(\dot{U}_1 \overset{*}{I}_1 + \dot{U}_2 \overset{*}{I}_2\right) = 1{,}5\left(\dot{U}_\alpha \overset{*}{I}_\alpha + \dot{U}_\beta \overset{*}{I}_\beta\right); \tag{1}$$

$$\underline{S}_2 = 3\left(\dot{U}_1 \overset{*}{I}_2 + \dot{U}_2 \overset{*}{I}_1\right) = 1{,}5\left(\dot{U}_\alpha \overset{*}{I}_\alpha - \dot{U}_\beta \overset{*}{I}_\beta\right), \tag{2}$$

where $\dot{U}_1, \dot{U}_2, \overset{*}{I}_1, \overset{*}{I}_2$ – complex voltages and complex conjugate currents of direct and reverse sequences, respectively; $\dot{U}_\alpha, \dot{U}_\beta, \overset{*}{I}_\alpha, \overset{*}{I}_\beta$ – complex voltages and complex conjugate currents in or Clark orthogonal coordinate system.

In [1, 2] algorithms for obtaining information regarding the components of total power $\underline{S} = P + jQ$ are developed, and in [3 – 6] – regarding the components of rated power of reverse sequence $\underline{S}_2 = P_2 + jQ_2$, while construction of which, the approach, comprising the integration of the sum or difference of products of instantaneous voltages and currents (instantaneous powers) on sliding time interval that equals half cycle of supply voltage ($T/2$) is used:

$$P(t) = \frac{3}{T}\int_{t-T/2}^{t}(u_\alpha i_\alpha + u_\beta i_\beta)dt; \quad Q(t) = \frac{3}{T}\int_{t-T/2}^{t}(u_\alpha' i_\alpha + u_\beta' i_\beta)dt; \tag{3}$$

$$P_2(t) = \frac{3}{T}\int_{t-T/2}^{t}(u_\alpha i_\alpha - u_\beta i_\beta)dt; \quad Q_2(t) = \frac{3}{T}\int_{t-T/2}^{t}(u_\alpha' i_\alpha - u_\beta' i_\beta)dt, \tag{4}$$

where u_α', u_β' – orthogonal components of grid voltage after integrating transformation (in conditions of nonsinusoidality – after Gilbert transform, that provides phase shift of all harmonic components of the voltage on the angle, that equals 90 electrical degrees).

Such an approach corresponds to C. Budeanu theory of reactive power.

However, as it is shown in [4, 5], transient characteristics of measuring channel for values P_2, Q_2, realized on the formulas (4), have considerable overshoot, that negatively influences the stability of the system of reactive power dynamic compensation. For decreasing the overshoot it was suggested to use the expressions [4]

$$P_2(t) = \frac{3}{T}\int_{t-T/2}^{t}(u_\alpha i_\alpha - u_\beta ' i_\beta ')dt; \quad Q_2(t) = \frac{3}{T}\int_{t-T/2}^{t}(u_\alpha ' i_\alpha + u_\beta i_\beta ')dt, \tag{5}$$

where $i_\beta '$ – integrating conversion of orthogonal component of the current.

The drawback of measuring channel is the necessity to apply, in case of considerable nonsinusoidality of Gilbert transforms currents, which are rather complex in realization [7].

For obtaining of powers components 90 electrical degrees phase shift, existing between orthogonal components of three-phase voltage and current can be used [5]:

$$P(t) = \frac{3}{T}\int_{t-T/2}^{t}(p_\alpha(t) + p_\beta(t))dt; \quad Q(t) = \frac{3}{T}\int_{t-T/2}^{t}(q_\alpha(t) - q_\beta(t))dt; \tag{6}$$

$$P_2(t) = \frac{3}{T}\int_{t-T/2}^{t}(p_\alpha(t) - p_\beta(t))dt; \quad Q_2(t) = \frac{3}{T}\int_{t-T/2}^{t}(q_\alpha(t) + q_\beta(t))dt, \tag{7}$$

where $q_\alpha = u_\beta i_\alpha; q_\beta = u_\alpha i_\beta$ – orthogonal components of instantaneous reactive powers.

Such an approach corresponds to S. Fryze theory of reactive power. It excludes the necessity of using integrating transformation, that greatly simplifies the realization of fast-acting measuring channels. At the same time, overshoot for P_2, Q_2 values will be considerable [5].

In order to decrease overshoot , the approach, applying phase shift guadrature cycle of signal supply voltage (T/4), proportional to orthogonal components of instantaneous powers is suggested. Then, instead of (4) we obtain

$$\begin{aligned} P_2(t) &= \frac{3}{T}\int_{t-T/2}^{t}(p_\alpha(t) - p_\beta(t - T/4))dt; \\ Q_2(t) &= \frac{3}{T}\int_{t-T/2}^{t}(q'_\alpha(t) - q'_\beta(t - T/4))dt, \end{aligned} \tag{8}$$

and instead of (7) we obtain

$$\begin{aligned} P_2(t) &= \frac{3}{T}\int_{t-T/2}^{t}\left(p_\alpha(t) - p_\beta(t - T/4)\right)dt; \\ Q_2(t) &= \frac{3}{T}\int_{t-T/2}^{t}\left(q_\alpha(t) + q_\beta(t - T/4)\right)dt, \end{aligned} \tag{9}$$

where $p_\alpha = u_\alpha i_\alpha; p_\beta = u_\beta i_\beta; q'_\alpha = u'_\alpha i_\alpha; q'_\beta = u'_\beta i_\beta$ – orthogonal components of instantaneous powers.

Fig. 1 a, shows dependences $p_\alpha(t), p_\beta(t), p_\beta(t - T/4)$, $p(t), p_2(t)$, Fig. 1 b shows dependences $q_\alpha(t), q_\beta(t), q_\beta(t - T/4), q(t), q_2(t)$, obtained by means of mathematical modeling in accordance with the formulas (6), (9). Similar dependences we obtain by the formulas (3), (8). Basic feature of dependences $p_2(t), q'_2(t), q_2(t)$ being the part of subintegral expressions (8) and (9), proving the lack of overshoot during transient process, is small amplitude of their oscillations. Due to this characteristic feature the lack of overshoot at the output of integrating devices of measuring channel is provided.

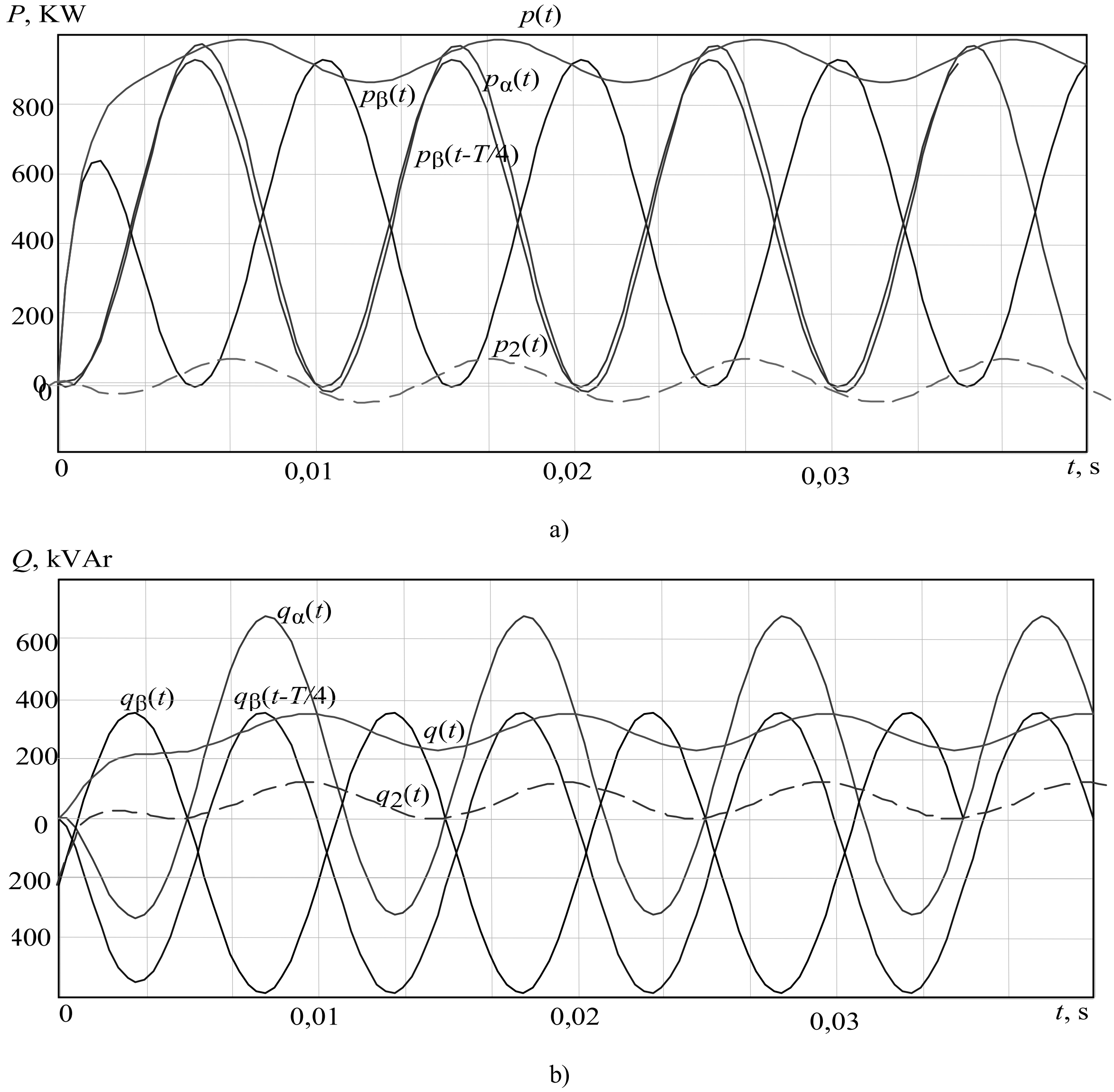


Fig. 1. Powers formation: a) $P(t), P_2(t)$; b) $Q(t), Q_2(t)$

Fig. 2 shows structural diagram of measuring channel, realizing the algorithm (8), that consists of voltage transformer (VT), current transformer (CT), scale converter of voltages (VC) scale converter of currents in voltages (CC), two integrators (I1), (I2), power converters (PC1,…, PC4), signal delay elements (DE1) and (DE2), sliding integration element (SIE) (elements of delay and sliding integration are realized, using microcontroller). In structural diagram of measuring channel (Fig. 2 b) realizing the algorithm (9) integrators are missing.

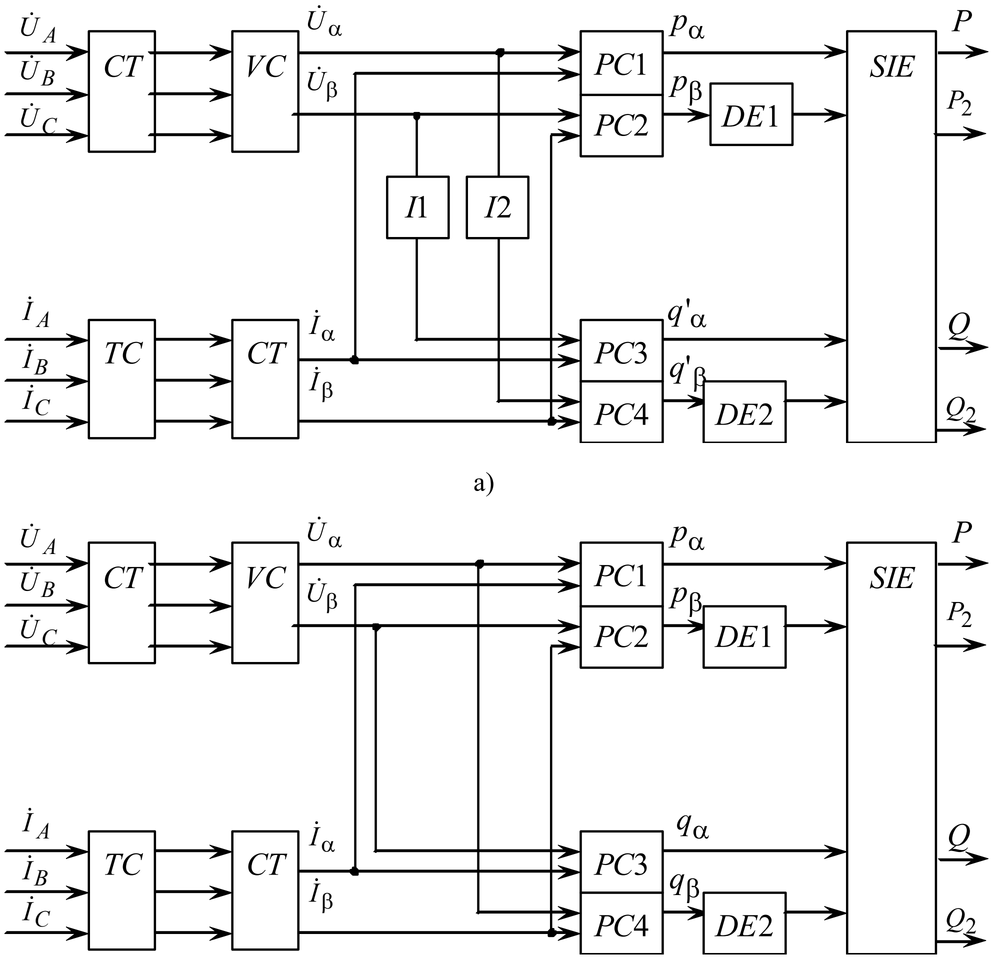
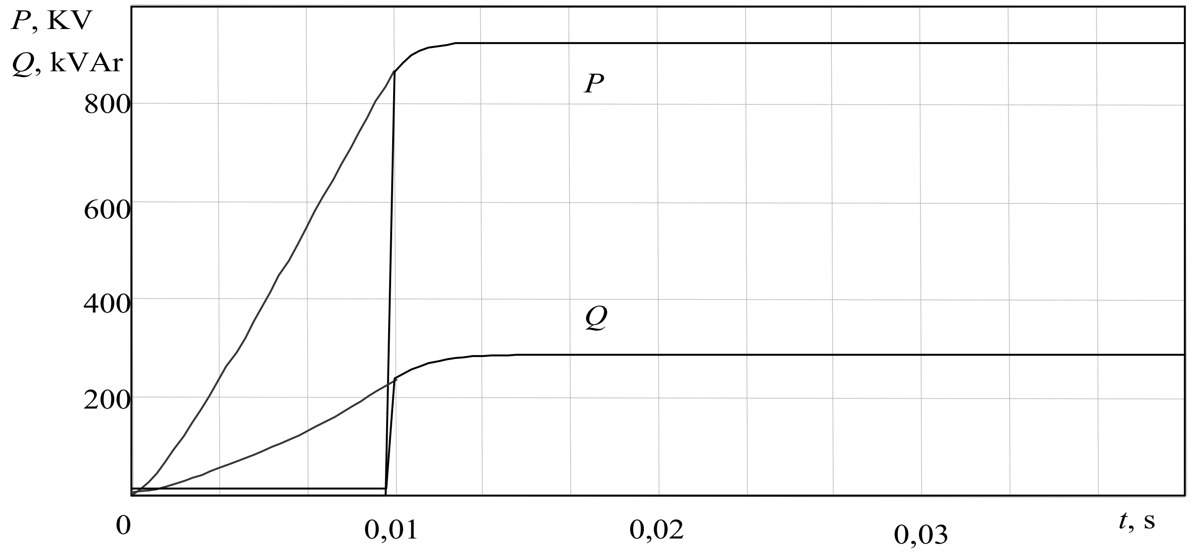
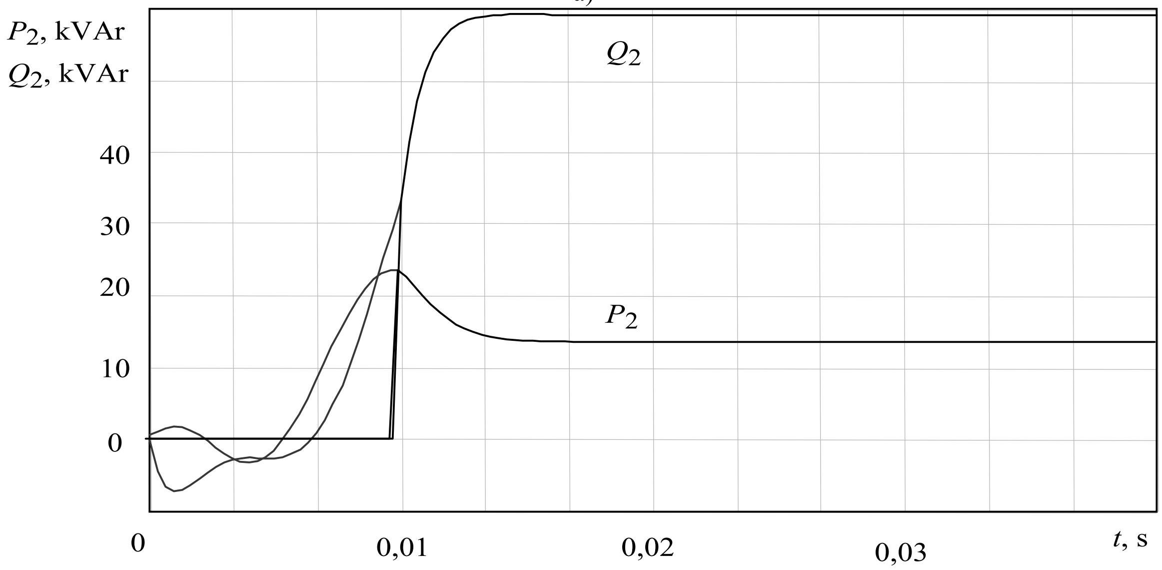


Fig. 2. Structural diagrams of measuring channel:
a) using the algorithm (8); b) using the algorithm (9)

We investigate the operation of measuring channel in transient mode, for instance , while connection of unbalanced load to the grid. Fig. 3 a and b show transient characteristics of measuring channel for values P, Q and P_2, Q_2 while connection to 10 KV unbalanced load $\underline{S} = P + jQ = 925 + j291$ KV·A, $\underline{S}_2 = P_2 + jQ_2 = 13 + j59$ KV·A. As it follows from the above-mentioned dependences, the overshoot while load connection of all the outputs of measuring channel is missing.



a)



b)

Fig. 3. Transient characteristics of measuring channel:
a) for values P, Q; b) for values P_2, Q_2

Basic sources of measuring channel errors are amplitude and phase errors of measuring transformers of voltage and current as well as errors, caused by non-conformity of integration interval to halt cycle of grid voltage [6].

The analysis showed that absolute errors of load asymmetric components measurements using algorithms (8) and (9) do not exceed errors of active and reactive power measurement. Usage of the algorithm (8) can be recommended if asymmetry of three-phase voltage and higher harmonics are available in load current. At the same time, algorithm (9) is sensitive to asymmetry of three-phase voltage but is invariant to the presence of highest harmonics in load current.

Conclusions

Measuring channel of asymmetric three-phase load parameters for units of dynamic compensation of reactive power is suggested. The operation principle of the channel is based on integration of instantaneous powers on sliding time interval, that equals halt cycle of supply voltage, using time delay of one of orthogonal components of instantaneous power. Measuring channel is rather stable in transient modes, and is characterized by the lack of methodical errors of measurements in case of asymmetry of three-phase voltage and highest harmonics of load current.

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