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The Compensation of the Reactive Power with Synchronous Motor

An optimal control system for the compensation of the reactive power in an energetic consumer assembly is presented, containing one or more synchronous motors, connected to the same power bars in parallel, including synchronous motors and static converters. The compensation of the reactive power absorbed from the system by the consumers is possible, using a optimal control system that controls the reactive power provided on the bars by the synchronous motors on condition that the power losses in the created whole are zero. A limited functional block diagram of the synchronous motor, which is the controlled object completed with the control circuits of the exciting tension and current is obtained having as set value the sum of all reactive currents of the consumers from the power assembly. The optimization is obtained using the module criterion of Kessler [1].

Keywords: *synchronous motor, reactive power, block diagram*

1. Optimal control system of the reactive power

For simplification a single synchronous motor and same reactive power consumers are involved, so that all reactive power necessary to be compensed will be provided by a single synchronous motor to the subsystem bars (figure 1).

The reactive currents of the energetic consumers are measured and their sum represents the set value of the optimal control system formed by two controllers connected in cascade ARCC (automatic reactive current controller) and AETC (automatic exciting tension controller) using grid control units (DCG) and a power DC controlled static converter. The converter provides the exciting current of the synchronous motor, so as the reactive current furnished by the synchronous motor I_{rs} compensates the sum $I_r^* = \sum_{i=1}^{n} I_{ri}$ absorbed by the consumers AM_i. We can mention that the synchronous motor is destined to a long time, constant load, e.g. an air station factory driving.

When the functional block diagram contains a single control loop, we control directly the reactive power provided by the synchronous motor on the intermediate bars b_2 with the aim of compensation. This aspect is taken into consideration further on.

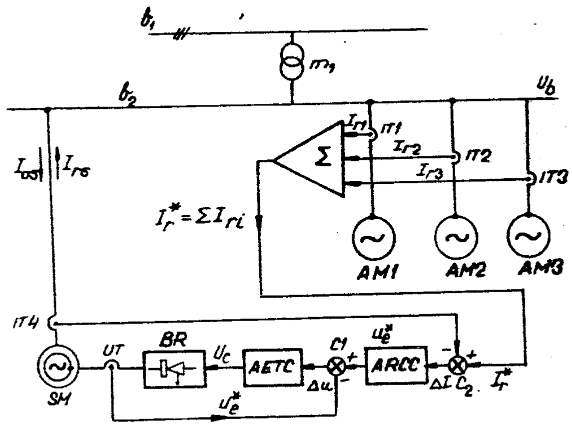

Figure 1. Functional block diagram for an optimal control system for the compensation of the reactive power: SM – synchronous motors, AM – asynchronous motor, Σ – sum device, ARCC – automatic reactive current controller, AETC – automatic exciting tension controller, C_1, C_2 – compararison block, UT – tension transducer, IT – current transducer, m_1 – transformer.

2. The transfer function of the element system

The control object is formed by the synchronous motor, having the exciting tension as set value and the output, this being the reactive current, respectively the reactive power. Using the Blondel-Park equations [2] a functional block diagram is obtained formed with two functional blocks having as intermediate value the exciting current. The transfer functions, indicated in figure 2, are the expressions [3]:

$$H_1(s)=\frac{I_E(s)}{U_E(s)}=\frac{1}{R_E}\cdot\frac{T_a\cdot s+1}{(T'_d\cdot s+1)\cdot(T''_d\cdot s+1)} \quad (1)$$

$$H_2(s)=\frac{I_r(s)}{I_e(s)}=K_R\cdot\frac{T_{kd}\cdot s+1}{T_a\cdot s+1} \quad (2)$$

Where:

R_e – the equivalent resistance of the excitation circuit;

T′$_d$ – the time constant of the excitation coil in case the stator coil is in short circuit, in the absence of the longitudinal damping coil;
T″$_d$ – the time constant corresponding to the supra transient currents in the stator;
T_a – time constant of the stator coil.

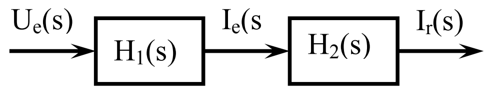

Figure 2. Functional block diagram for the synchronous motor

In the functional block diagram the afferent blocks of the intern angle, so as those of the resisting moment are omitted.

The transfer function of the excitation block is formed from the grid control unit (DCG) and the power DC static converter block:

$$H_{DC}(s) = K_{DCG} = \frac{180^0}{U_{c\max}} \tag{3}$$

And the transfers function of the three-phase thyristor bridge:

$$H_p(s) = K_p \cdot e^{-T_\mu s} \tag{4}$$

Where:

$$K_p = \frac{1}{2} \cdot \frac{1}{f} \cdot \frac{1}{p} \tag{5}$$

Where:
f – being the network frequency;
p – the number of the pulses in one period of the no filtered converted tension;
T_μ – the dead time constant.

The transfer functions of the measure elements M_1 and M_2 are constant: $H_{M1}(s) = K_{M1}$ and $H_{M2}(s) = K_{M2}$. The transfer functions of the filters after the transducers are PT1 elements:

$$H_{F1}(s) = \frac{1}{1+T_{f1}(s)}; \quad H_{f2}(s) = \frac{1}{1+T_{f2}(s)} \tag{6}$$

The transfer function of the optimal closed loop of the excitation current is:

$$H_{0i}(s) = \frac{H_{R1}(s)H_E(s)H_1(s)}{1+H_{R1}(s)H_E(s)H_1(s)H_{M1}(s)H_{F1}(s)} \tag{7}$$

In the case where we use a single controller, the controlled parameter being just the reactive power, itself then the transfer function will be: $H(s) = H_1(s) \cdot H_2(s)$ and the functional block diagram is presented in figure 5.

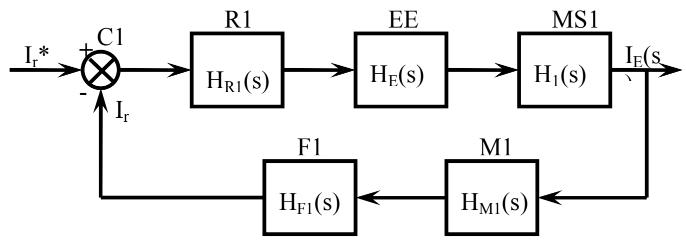

Figure 3. Functional block diagram of the control circuit of the excitation current: R_1 – controller; EE – executive element (DCG + power DC converter); MS1 – the first block diagram of the synchronous motor $H_1(s)$; M_1 – current transducer; F_1 – filter

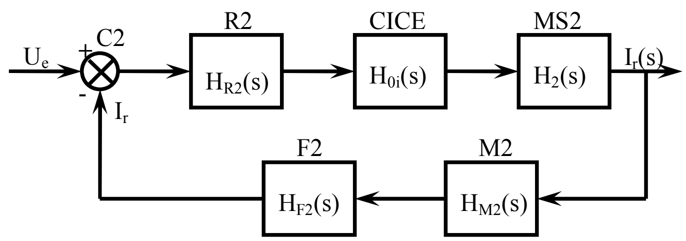

Figure 4. Functional block diagram of the reactive current: R_2 – controller; CICE – optimal closed loop of the excitation current; MS2 – the second block diagram of the synchronous motor $H_2(s)$; M_2 – current transducer; F_2 – filter

3. The optimizing of the control circuits

In both variants, I and II, the structure of the controllers $H_R(s)$ can be established by the modulus criterion (Kessler), because the fixed transfer function of the system isn't affected with poles in the origin. For each case in part we estimate the fixed transfer functions of the system containing the executive element (or CICE), the afferent block element of the process $H_1(s)$, $H_2(s)$, $H(s)$, of the transducer and of the filter. The transfer function of the open circuit has the expression:

$$H_c(s) = \frac{\frac{1}{2T}}{s(1+T\cdot s)} \tag{8}$$

That corresponds for a closed circuit, having the transfer function:

$$H_0(s) = \frac{1}{2T_\Sigma^2 s + 2T_\Sigma s + 1} = \frac{1}{\frac{1}{\omega_0^2}s^2 + \frac{2\xi}{\omega_0}s + 1} \tag{9}$$

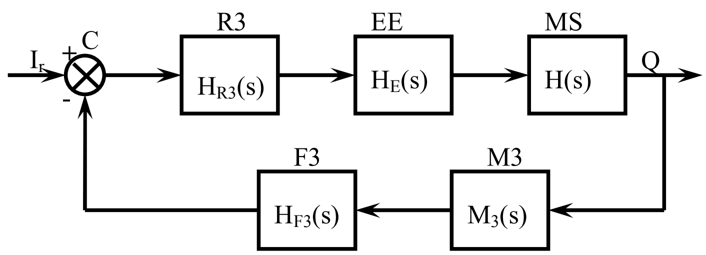

Figure 5. Functional block diagram of the optimal system with a single controller: R_3 – controller; MS – synchronous motor; EE, M3, F3 – idem than figure 3

With excellent performance: ξ = 0,707, the super adjustment σ = 0,043, the stabilization time T_{stab} = 7T_Σ when the fitting band is ± 5%. We estimate the time constant T using the little parasite time constants T_k, so $T_\Sigma = \Sigma T_k$, where T_k are less than 10% of the principal time constant of the process, namely T_d' of the synchronous motor. That condition is accomplished by the time constants mentioned above T_a, T_d'', T_f and T_μ. The transfer function of the controller is obtained from the formula:

$$H_R(s) = \frac{H_c(s)}{H_F(s)} \tag{10}$$

Where $H_F(s)$ is the transfer function of the fixed part. The amplification factors will be included in the total amplification factor K_F of the fixed part:

$$K_F = K_p K_M K_f ; \quad T_\Sigma = \sum_{k=1}^{n} T_k \tag{11}$$

Using the relation (10) and fixing the principal time constant T_d', results, for the controller, a transfer function of the type PI:

$$H_R(s) = \frac{\tau_1 \cdot s + 1}{T_1 \cdot s} = K_1 \cdot \left(1 + \frac{\tau_1}{T_i}\right) \tag{12}$$

Where: $\tau_1 = T'_d ; T_i = 2K_F T_\Sigma$

For an experimental model station of the compensation process with a single controller, having the transfer function of the fixed part:

$$H_F(s) = \frac{K_F}{(T'_d\, s + 1)\cdot(1 + T_\Sigma s)}; \; T_\Sigma = 31{,}8 \cdot 10^{-6}\, s; \; K_F = 0{,}934$$

The modulus criterion of Kessler gives $\tau_1 = T'_d = 0{,}064 s$???? T_i = 59,4·10^{-6} s. With these parameters the values R_1, R_2 and C, of the operational amplifier are determined for proportional-integrative (PI) action.

4. Conclusions

The compensation of the reactive power of some energetic consumer fed into an energetic subsystem may be realized when to the same bars are connected synchronous motors for air instrumental station. The reactive power provided by these synchronous motors driving the air compressors, can compensate the reactive power absorbed by the other consumers realizing an optimal compensation, e.g. the power losses being minimal. With this aim a pursuit control system is realized in which the leading parameter is the sum of the reactive currents for the other consumers. The reactive current sum is compared with the reactive current of the synchronous motor, which is the controlled parameter. Having the possibility to make optimal the system by the modulus criterion, the optimal system permits excellent performances and thus great energy efficiency [3].

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