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The Block Diagram for the Synchronous Motors used for the Compensation of the Reactive Power

The 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 asynchronous 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.

Keywords: synchronous motors, reactive power, block diagram, Kessler

1. Optimal Control System of the Reactive Power

For simplicity a single synchronous motor and same reactive power consumers are involved, so that all reactive power necessary to be offset 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 $I_r^* = \sum_i I_{ri}$ absorbed by the consumers AM_i . We can

mention that the synchronous motors are destined to a long time, constant load, for example an air station factory driving.

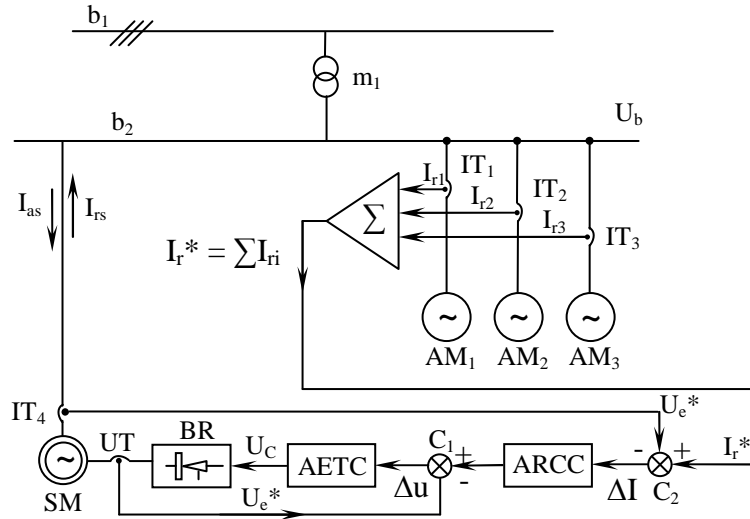


Figure 1. Functional block diagram for an optimal control system for the compensation of the reactive power: SM – synchronous motors; AM – asynchronous motors; Σ - sum device; ARCC – automatic reactive current controller; AETC – automatic exciting tension controller; C_1 , C_2 – comparator block; UT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

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.

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 [1] 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 [2]:

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

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

where: R_e is 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 supratransient currents in the stator; T_a – time constant of the stator coil.

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

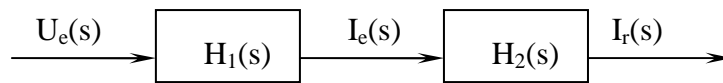


Figure 2. Functional block diagram for the synchronous motor

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

$$H_{DC}(s) = K_{DCG} \cdot \frac{180^\circ}{U_{c \max}}, \quad (3)$$

and the transfer function of the three-fazed bridge with thyristors:

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

where:

$$K_p = \frac{1}{2} \cdot \frac{1}{f} \cdot \frac{1}{p}, \quad (5)$$

f being the network frequency, p the number of the pulses in one period of the non-filtered converted tension, and 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:

$$H_{F1}(s) = \frac{1}{1 + T_{f1}(s)}; \quad H_{F2}(s) = \frac{1}{1 + T_{f2}(s)}, \quad (6)$$

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

$$H_{oi}(s) = \frac{H_{R1}(s) \cdot H_E(s) \cdot H_1(s)}{1 + H_{R1}(s) \cdot H_E(s) \cdot H_1(s) \cdot H_{M1}(s) \cdot H_{F1}(s)}, \quad (7)$$

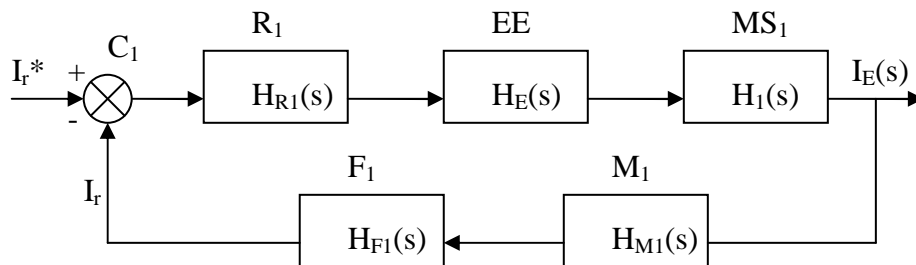


Figure 3. Functional block diagram of the control circuit of the excitation current: R_1 – controller; EE – executive element (DCG+ power DC converter); MS_1 – the first block diagram of the synchronous motor $H_1(s)$; M_1 – current transducer; F_1 – filter.

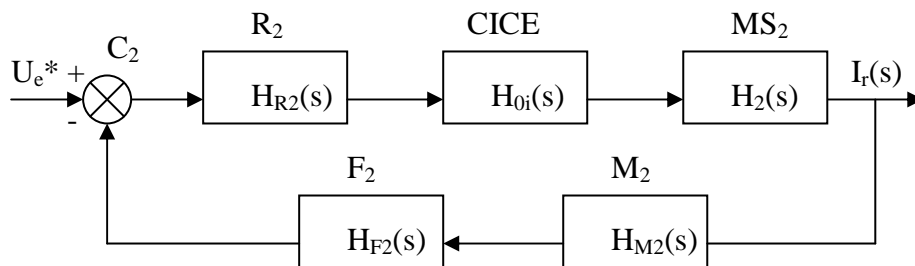


Figure 4. Functional block diagram of the reactive current: R_2 – controller; CICE – optimal closed loop of the excitation current; MS_2 – the second block diagram $H_2(s)$ of the synchronous motor; M_2 – current transducer; F_2 – filter.

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

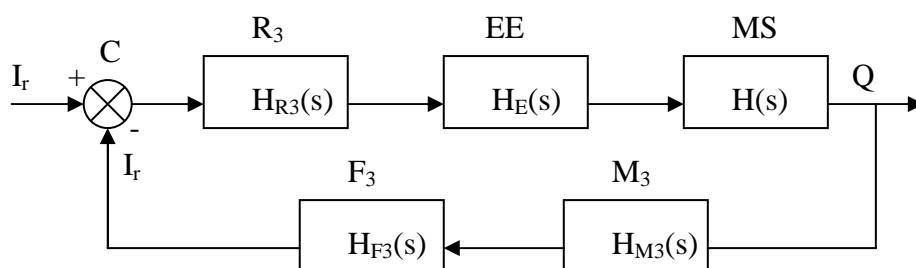


Figure 5. Functional block diagram of the optimal system with a single controller: R_3 – controller; MS – synchronous motor; EE – executive element; M_3 – current transducer; F_3 – filter.

3. The Optimizing of the Control Circuits

In both variants, 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:

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

that corresponds for a closed circuit oscillating damped transient regime, having the transfer function:

$$H_0(s) = \frac{1}{2T_\Sigma^2 \cdot s + 2T_\Sigma \cdot s + 1} = \frac{1}{\frac{1}{\omega_0^2} \cdot s^2 + \frac{2\zeta}{\omega_0} \cdot s + 1} \quad (9)$$

with excellent performances: $\zeta = 0,707$; the super-adjustment $\sigma = 0,043$; the stabilization time $T_{stab} = 7T_\Sigma$ when the fitting band is $\pm 5\%$. We estimate the time constant T using the little parasite time constants T_{kr} , so $T_\Sigma = \sum_k T_k$, 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:

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

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:

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

Using the relation (10) and fixing the principal time constant T'_d , results, for the controller, a transfer function of the type PI:

$$H_R(s) = \frac{\tau_1 \cdot s + 1}{T_1 \cdot s} = K_R \cdot \left(1 + \frac{\tau_1}{T_1 \cdot s} \right) \quad (12)$$

where: $\tau_1 = T'_d$; $T_1 = 2K_F \cdot T_\Sigma$.

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

$$H_F(s) = \frac{K_F}{(T'_d \cdot s + 1) \cdot (1 + T_\Sigma \cdot s)}; T_\Sigma = 31,8 \cdot 10^{-6} \text{ s}; K_F = 0,934, \quad (13)$$

The modulus criterion of KESSLER gives $\tau_1 = T'_d = 0,064 \text{ s}$ and $T_i = 59,4 \cdot 10^{-6} \text{ s}$. 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, for example 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 of the other consumers. The reactive current sum is compared with the reactive current of the synchronous motor that is the controlled parameter. Having the possibility to make optimal the system by the modulus criterion, the optimal system permits excellent performance and thus a great energetic efficiency [2].

References

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