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AUTOMATIC SYSTEM FOR OPTIMAL REPARTITION AND CONTROL OF REACTIVE POWER IN INDUSTRIAL PLANTS WHICH USE SYNCHRONOUS MACHINES AND FACTS DEVICES

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ABSTRACT

The paper presents an automatic distributed system for reduction of power losses caused by reactive powers and compensation circuits in industrial plants.

The automatic system presented in this paper is based on extensions of a digital algorithms implementation, which is based on patent 107048 B1 RO/1993, named "Metodă şi sistem automat pentru reducerea pierderilor de putere activă produse de puterile reactive ale ansamblului surselor de compensare din sistemele electroenergetice industriale".

INTRODUCTION

The automatic system presented in the present paper allow active power loss minimising being organised on two levels:

- the optimal control of the reactive power of the synchronous machines (MS) and the static var compensators SVC which belong to the Flexible AC Transmission Systems FACT (level I);
- the optimal repartition of the reactive powers of the supplies at the industrial system (level. II)

This paper presents an improved digital multilevel structure, where the secondary level use only dedicated microcontrollers, and the optimal repartition of the reactive power of an industrial system are performed with a workstation as co-ordination level.

The proposed architecture supports a high performance computing of a critical distributed real-time system and a time-constrained communication. The system of the serial bus communication connects the workstation, the data acquisition boards and the data storage units.

PRINCIPLE OPTIMAL REPARTITION OF REACTIVE POWERS (level II)

The automatic system is shown in Fig.1. It allows an optimal repartition for all the compensating resources of industrial system (SEI) e.q. the synchronous machines (MS) and the static compensators (SVC), using measurement of by the industrial system (SEN) delivered reactive power (Q_s).

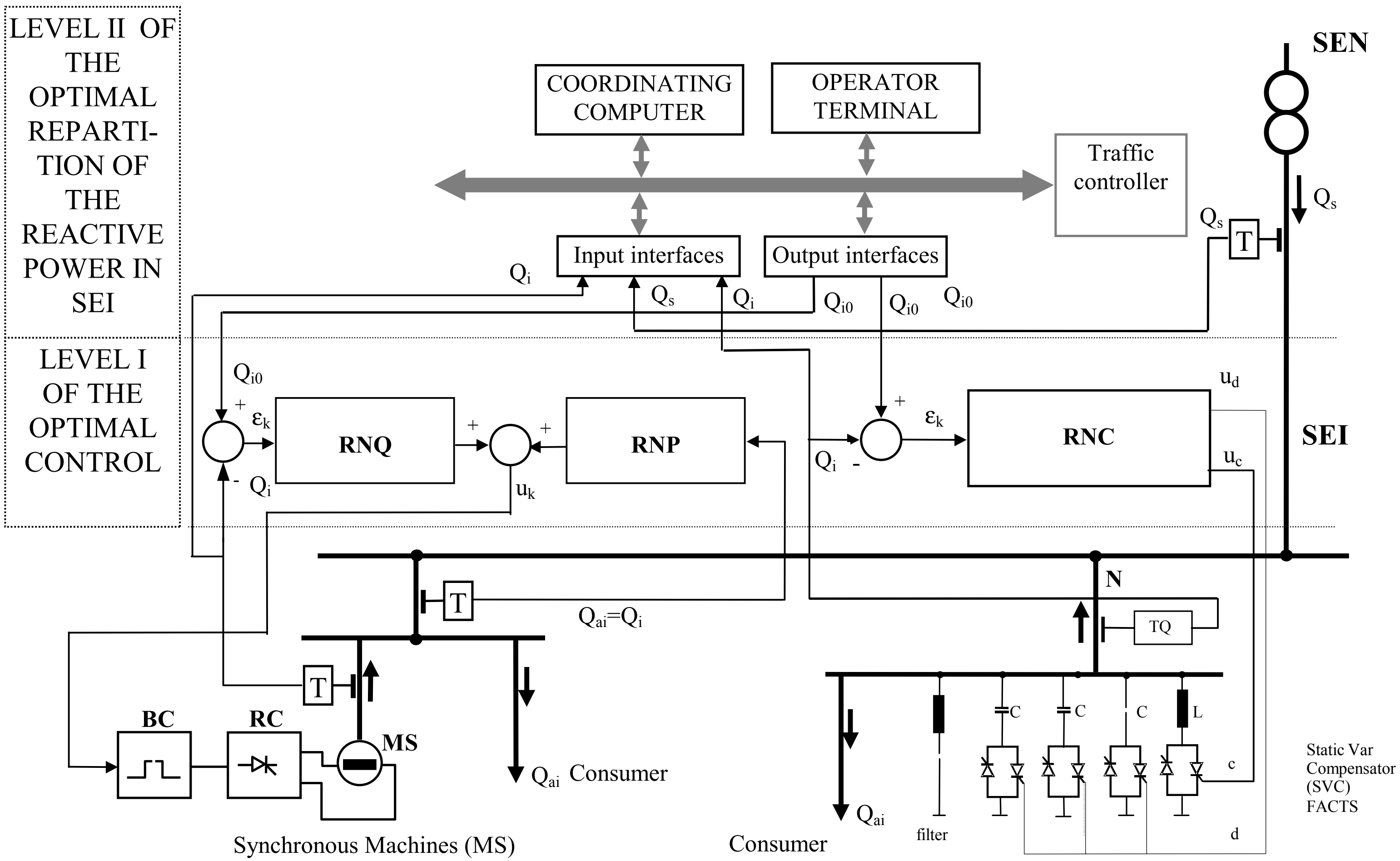
LEVEL II OF THE OPTIMAL REPARTITION OF THE REACTIVE POWER IN SEI
LEVEL I OF THE OPTIMAL CONTROL
COORDINATING COMPUTER
OPERATOR TERMINAL
Traffic controller
SEN
Input interfaces
Output interfaces
RNQ
RNP
RNC
SEI
N
TQ
T
BC
RC
MS
Qai=Qi
Qai Consumer
Synchronous Machines (MS)
Consumer
filter
Static Var Compensator (SVC) FACTS

Fig. 1

The powers absorbed by SEI is:

$$Q_a = Q_s + \sum_{i=1}^{n} Q_i \qquad (1)$$

The Q_s and Q_i reactive powers supplied by the compensating sources.

The Q_s and Q_i reactive powers are input for a optimiser, based on process co-ordinator computer, which is minimising the $f(Q)$ loss function, delivers the optimal Q_{i0} reactive powers of the compensating sources.

The obtained optimal power values are used as reference values for the reactive power regulator (RNQ) of the synchronous machines (MS) and the RNC (for SVC compesantor) or they are converted and used for switching the element (a_j) of condensers batteries. The objective function for the total losses of the active power is given by:

$$\Delta P_{rt} = \Delta P_{rp} + \Delta P_{rd}; \qquad \Delta P_{rt} = \Delta P_r + \Delta P_{rs} + \Delta P_{rd}; \qquad (2)$$

where: ΔP_{rt} - represents the active power losses for steady mode;

ΔP_r - represents the active power for industrial system sources in steady mode;

ΔP_{rd} - represents the active power losses of industrial systems in dynamic mode;

ΔP_{rs} - represents the active power losses for the national system delivered reactive power Qs.

The co-ordination controllers minimises the object function given by:

$$f(Q) = \Delta P_{rp}; \qquad \Delta P_{rp} = \Delta P_r + \Delta P_{rs}$$

$$\begin{aligned}
f(Q) = {} & \sum_{i=1}^{j-1} \frac{a_i}{2} \cdot Q_i^2 + \sum_{i=1}^{j-1} b_i \cdot Q_i + && \left.\right\} \text{sinchrones generators (GS)} \\
& + \sum_{i=j}^{k-1} \frac{a_{li}}{2} \cdot (Q_{ai} - Q_i)^2 + \sum_{i=j}^{k-1} b_i \cdot (Q_{ai} - Q_i) + && \left.\right\} \text{sinchrones motors (MS)} \\
& + \sum_{i=k}^{n} \frac{a_{li}}{2} \cdot (Q_{ai} - Q_i)^2 + \sum_{i=k}^{n} b_{ci} \cdot Q_i + && \left.\right\} \text{static compensator (SVC)} \\
& + \frac{\tilde{a}_s}{2} \cdot Q_s^2 + \tilde{b}_s \cdot Q_s && \left.\right\} \text{power losses for the national system (SEN)}\Delta P_{rs}
\end{aligned} \qquad (3)$$

where: Q_i –is the reactive power in KVAR, delivered by

i=1,2,..,j-1 the synchronous generators;

i=j,...,k-1 the synchronous motors;

i=k,...,n the static condensers;

Q_{ai} - the reactive power absorbed by the consumers placed in the compensating nodes (mean values);

a_i, a_{li} – a loss parameters, in kW/kVAR^2 for the synchronous machines and the connected supply lines;

b_i, c_i – a loss parameters, in kW/kVAR for the synchronous machines and the condensators batteries (0,003kW/kVAR).

a_s, b_s – a estimated loss parameters of the national system for the industrial system (missing if **cos**φ optimal imposes).

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REACTIVE POWER CONTROLLERS FOR SINCHRONES MACHINES (RNQ, RNP)

These controllers contain a microcontrollers of the direct control after the reference RNQ and the disturbance (feedforward) for the synchronous machines connected to the distributive station SEI (in consumers nodes N). These controllers are presented in Fig. 2.

The RNQ controller provides the synchronous machine with a reactive power following the optimal value Q_{io} provided by the co-ordinator computer of SEI. The RNP controller compensates the disturbance of the Q_a reactive powers of the industrial consumer in node N.

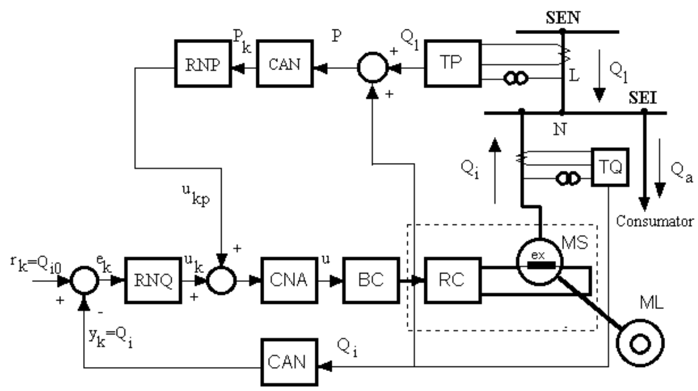

Fig.2

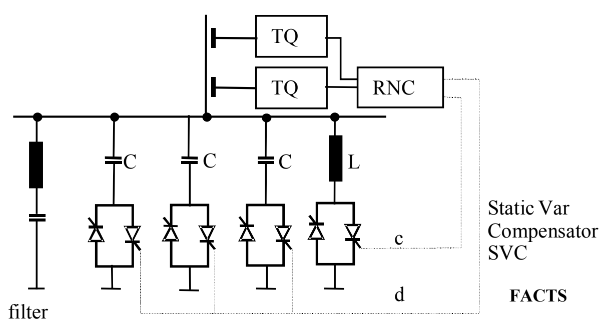

Fig.3

REACTIVE POWER CONTROLLERS FOR STATIC VAR COMPENSATOR (RNC)

In Fig. 3 is shown a RNC controller for reactive power control produced by a Static Var Compensator which realises the phase control in coil L and the discontinuous command of condenser batteries C

The regulation of the reactive power provided by the SVC can be discontinuous, executed through the command of the three steps of the C condenser batteries, or it can be continuos executed through the modification of the coil current L. The RNC controller controls the reactive power provided by the SVC static compensator and the voltage in node N, producing at output discrete signals d for connecting thiristors corresponding to the conducting batteries, the moment when momentary voltage in node N is maximum, in order to minimise the transitory processes that appear at commutation. The RNC Controller produces at output the (c) signal for the command in complete conduction of the thiristors of the L coil, which provides a delay angle $\alpha \geq \pi/2$ in relation to the moment of the passing through the zero of the network voltage. This command leads to decrease of the distortion of the electric current of the compensator and to reducing the amplitude of the higher harmonics.

THE FUNCTIONING OF THE SYSTEM IN STATIONARY AND TRANSITORY MODE

The two reactive power sources (synchronous machines MS and SVC static var compensator) provide a process of compensating the reactive power and regulating the voltage in complementary SEI, both in stationary mode and in transitory mode.

In stationary mode, the reactive power produced by a synchronous machines MS is given by relation

$$Q = \frac{3E_0 U}{x_s}\cos\theta - \frac{U^2}{X_s} \qquad (4)$$

where U is the voltage of the network (in node N) and E_0 is the electromotor voltage produced by the excitation of the machines.

The reactive power produces by a static compensator SVC is determined by the relation:

$$Q = n3\omega C U^2 - \frac{3U^2}{\omega L} \qquad (5)$$

where n is the number of steps of the batteries of condensers.

In the stationary mode the main weight in the continuous regulation of the produced reactive power falls on the synchronous machines MS, because of the possibility of continuous regulation of the electromotor voltage E_0 (through excitation) and the reactive power absorbed by the L coil, which produces distortion of the electric current and distorting power, plays a small part.

The external characteristic U-I of the synchronous machines when the excitation regulator (RNQ) is missing, is decreasing with a small slope at the increasing of the inductive current as shown in Fig.4

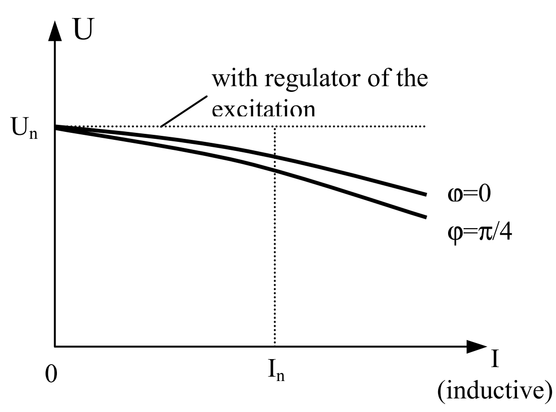

Fig. 4

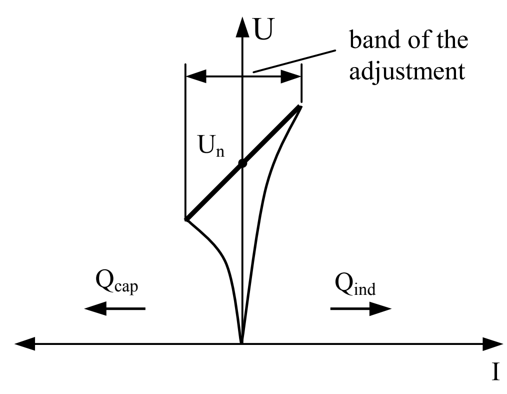

Fig.5

The regulation characteristic U-I of the static compensator SVC imposed by the RNC regulator is increasing with a pronounced slope, as shown in Fig.5.

The analysis of two diagrams presented in Fig.4 and Fig. 5 show that two reactive power sources (MS, SVC) work complementary in stationary mode. By rising the voltage of the network increase the reactive inductive power absorbed by the L coil, and by decreasing the voltage supplementary steps of condensers C are introduced and the reactive capacitor power provided by the synchronous machines MS is increased (E_0 is increased through the excitation regulator).

In transitory mode by decreasing the voltage of the network (in node N) at first several steps of the batteries of the condenser are introduced through the RNC regulator, process which is very short, followed by a slower second process when the electromotor voltage E_0 and the reactive power provided by the synchronous machines are increased. If the voltage of the network is very decreased then the role of the synchronous machines according to relation (4) and (5), prevails in producing the reactive capacitors power because this power is not decreased with the square of the voltage.

CONCLUSIONS:

1. This paper presented a distributed automatic system [2] in the electrical plant that allows the loss minimisation of the active power by compensating the reactive power sources.
2. The present structure of the system has on secondary level dedicated microcontrollers. On the first level the optimal repartition of reactive power of an industrial system are performed with a workstation as co-ordination level.
3. The presented system provides a complementary running of the two reactive power sources (synchronous machines and static compensators) in stationar and dynamic regime. In stationary regime the principal weight in continuous adjustment of the reactive power comes to synchronous machines, and in transitory regime static compensator provides a fast way of connecting of the high power condenser steps of batteries
4. This automatic system is organised on two level witch uses two complementary reactive power sources (synchronous machines and static compensating). The system provides a complete real-time digital control of the energetic process of the optimal regulation "U-Q" in the electroenergetic system.

REFERENCE

[1] Zărnescu H. - *Utilizarea optimală a motorului sincron* Ed. Tehnică, Bucureşti, 1984
[2] Zărnescu H. - *Patent 107048 BI RO/1993*