

# Automatic compensation of reactive power with a system for monitoring a 6 kV electrical power grid in a mine

*The paper features a concept, execution and results of a central system for automatic reactive power compensation of a 6 kV electrical power grid in a mine. The following were used as controlled compensators of reactive power: synchronous motors of driving systems working in a mine, capacitor batteries and filters of higher harmonics. Then a communication system was described. Finally, a system for monitoring the state of the mine grid was presented.*

*key words: reactive power compensation, automatic regulation, monitoring*

## 1. INTRODUCTION

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The objective of reactive power compensation is to relieve the electrical power grid of the flow of reactive currents. This is achieved through eliminating the phase shift between basic harmonics of the current and voltage, as well as eliminating higher harmonics of the current independently of the shape of the supply voltage. In such conditions it is possible to minimize the current and the apparent power of the source for a certain active power of the receiver [4, 6, 7].

In industrial electrical power grids it is customary to use partial compensation which is equal to the compensation of basic harmonics of the current and voltage in order to maintain the value of the power coefficient within acceptable limits and, concurrently, to reduce the losses of active power and voltage drops in power lines.

With partial compensation, the following are used as reactive power sources: capacitor batteries, passive filters of higher harmonics, and synchronous compensators, both in the form of unloaded synchronous machines and loaded synchronous motors or generators [1, 6, 7].

The failure to maintain proper technical parameters of energy, consumed by the users in the points of coupling,

results in extra fees charged by energy suppliers. In order to reduce the costs of electrical energy, it is necessary to properly compensate reactive power taken from power grids in each point of the system supply.

With changing loads of active and reactive power, resulting from the production cycle of a plant, a solution is to have an automatic, tracking system for reactive power compensation. This system would allow independent compensation of each coupling. To achieve this, the system would use reactive power sources available in the power grid of the plant [2].

## 2. CONCEPT OF THE SYSTEM

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The analyses conducted in several hard coal and copper mines demonstrated that, usually, the power of compensation devices is enough to maintain the values of the power coefficient within the acceptable limits in all settlement periods. In addition, individual regulation possibilities of particular compensation devices, particularly synchronous motors which work continuously [1], are enough to adapt their power to current needs. If necessary, it is possible to use extra capacitor batteries or higher harmonics filters installed in the supply systems of thyristor winding machines.

In order to make optimal use of reactive power sources which are available in the power grid, an automatic reactive power compensation system was

developed. The structure of the system is described in Fig. 1.

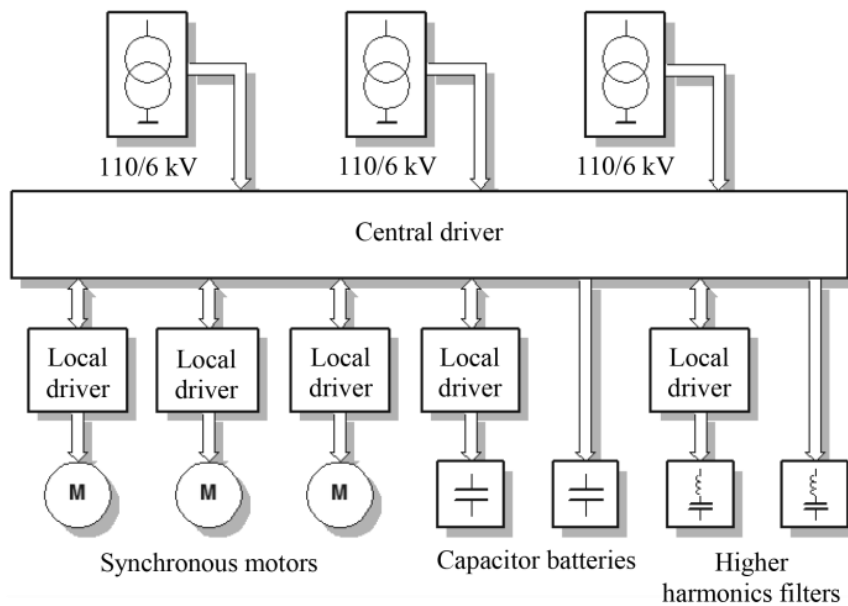


Fig. 1. Reactive power automatic compensation system (author's own elaboration based on [2])

The central driver is responsible for the measurements of instantaneous values of active and reactive power in the power supply points of the plant. Additionally, the driver identifies the current configuration of the plant grid and decides about the distribution of requested reactive power to particular regulated sources of reactive power available in the plant grid. Thanks to the knowledge about the configuration of connections in each point (110/6 kV transformers), the compensation is carried out independently.

The task of the local driver is to work out the requested reactive power in the compensator, with respect to exploitation limits of the device. Then the local driver sends the information about the current work state of the capacitor to the central driver.

The algorithm, which allows to regulate the central driver on the basis of measurements in the supply points, determines the current demand for the change of reactive power of the supply transformer in compliance with the following equation [3]:

$$\Delta Q_z = P \cdot tg \phi_z - Q, \quad (1)$$

where:

$\Delta Q_z$  – requirements for the change of reactive power in the given step of the regulation,

$P, Q$  – current instantaneous value of active and reactive power in the supply point,

$tg \phi_z$  – set power coefficient in a supply point of the plant.

The next stage is to determine the total reactive power  $Q_z$  which has to be produced by  $n$  available compensators in compliance with the following dependency [3]:

$$Q_z = \Delta Q_z + \sum_{i=1}^n Q_i, \quad (2)$$

where:

$Q_i$  – current reactive power of the  $i$ -th capacitor.

Then the requested reactive power is distributed to particular engines according to the selected criterion.

The simplest criterion for the distribution of reactive power is even distribution according to the following dependency [3]:

$$Q_{zi} = \frac{Q_z}{n}, \quad (3)$$

where:

$Q_{zi}$  – set reactive power of the  $i$ -th capacitor.

The control of selected compensators can be related to the state of other devices, e.g. switching the higher harmonics filters can depend on the work state of winding machines [3]. After the power distribution, there is control over the limitations which are related to admissible values of reactive power resulting from such factors as: the limitations in the excitation current of synchronous motors, discrete values of power and the unloading time of the capacitor batteries, as well as the necessity to switch on higher harmonics filters, etc.

If necessary, the set power of such a compensator is limited to the admissible value and the compensator is excluded from the further procedure of reactive power distribution. After the compensator is excluded, there is a correction of the requested reactive power of other compensators and the reactive power is re-distributed to these compensators. The proce-

cedure is repeated until it is not necessary to limit the set reactive power for each compensator or until there are no more compensators available.

After the reactive power of each compensator is determined, the data are sent to the executive element and the regulation algorithm is carried out again [3].

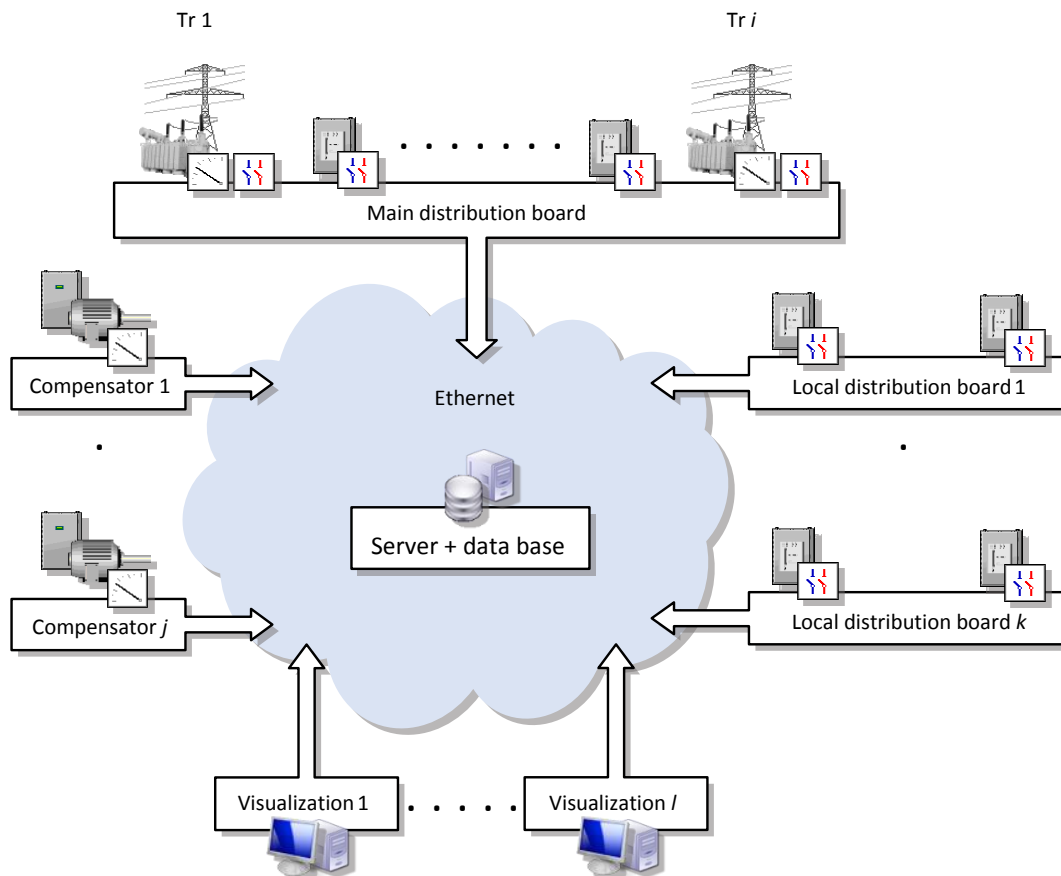


Fig. 2. Communication in the central system of automatic compensation of reactive power [author's own elaboration]

### 3. COMMUNICATION SYSTEM

Figure 2 features a communication structure of the automatic reactive power compensation system.

The core of the system is the software of the central driver, implemented in the application of the server which co-operates with the data base.

Full automation of the compensation system enforces the system to work independently of the current configuration of the the plant grid as well as the location, availability and regulation capacities of particular executive elements. For this reason it is necessary to have a communication system between all elements which influence the work of the compensation system. Data transmission can be carried

out with the use of the RS-485 network, radio communication or Ethernet. The employed solution allows to apply practically any kind of configuration and to extend the system.

### 4. SYSTEM MONITORING

In order to monitor the power grid in the plant and the system of automatic reactive power compensation, dedicated software was developed. The software enables to read current measurement values of selected points of the grid. It allows to visualize the network configuration, archive and analyze measurement data, configuration changes and changes in the

state of executive elements of the compensation system, as well as the configuration of parameters of the system. The software co-operates with the central server of the system and the data base.

The visualization software can be installed on any PC or touch panel embedded, for example, in the control box with an active connection with the server.

Figure 3 features sample information available on the touch panel.

## 5. EFFECTS OF OPERATION

Figures 4 and 5 present the results of measurements conducted in a supply point of a coal mine before the automatic reactive power compensation system was implemented there. The measurements were carried out on a working day and on a free day.

It can be observed that the value of the admissible power coefficient  $tg\phi$  is exceeded. According to the contract with the energy supplier the coefficient should be in the range between 0.2-0.4. The periods of reactive power return to the grid are exceeded too. Under- and overcompensation of the system implies that extra fees are paid to the energy supplier for reactive power.

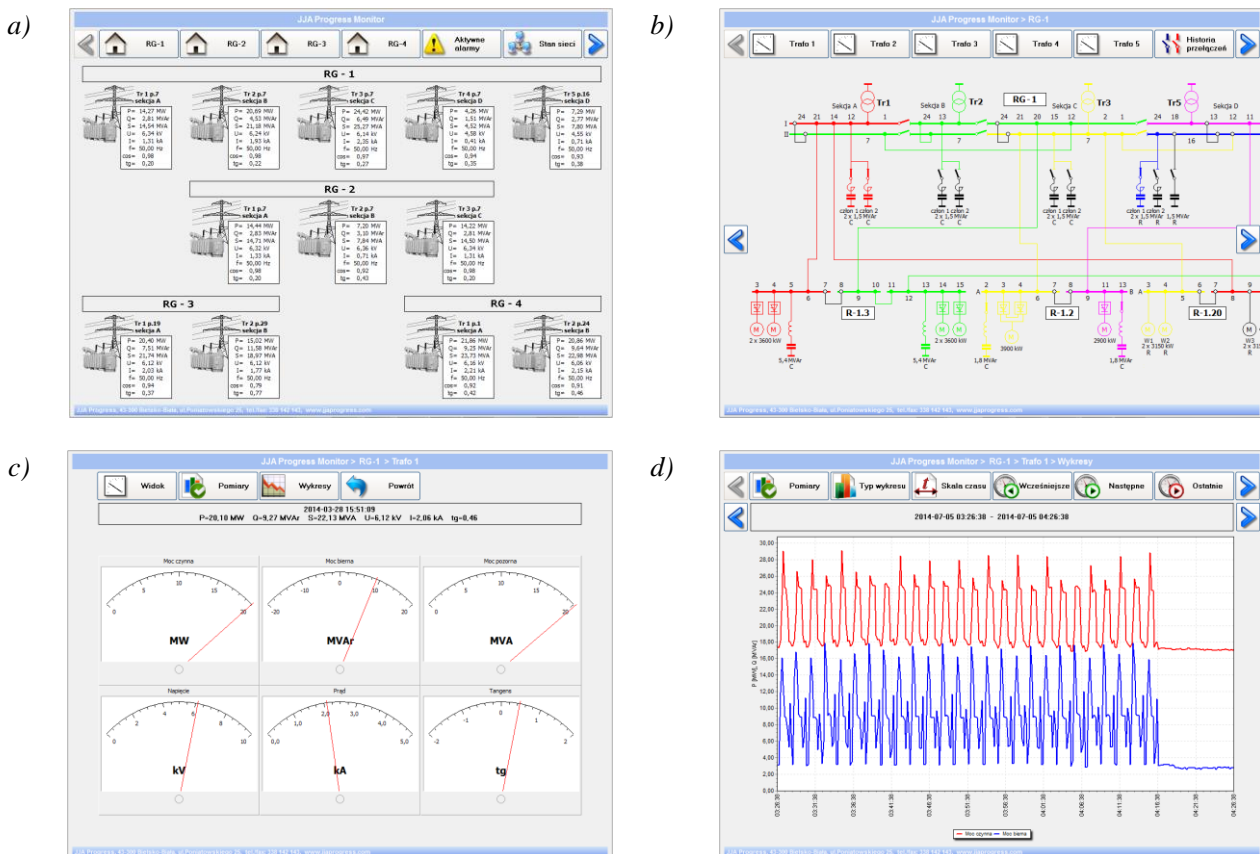


Fig. 3. Monitoring the system of reactive power compensation: a) measurements in supply points of the plant, b) configuration of the plant grid, c) instantaneous measurements, d) time waveforms of measurement values [author's own elaboration]

In order to improve the management of reactive power, the automatic compensation system was implemented – according to the concept featured in Fig. 1. The operation of the system was verified by repeated measurements in the supply points of the plant.

Figures 6 and 7 feature the results of measurements after the implementation of the automatic

compensation system. As compensators the following were used: synchronous motors of ventilators for ventilating the underground part of the mine and converter drives of Ward Leonard motor control systems in winding machines, equipped with local reactive power which work with the central driver of the system.

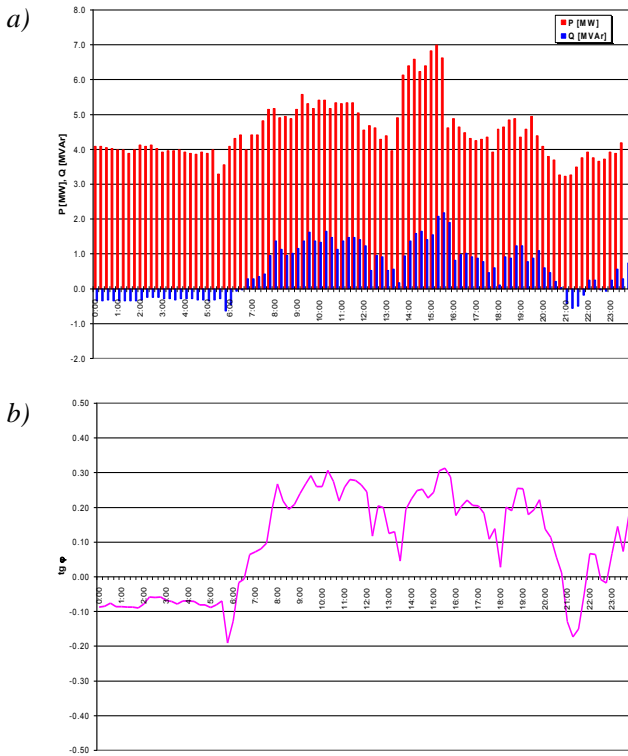


Fig. 4. Average 15-minute measurements without the compensation system on a working day: a) active and reactive power, b) power coefficient  $\text{tg } \varphi$  [author's own elaboration]

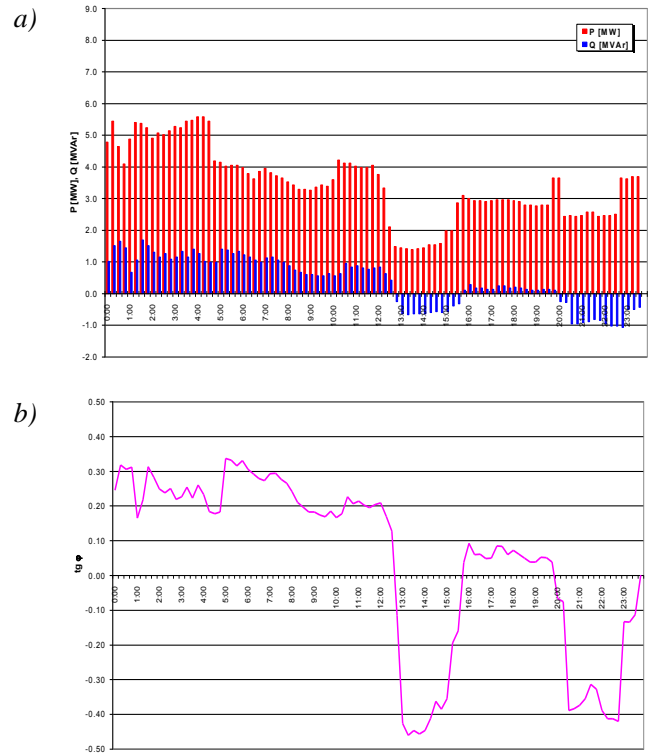


Fig. 5. Average 15-minute measurements without the compensation system on a free day: a) active and reactive power, b) power coefficient  $\text{tg } \varphi$  [author's own elaboration]

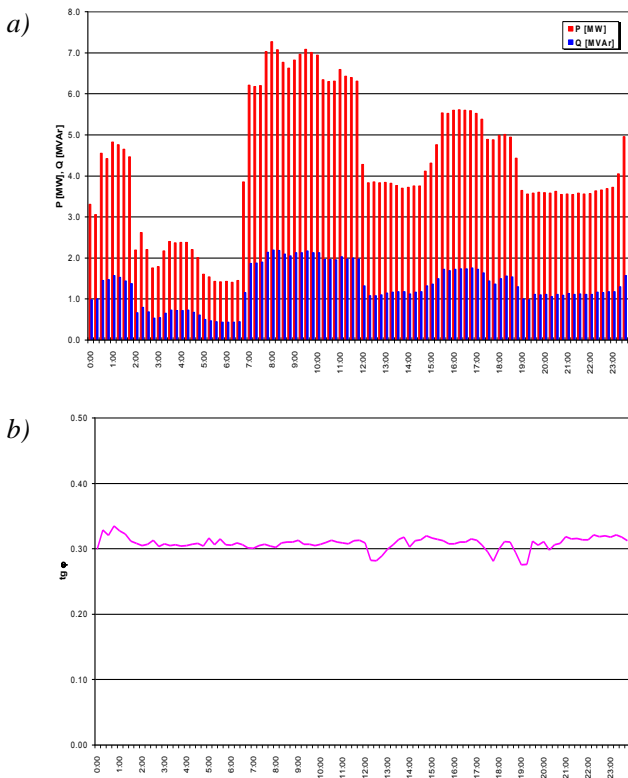


Fig. 6. Average 15-minute measurements with the compensation system on a working day: a) active and reactive power, b) power coefficient  $\text{tg } \varphi$  [author's own elaboration]

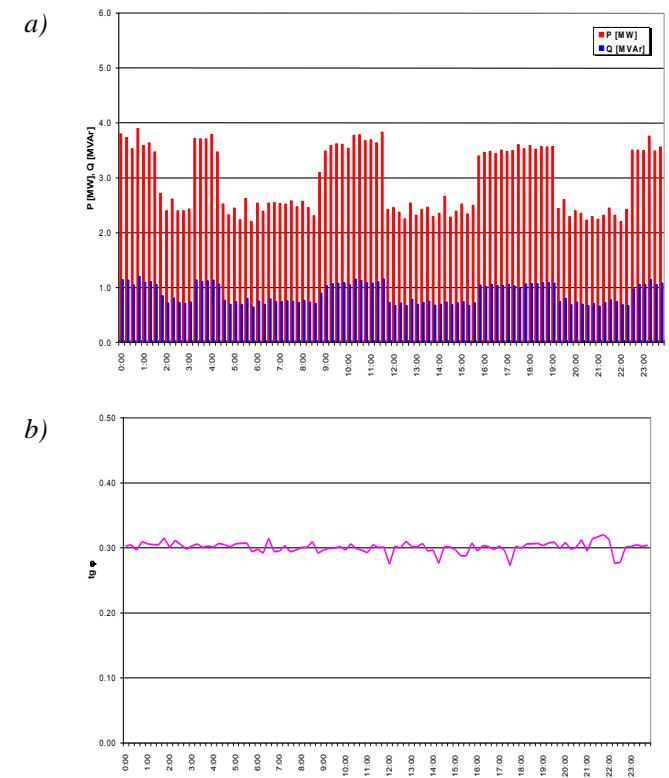


Fig. 7. Average 15-minute measurements with the compensation system on a free day: a) active and reactive power, b) power coefficient  $\text{tg } \varphi$  [author's own elaboration]

## 6. CONCLUSIONS

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The specifics of coal mines lie in many drives of synchronous motors working simultaneously and in a continuous manner, independently of the production cycle of the mine. This group comprises, first of all, ventilators for ventilating the underground part of the mine and converter drives of Ward Leonard motor control systems in winding machines, which generate significantly large volumes of reactive power.

The personnel-made attempts to provide reactive compensation are often not enough to ensure the desired power coefficient in the supply point. A solution is an automatic system for reactive power compensation. The system reacts immediately to the changes in the active and reactive power load flowing through 110/6 kV transformers and switches in the power grid of the plant. It also reacts to the changes in the availability and regulation scope of compensation devices which result from the production cycle of the plant.

The JJA Progress company, in co-operation with the Silesian University of Technology, has developed a central system for automatic compensation of reactive power. The system enables full use of regulation capacities of compensation devices. Thanks to this

feature it is possible to eliminate or significantly reduce the fees for extra consumption of reactive power. The system was implemented in several hard coal and copper ore mines. These implementations allow to speak for its efficiency and short period of return on investment.

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*The article was reviewed by two independent reviewers.*