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SMART SYSTEM FOR ELECTRIC GRID MANAGEMENT IN COAL MINES

Summary. This paper presents the results of a European project – M-SmartGrid. A smartgrid is an electric grid that uses new technologies to improve the efficiency of the production and distribution of electrical energy. The article presents the software based on idea of the smart electric grids.

Keywords: mining, colliery, Information and Communication Technologies, electrical grid

INTELIGENTNY SYSTEM ZARZĄDZANIA SIECIĄ ENERGOELEKTRYCZNĄ KOPALNI

Streszczenie. W niniejszej pracy przedstawiono wyniki projektu europejskiego M-SmartGrid. Smartgrid jest siecią elektryczną, w której zastosowano nowe technologie w celu poprawy efektywności produkcji i dystrybucji energii elektrycznej. W artykule przedstawiono oprogramowanie oparte na idei inteligentnych sieci elektrycznych.

Słowa kluczowe: górnictwo, kopalnia, teleinformatyka, sieć elektryczna

1. Introduction

In a view of the emerging threats in both the deficit of primary energy resources and too low efficiency of its generation, transmission, distribution and use, there is a need to introduce a new quality to the power grid - the creation of intelligent energy supply systems commonly known as "smart grids" [1, 9, 17, 16]. Such corporate actions are developed in many universities not only in a single department, but also across the university as well as on
the country and the regional community economy level [4, 5, 10, 16]. It should be noted that also large companies from many industries, including the mining industry, are interested in this type of systems [6, 9, 11, 14, 15].

Accessibility of electrical energy is basic factor in running a mining business. Safety and processes like: ventilating underground excavations, transportation of personnel in and out of mine, require constant supply of power, if work safety and maintenance of mining equipment is to be ensured.

Electrical systems in mines are quite often over-designed, and as such have high energy consumption in an idling state and quite often having peak power values several times higher than the average power [3]. High peak power values are effect of discontinuous work of power receivers. Substantial lengths of underground power networks and demand for a lot of power require higher voltages in mining electrical grid.

Necessity for efficiency of power transfer, its division and consumption require changes in supervision and management of electrical grid. During realization of project M-SmartGrid, which was subsidize by European Research Fund for Coal and Steel, there have been works conducted on system for managing mine electrical grid [13]. Main goal of the project was to design new hardware and software solutions allowing for reduction in cost of used electric power. During realization of project, ITG KOMAG designed software for managing mining electrical grid that would allowed monitoring of surface and underground mining electrical grid, anticipating loads and support decision-making in various conditions of electrical grid.

2. System for electric grid management

Mine electric power grid management system managing the electric power grid in mine collects information from the controllers and meters installed both on surface and underground switching stations. The system enables predicting the power load, monitoring the surface and underground electrical grid as well as it can help taking decisions in changing conditions of the grid. Communication is realized with use of the selected protocols and interfaces with a possibility to extend the database of used protocols. Modules of the grid managing system were integrated in one coherent system application. Structure of the system is presented in Fig. 1. Modules included in the application are as follows:

- module for automatic management of electric power grid,
- module for planning,
- modules for support decisions:
module for grid management in non-standard conditions,
- module for grid management in the case of emergencies.

“Measurements” represent electric load of the grid in specified points of the switching station. “Control signals” is the information about the methods for switching distribution of energy in the grid. In the case of non-standard and emergency situations, module for automatic management of electric power grid exchanges information with modules for support decisions through the expert sub-module.

![Diagram of the system managing the electric power grid in mine](image)

**Fig. 1. Structure of the system managing the electric power grid in mine [13]**

**Rys. 1. Struktura systemu zarządzającego siecią energetyczną w kopalni [13]**

### 2.1. Main part of the software

The main part of the software is the automatic grid management module. It is a power management application, with its own GUI, to automatically manage network power usage. It considers all the mine services, both underground and on the surface. The software retrieves information from the sensors of switching stations, which are part of the segment of the mine electrical grid or from the model (Fig. 2).

This module is responsible for continuous monitoring of power grid condition and for activation of module for grid management in nonstandard conditions in the case when untypical configuration is found. After literature survey, it has been decided to use the expert system for this solution. Such approach enable creating window application, which can diagnose the grid condition on the basis of data obtained from sensors. The diagrams delivered by coal mine, describing a normal operation of electric-power grid made grounds for creation of knowledge database [13].

Main window of the application presenting the electric power grid of coal mine is presented in Fig. 3. Pressing the selected switching room causing opening the bookmark with
actual layout of connections in this switching station. Change of grid configuration is realized by clicking the selected power switch or disconnector. If the application receives confirmation of switchover, colour of connections changes according to new configuration.

In Fig. 4 and Fig. 5 the switching stations are presented.

Fig. 2. Model of loads for different mine energy receivers [13]
Rys. 2. Model obciążeń sieci elektroenergetycznej kopalni [13]
Fig. 3. Software interface – general diagram of mine electricity grid [13]

Rys. 3. Okno programu – ogólny schemat sieci elektroenergetycznej kopalni [13]

Fig. 4. Fragment of user’s interface presenting the switching station [13]

Rys. 4. Fragment interfejsu użytkownika prezentujący rozdzielnię [13]
Fig. 5. Fragment of user’s interface presenting the bookmark of RS-7 switching station with loaded settings of power switchers or disconnectors and with end receivers [13]

Rys. 5. Interfejs użytkownika z wybraną zakładką przedstawiającą rozdziałkę RS-7 z odbiornikami końcowymi [13]

Time process of the given receiver electricity load (Fig. 6) can be displayed by pressing the receiver symbol by left mouse button.

Fig. 6. Diagram of hourly consumption of electricity [13]

Rys. 6. Wykres całkowitego godzinowego zużycia energii elektrycznej [13]
2.2. Module for planning

Module for planning the switching on operations and for prediction of load is the next important functionality of the system. Software for prediction of energy consumption is based on the model of electricity grid and model of load [12]. Signals from each available measuring points of switching stations are modeled independently. The ARMA, ARIMA and regression models structures are used for energy consumption modelling [2]. To ensure correctness of the parameter estimation procedure, it is necessary to prepare the signals in advance. The signals should be smoothed and purified from noise. A special support software were designed to test different methods of smoothing signals (Fig. 7). In the case of prediction of energy consumption it was assumed that the forecast will be possible maximally for two days ahead and the application will play an advisory role. In the case of prediction of exceeding peak power, the application, on the basis of priorities list entered to the database, will switch off or display information about demand to switch off a given machine to the dispatcher, when there is a possibility of exceeding the peak power [3].

Coal mine grid infrastructure does not allow monitoring electric load of all grid nodes, the system enables reading the simulated load from the file. Generation of a transformer load is also possible. The load is a sum of loads of all electricity receivers connected to it.
The application enables generating the diagrams for time interval set by the user. For a given day or simulation, the system automatically calculates the average and maximum load value. Planning the switching on operations is realized by user’s interface adapted for scheduling the tasks (Fig. 8).

![User’s interface for scheduling the tasks](13)


Switching between the variants of power grid is based on another software application. It includes the instructions to operators that enable switching over the variants. These variants are sets of predefined connections in the main switchgears, enabling the operation of mine power grid in different combinations of operating and not-operating transformers. The electronic version of the switching over application was created to assist the operators executing this task (Fig. 9).

![Electronic version of switching application at switching from variant 1 of supply to variant 4 of supply](13)

Rys. 9. Program łączeń przy przejściu z wariantu zasilania 1 na wariant zasilania 4 [13]

Switching between the variants of power grid is based on another software application. It includes the instructions to operators that enable switching over the variants. These variants are sets of predefined connections in the main switchgears, enabling the operation of mine power grid in different combinations of operating and not-operating transformers. The electronic version of the switching over application was created to assist the operators executing this task (Fig. 9).
2.3. Module for supporting the decision in nonstandard conditions

Supporting the decision making process in non-standard situations is an important part of the system for management of electricity grid in mine. It is especially important during repairs of grid or planned switchovers. The operator has a possibility to check all alternative “paths” of power supply to a given switching station. It enables to supply the devices, which are behind the area of connection being repaired. The process of selection of supply “path” is supported by a user’s interface displaying the electricity grid. The colours assigned to transformers enable intuitive change of connections between the switching stations to supply the power from different source [13].

For the presented transformers the system automatically calculates, if permissible average power and maximum power are exceeded in each branch of the system, basing on data of grid connections and work schedule. This function is especially useful in non-standard conditions of grid operation, because it protects against exceeding the limits imposed by electricity suppliers [13].

Table 1

<table>
<thead>
<tr>
<th>Fragment of the code detecting the variant 1</th>
</tr>
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<tbody>
<tr>
<td>variant_may_be(variant1):=</td>
</tr>
<tr>
<td>user_says(ifTR1isON,yes),</td>
</tr>
<tr>
<td>user_says(ifTR1_1isON,no),</td>
</tr>
<tr>
<td>user_says(ifTR1_2isON,no),</td>
</tr>
<tr>
<td>user_says(ifTR2isON,yes),</td>
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<td>user_says(ifTR2_2isON,no),</td>
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<tr>
<td>user_says(ifTR2_1sys1isON,yes),</td>
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<td>user_says(ifTR2_1sys2isON,no),</td>
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<td>user_says(ifTR2_2sys1isON,yes),</td>
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<td>user_says(ifJamnice_1_1sys1isON,yes),</td>
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<td>user_says(ifJamnice_1_2sys1isON,yes),</td>
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<td>user_says(ifJamnice_1_1sys2isON,yes),</td>
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<td>user_says(ifJamnice_1_2sys2isON,yes),</td>
</tr>
</tbody>
</table>

Variants of grid switchovers, which enable change of grid configuration in the case when some transformers have to be disconnected, were implemented in the application. Identification of these variants was programmed in Prolog language (Table 1) and the variants are made available in a form of ready connection diagrams. The variants present the procedure for changing the grid configuration to supply the power to receivers in the case, when one of transformers is damaged or withdrawn, e.g. for repair. Fragment of main window with the selected variant is given Fig. 10 [13].
2.4. Module for incident and post-incident grid management

The application supports the operator’s decision-making process during failure or after failure. When detecting the failure the operator can check all alternative connections between switching stations, where power supply was cut off. This function enables quick finding the alternative connection paths and restoration of power supply to devices in area of damaged part of the grid. This process is supported by the user’s interface presenting mine electric power grid. Advice from the system is not critical, the final decision on the actions to be taken always left in the hands of the human [13].

There are previously prepared procedures for the situations of transformers failure. Selection of variants in the case of failure is realized by drop-down list in the right top corner of the main window. The variants switchover requires switching in the main switching station in the strictly specified order [13].

The application enables simulating the failure. Connection failure is signalized in the application by highlighting the damaged connection (Fig. 11). Connection parallel to the damaged one was selected to overcome the failure (Fig. 12). This function is used in training the operators. In the case of emergency and extraordinary conditions, a set of actions should
Fig. 11. Failure of connection between RG-2 and RS-7 switching stations [13]
Rys. 11. Awaria połączenia między rozdzielnią RG-2 i RS-7 [13]

Fig. 12. Alternative connection of switching stations [13]
be done, i.e.: determining the location of emergency; cutting-off the power supply to
dangerous areas, with the exception of equipment required during the rescue; and bypassing
damaged power switching substation, using alternative energy sources (another plant). In
a stress situation an employee can make a mistake at each previous task, which can lead to
serious accidents. In the proposed application, including the simulation software, the
employee has to deal with selected staged situations. The simulation software includes an
advisory expert module, which is used to verify the employee's [8].

Managing system enables recording current grid configuration, what is very helpful in the
case of emergency. Then operator can activate one of the previously recorded configurations,
what shortens duration of failure [13].

Restoration of power supply in the area of failure requires selecting the connection
variants in such a way not to exceed limits settled by electricity suppliers. To facilitate taking
decision by the operator, the system enables determining average and maximum load for
a given day.

3. Summary

The result of the project is system for electric grid management in coal mines, aiming to
reduce energy consumption. Tests of the application with use of data delivered from the mine
and data from the simulation models delivered by partners, were carried out within the
project. That enabled verification of the power grid module for its ability of reading the load
in the selected points of electricity grid. Conducted tests allowed to confirm if predefined
requirements were met and system readiness to connect it to monitoring system of
distribution boards in electrical grid [13].

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Omówienie

Dostępność energii elektrycznej jest podstawowym czynnikiem warunkującym prowadzenie bezpiecznej działalności w zakładach górniczych. Przeciwdziałanie zagrożeniom oraz prowadzenie procesów, m.in. takich jak: przewietrzanie wyrobisk podziemnych, transport załogi czy produkcja surowców mineralnych, wymagają ciągłości dostaw energii, w celu zapewnienia bezpieczeństwa pracy ludzi i ochrony środków produkcji.

Instalacje elektryczne w kopalniach, często bardzo złożone, przesyłają dużą ilość energii, zwłaszcza gdy szczytowe wartości obciążenia mocy są znaczne. Kontrola przepustowości poszczególnych linii zasilających może zapewnić odpowiednią jakość dostarczanej energii i zmniejszyć ich awaryjność, co prowadzi do ograniczenia strat wynikających z przestojów awaryjnych.

Konieczność poprawy efektywności przesyłu i użytkowania energii wymusza potrzebę wprowadzania zmian w sposobie nadzorowania i zarządzania sieciami energetyko-elektrycznymi. W ramach projektu o akronimie M-SmartGrid, dofinansowanego przez europejski Fundusz Badawczy Węgla i Stali, prowadzono prace nad oprogramowaniem systemu służącego do zarządzania siecią energetyko-elektryczną kopalni. Opracowano nowe rozwiązanie sprzętowo-programowe, pozwalające na obniżenie kosztów zużycia energii elektrycznej. W artykule zaprezentowano opracowane w Instytucie KOMAG oprogramowanie do zarządzania powierzchniową i dołową siecią energetyko-elektryczną kopalni, umożliwiające monitorowanie, prognozowanie obciążeń oraz wspomaganie podejmowania decyzji w zakresie jej funkcjonowania.

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