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Energy-efficient power supply system for mines

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Abstract

The research group developed an independent power supply system for a mine, which generates electrical power to supply electrical loads inside the mine. The electrical power is generated from kinetic energy of gangue material transported from the upper level of the mine to the lower one and thanks to the improved operation of fan exhauster stations controlling air flows inside the mine. A new design of the turbine for electric power generation in the process of slurry transportation was suggested and its pilot sample was produced.

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Keywords: turbine, generator, self-commutated inverter, slurry, backfilling material, mine, mine water

Introduction

The wide range of ore mining electrical machinery for mines requires an extensive power network with various voltage ratings, current and consumed power. Electrical machinery for mines usually consists of alternating current power consumers based on a squirrel-cage induction motor: exhauster fans, deep well pumps for pumping water out of mines, grinding machines for ore reduction, drilling machines, hoisting equipment, etc. Electric power supply of this equipment is provided by 0.4 and 6 kW network by means of cables laid both at grass and on all levels inside the mines. Mine electrical equipment is characterized by abruptly variable loads with high starting currents. That is why a separate supply substation with equipment for power compensation, which is connected with the main transmission line, [1].

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Capital costs of mine development as well as huge electric energy consumption by mining equipment result in the increase of the unit cost and, consequently, in the decrease of competitiveness of the whole enterprise. Development and maintenance of some remote deposits, which are located far from the infrastructure and from the national grid of the Russian Federation, could even become unprofitable [2, 3]. The issues of ecology and preservation of environment, the increase of tax levies on industrial enterprises for harmful emissions into atmosphere encourages the study of the problem of energy saving by making use of renewable energy sources, [4, 5]. Each deposit is a unique object with its special features, that is why an individual approach should be applied in each case to solve this problem.

Modern projects of ore deposit development do not take into account the capabilities of electric power generation by low and medium power generators making use of energy of flows to drive auxiliary equipment of the mine. The following moving flows could be used for the purpose: underground water flowing out of cracks in the ceilings or mine sides; underground, surface and process water contaminated with ore particles incoming from the upper levels into the main water collector, which is later pumped out to the surface by the mine drainage complex; backfilling material flowing under gravity along vertical and sloping stowage pipelines into the empty mined-out spaces; slurry of mill tailings in the process of hydraulic filling of mined-out spaces of open-pit mines; outside air blown by the main fan into tunnels of the mine to provide their ventilation and further evacuation of contaminated dust and gas flow of mine air into the atmosphere, [6].

The authors of the article offer original engineering solutions to a number of problems aimed at energy saving in mines:

1. Generation of electric energy for auxiliary equipment from kinetic energy of slurry descending into the mine to fill the mined-out spaces and from water descending from the upper level of the mine to the lower ones.
2. Compensation of reactive power of the mine power network.
3. Energy saving due to optimized control of air flow rate on various levels of the mine

Electric energy generation from the slurry (backfilling material) going down the mine

The developed turbine for slurry (Fig. 1) is unique as no turbine has ever been used for such an aggressive material, that is why the authors applied for a useful model patent of the turbine used for slurry. The backfilling material contains fine ground ore (slag) and has high abrasive properties, that is why the turbine wheel will be subjected to increased wear and breakdown. The offered design of the turbine consists of a wheel with blades (Fig. 1b), strengthened reinforcement ribs, as the blades will be subjected to high pressure. The number of reinforcement ribs can be from one to two depending on the area of the blade and diameter of the pipe with slurry. The material of the wheel must have high resistance to rupture resulting in the high cost of the turbine and capital costs, [7, 8]. The second variant is to use cheaper materials but to shorten the service life of the turbine wheels. As backfilling is a discontinuous process, the worn out turbine can be quickly changed during out-of-service time, while welded metal wheels for the turbine can be manufactured by one of the departments of the enterprise. The bottom part of the turbine shell must be elongated (Fig. 1a) to provide cleaning of the blade from slurry due to the centrifugal effect. This will prevent the wheel from jamming during the turbine operation.

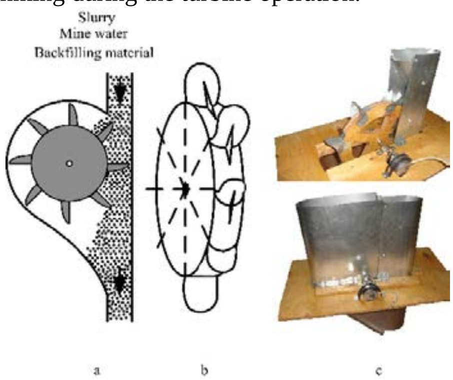

Fig. 1. The turbine for slurry (a), the wheel (b) and the pilot sample of the turbine for laboratory tests (c)

At present, slurry and backfilling material is transported to the mined-out spaces through pipelines with elevation difference from 50 to 500 meters, [2]. Dissipation of kinetic energy of the falling slurry is provided by the assembly of pipe knee joints on various levels of the mine (Fig. 2a). Frequent failures of these joints increase the time of the backfilling process and is a very important problem at present. It seems reasonable to install hydraulic turbines instead of knee joints (Fig. 2b), thus solving two problems: electric energy generation due to the decrease in velocity of the falling slurry (backfilling material) and elimination of the possibility of pipeline failure in the knee joints of the transportation pipeline.

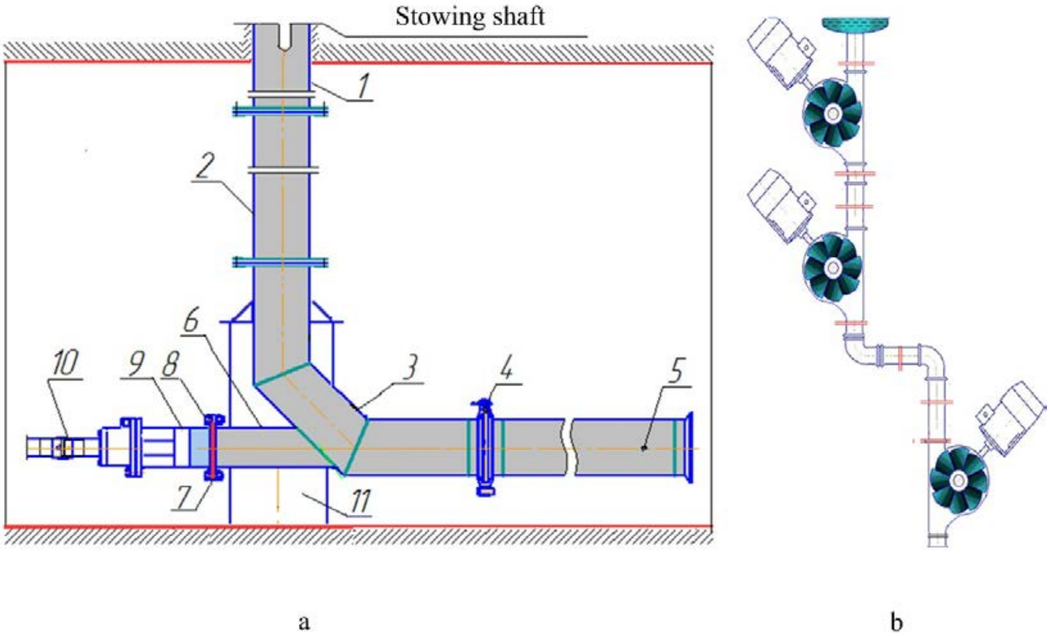

Fig. 2. Stowing pipeline design (a): 1- surface pipe; 2-vertical insertion piece; 3-welded knee joint with 90º bend; 4-make-and-break joint; 5-horizontal pipeline; 6-connecting pipe; 7-diaphragm; 8-flange coupling; 9-hydraulic cylinder with a piston; 10-a fixed joint of the piston rod with the vibration source; 11-seating unit; (b) – installation diagram of hydraulic turbines on the stowing pipe.

Energy saving due to control of air flow rate

The problem of optimized control and air flow circulation in mines has been only partially solved. The exhaust fan stations on the surface providing air supply and air exhaust operate with the nominal rating and at a uniform rate 24 hours a day. Such stations consume up to 30% of the total energy supplied to the mine electrical installations.

Air flow rate is different on different mine levels. On lower levels air circulation is weak, which makes it necessary to install additional exhaust fan stations. On upper levels the air flow rate is so high, that it makes it difficult to for miners and operating staff to work. At present, in order to reduce the air flow rate, special dampers are installed, which slow down the air velocity, thus making the working environment more comfortable. The offered measures aimed at optimization and control of air flow in a mine include installation of a wind turbine instead of the dampers, which will generate electric energy from excessive air flow and feed it into the mine network. Capital costs of such an installation are not very high because it is not necessary to design a special air turbine with a generator, [9]. It is only necessary to install an industrial fan with an induction motor. The complete circuit diagram of air flow rate control in the mine is given in Fig. 3. The fan turbine is supplied with an air collector, which is mounted into the damper opening. The frame of the air collector will increase the density of the air flow going through the turbine, thus improving the energy efficiency of the wind turbine. In the process of air injection, the induction motor is switched to the generator mode by means of a controlled inverter [10, 11], which controls the speed of the fan blades.

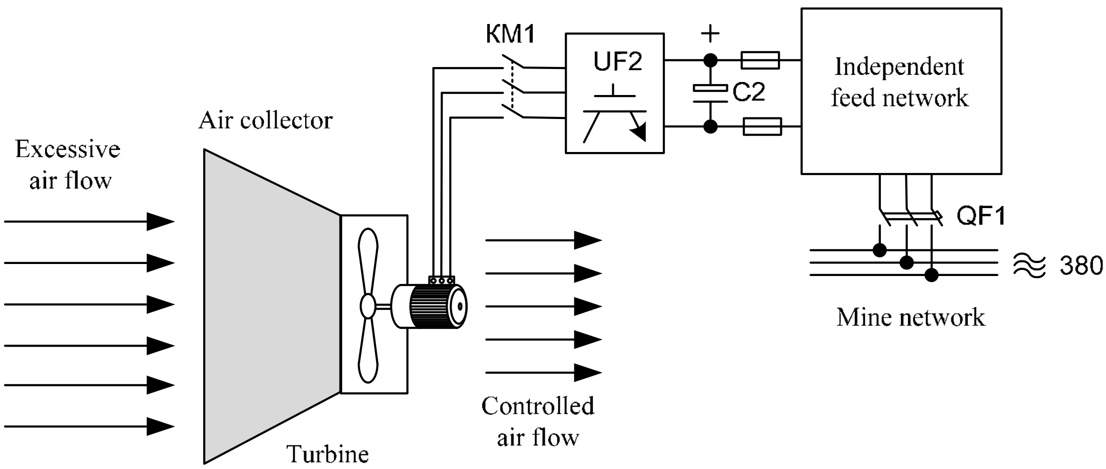

Fig. 3. The complete circuit diagram of air flow rate control with regeneration of current into the mine network

Air flow rate is controlled by the inverter current. The higher the inverter current, the weaker the air flow at the turbine exit and, subsequently, the more electric energy is generated and fed into the mine network. If the air flow in the mine shaft is low, the inverter switches off and the turbine fan is allowed to rotate freely without changing the air flow rate. Modern inverters have microprocessor modules capable of calculating and setting the necessary generator speed on a real-time basis depending on the preset scheme or by means of remote control.

Circuit diagram of the energy saving power supply system of a mine

The circuit diagram of the independent power supply system of a mine is given in Fig. 4. In the process of slurry (water) transportation along the pipeline to the worked-out spaces, the blade turbine drives a low-speed generator, which generates three-phase alternating voltage, [5]. The independent controlled inverter converts alternating voltage into direct constant one. Direct voltage is supplied is supplied to each consumer by cable. Thus, the mine gets an independent direct current network with the voltage of up to 400 V. This network has lower electric energy loss compared to the alternating current network, because it has no losses caused by reactive power. Electric energy consumers require alternating current, that is why they are equipped with additional independent controlled inverters, which are capable of speed control. For example, to control the air flow in the shaft, the inverter feeding the induction motor can change the fan speed and, consequently, electric energy consumption rate. The smoothness of speed control effects the reactive power consumption from the main, for example, it eliminates the risk of voltage sags at the moment of motor starts. Electric energy generation in the redundant circuit is not constant and depends mainly on kinetic energy of slurry in the backfilling process, while mine equipment must be constantly supplied by electricity. If the turbine does not rotate, voltage value in the redundant circuit decreases, and the circuit automatically switches to the mine network either by means of a UD diode bridge or by means of a UF6 inverter. Thus, power consumers will be constantly supplied by electric power. If the UF6 inverter is used instead of the UD diode bridge, it makes it possible to feed electric power into the 380 V mine network.

Conclusion

The developed independent power supply system is capable of satisfying more than 50% of power demand of the mine facilities both inside and outside the mine. The new set of energy saving measures in the process of mining can significantly reduce the operating costs of the mining enterprise.

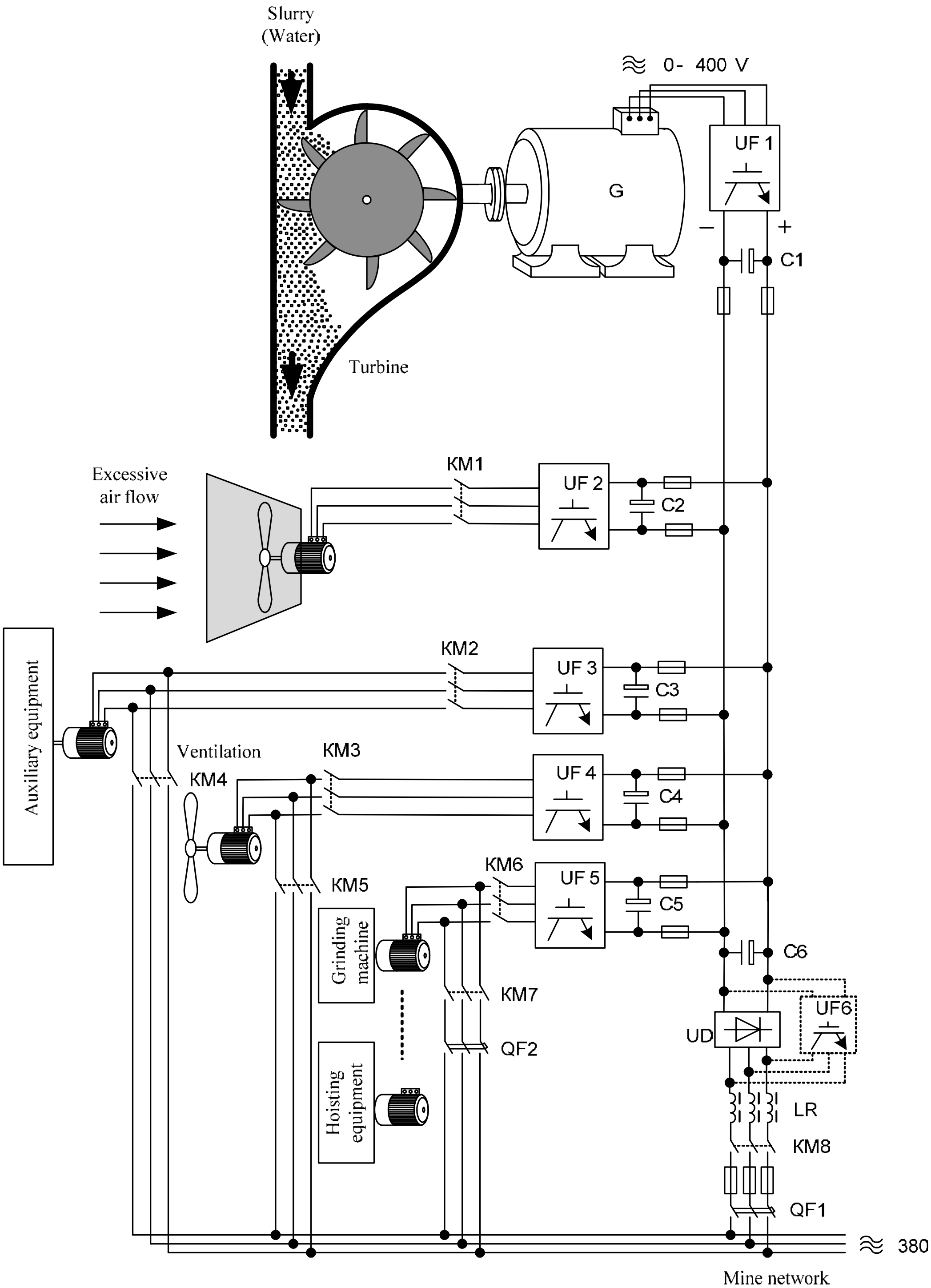

Fig. 4. The scheme of the independent power supply system of the mine

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References

[1] D.R. Kaplunov, M.V. Rylnikova, D.N. Radchenko, Application of renewable energy sources in the process of hard minerals mining, Physical and engineering issues of mineral mining. 1 (2015) 88–96.

[2] A.S. Maklakov, A.A. Radionov, Integration prospects of electric drives based on back to back converters in industrial smart grid, 2014 12th International Conference on Actual Problems of Electronic Instrument Engineering, APEIE 2014 – Proceedings. (2014) 770–774. DOI: 10.1109/APEIE.2014.7040790

[3] A.A. Radionov, A.S. Maklakov, V.R. Gasiyarov, Smart Grid for main electric drive of plate mill rolling stand, Proceedings of 2014 International Conference on Mechanical Engineering, Automation and Control Systems, MEACS 2014. (2014). DOI: 10.1109/MEACS.2014.6986842

[4] M.V. Rylnikova, V.A. Angelov, I.S. Turkin, Some features of engineering solutions and design of recycling wastes from ore mining and processing in worked-out spaces of open-pit mines, Proceedings of Universities, Mining Journal. 2 (2015) 59–66.

[5] M.V. Rylnikova, V.A. Angelov, I.S. Turkin, Justification of manufacturing scheme and equipment system for utilization of mill tailings in underground worked-out spaces, Mining research and information journal. S41 (2014) 138–149.

[6] M.V. Rylnikova, V.A. Angelov, I.S. Turkin, Prospects of underground hydroelectric station construction in areas with worked out mines, Surveyor bulletin. 5 (2014) 24–27.

[7] A.A. Kuzmenko, Control system of hydraulic turbine speed: integrated adaptation, Proceedings of YuFU, Engineering sciences. 4(129) (2012) 175–181.

[8] A.P. Barabanova, T.N. Skorobogatova, Simulation of load distribution along hydraulic turbine blade as a system with distributed constants, Young scientist. 14(2) (2015) 92–94.

[9] S.A. Linkov, A.S. Sarvarov, I.V. Bachurin, Development prospects of wind power generation in Russia and abroad, Electrical systems and complexes. 21 (2013) 220–225.

[10] A.A. Radionov, A.S. Maklakov, E.A. Karyakina, New control method of back to back converter, 2015 International Siberian Conference on Control and Communications, SIBCON 2015 – Proceedings. (2015). DOI: 10.1109/SIBCON.2015.7147135

[11] A.S. Maklakov, A.A. Radionov, EMC evaluation of three level NPC converter based on space vector PWM, Proceedings of the 2015 IEEE North West Russia Section Young Researchers in Electrical and Electronic Engineering Conference, ElConRusNW 2015. (2015) 236–240. DOI: 10.1109/EIConRusNW.2015.7102269