ZYGMUNT SZYMAŃSKI*

INTELLIGENT, ENERGY SAVING POWER SUPPLY AND CONTROL SYSTEM OF HOISTING MINE MACHINE WITH COMPACT AND HYBRID DRIVE SYSTEM

INTELIGENTNE, ENERGOOSZCZĘDNE UKŁADY ZASILANIA I STEROWANIA GÓRNICZYCH MASZYN WYCIĄGOWYCH Z NAPĘDEM ZINTEGROWANYM LUB HYBRYDOWYM

In the paper present's an analysis of suitableness an application of compact and hybrid drive system in hoisting machine. In the paper presented the review of constructional solutions of hoisting machines drive system, driving with AC and DC motor. In the paper presented conception of modern, energy sparing hoisting machine supply system, composed with compact motor, an supplied with transistor or thyristor converter supply system, and intelligent control system composed with multilevel microprocessor controller. In the paper present's also analysis of suitableness application an selected method of artificial intelligent in hoisting machine control system, automation system, and modern diagnostic system. In the paper one limited to analysis of: fuzzy logic method, genetic algorithms method, and modern neural net II and III generation. That method enables realization of complex control algorithms of hosting machine with insurance of energy sparing exploitation conditions, monitoring of exploitation parameters, and prediction diagnostic of hoisting machine technical state, minimization a number of failure states. In the paper present's a conception of control and diagnostic system of the hoisting machine based on fuzzy logic neural set control. In the chapter presented also a selected control algorithms and results of computer simulations realized for particular mathematical models of hoisting machine. Results of theoretical investigation were partly verified in laboratory and industrial experiments.

Keywords: hoisting machine, energy saving supply system, digital control, predictive control,

Przedstawiono analizę celowości wprowadzania, napędów zintegrowanych oraz napędów hybrydowych, do układów napędowych maszyn wyciągowych. Zamieszczono przegląd rozwiązań konstrukcyjnych wybranych hybrydowych oraz zintegrowanych napędów maszyn wyciągowych z silnikami DC i AC. Opisano koncepcję nowoczesnego, energooszczędnego układu zasilania górniczych maszyny wyciągowej, złożonego z silnika zintegrowanego, (tranzystorowego lub tyrystorowego) zasilacza przekształtnikowego, oraz inteligentnego obwodu sterowania zbudowanego na wielopoziomowych sterownikach mikroprocesorowych. Przedstawiono analizę możliwości zastosowania wybranych metod sztucznej inteligencji w układach sterowania, automatyki oraz diagnostyki maszyn wyciągowych. W referacie ograniczono się do analizy metod sterowania rozmytego, metod algorytmów genetycznych oraz nowoczesnych sieci

* SILESIAN UNIVERSITY OF TECHNOLOGY, GLIWICE, POLAND

neuronowych II oraz III generacji. Metody te zapewniają realizację złożonych algorytmów sterowania maszyną wyciągową z zapewnieniem energooszczędnych warunków eksploatacyjnych, monitoringu parametrów eksploatacyjnych oraz predykcyjną diagnostykę stanu technicznego maszyny wyciągowej, minimalizującą liczbę stanów awaryjnych. Przedstawiono koncepcję układu sterowania i diagnostyki maszyny bazującej na metodzie: fuzzy-logic neuro set control system (sterowanie rozmyte w sieciach neuronowych). Przedstawiono wybrane algorytmy sterowania oraz wyniki analiz komputerowych wybranych modeli matematycznych maszyny wyciągowej. Wyniki rozważań teoretycznych zostały częściowo sprawdzone w warunkach laboratoryjnych oraz przemysłowych.

Słowa kluczowe: maszyna wyciągowa, zasilanie energooszczędne, sterowanie cyfrowe, sterowanie predykcyjne

1. Introduction

The exploitation of transportation machines in horizontal and perpendicular underground mining transport require practical realizations of next conditions: energy-savings, reliabilities, and work safeties. In drives of mining-shaft hoists the distinct improvement of energy and economic coefficients one obtains by: application of hybrid driving system, application of modern supply inverters, optimal control of hoisting machine work, application of artificial intelligence methods in control systems, implementation of modern monitoring methods, and predictive diagnostic research to estimation of hoisting-machines technical state. Control systems of supply inverters are controlled from industrial computers, and required different kinds of digital regulators in drive system (Golden, 1996; Kowalski, 2006). Depending on automation degree of hoisting-machine are used in practical solution a different control systems: discreet control system, fuzzy logic control system, and systems of artificial intelligence (Golden, 1996). The application of digital technique (digital regulators of drive system, digital measuring sensors, and digital measuring transducers) assures automatic or semi-automatic control of the hoisting machine work in real-time, with actually registration of exploitive parameters. Industrial computers assure also monitoring and diagnostics of hoisting-machine work, what enable earlier detection of damage states and enlarges the work safety. In the paper one placed the review of constructional solutions a chosen variants of hoisting-machines drives systems: hybrid and compacted, with DC and AC motors. One described the idea of modern, energy-saving supply system of mining hoisting-machine, composite with compact motor, transistor or thyristor supply system, and intelligent control system based on multi-level microprocessor drivers. In the paper presented an analysis of possibility application of chosen artificial intelligence methods in control systems, automatics systems and diagnostics systems of hoisting-machines. One introduced a chosen algorithms of control system and results of computer analyses a chosen mathematical models of the hoisting-machine. Results of theoretical considerations were partly verified during a laboratory and industrial experiments.

2. Modern power supply system of hoisting machine

In Polish mines are applied practical an exploitation systems leaning on high coal concentration. Demands this application of effective cutting machines and unfailing transportation systems in horizontal transport and perpendicular transport. Systems of horizontal transport should work impromptu continuous and assure the liquid coal transportation to loading stations on the shaft station, or directly on the surface. Systems of perpendicular transport (cable lift hoisting shafts,
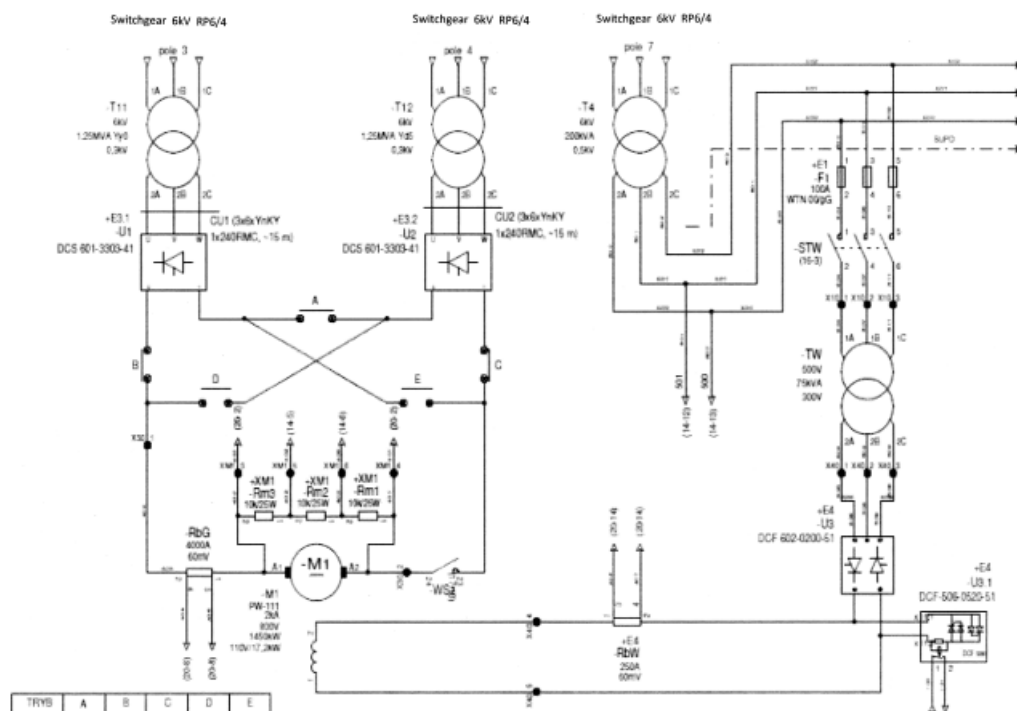
Fig. 1. The schema of hoisting-machine supply system with supply inverter
(Szymański, 2007; Oleksy & Szymański, 2010)

riding downhill shafts) should be coordinated with the coal inflow and with downhill rides and trips of mining-crews.

On main hoisting shafts are practical applied a hoisting-machines with driven of a direct current separately-excited motors, supplied from rectifier suppliers system (Oleksy & Szymański, 2010). Rated powers of driving motors attain the level: (1000-6000) kW (Szklarski, 2000). Hoisting-machines are supplied with main mine distribution system of three-phase- network with nominally voltage 6 kV, by lowering transformer: 110 kV/6 kV, at short circuit power of networks exceeding 300MVA. A consequence of such manner of the power supply are large voltage drops in connectors of mains hoisting-machines.

The application of supply inverter causes the enlargement of deformation degree in supply voltage and current of power supply system (generate of high harmonic), large voltage fluctuations of network as result of sudden changes of the passive power, the break down commutation supply voltage, comparatively minimization of power factor (cosj»0,55-0,60) (Szklarski & Zarudzki, 2000; Szymański, 2007). They can influenced on other drives system supplied from the same main mine distribution system, causing disturbances of their work (disturbances of work in main airing fun), driven with synchronous motors, or drives with induction motor in system of sub synchronous cascade (Oleksy & Szymański, 2010; Szklarski & Zarudzki, 2000).

For limitation of negative results of influence of supply inverters on main mine distribution system, we should take part to great of short circuit network power, applied a higher harmonic
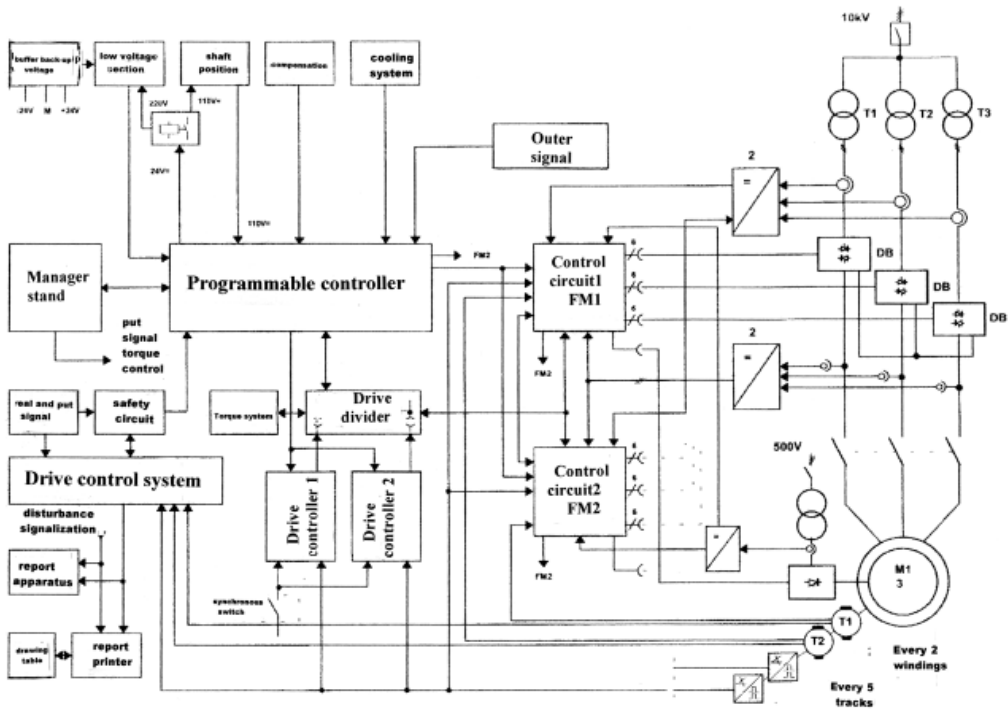
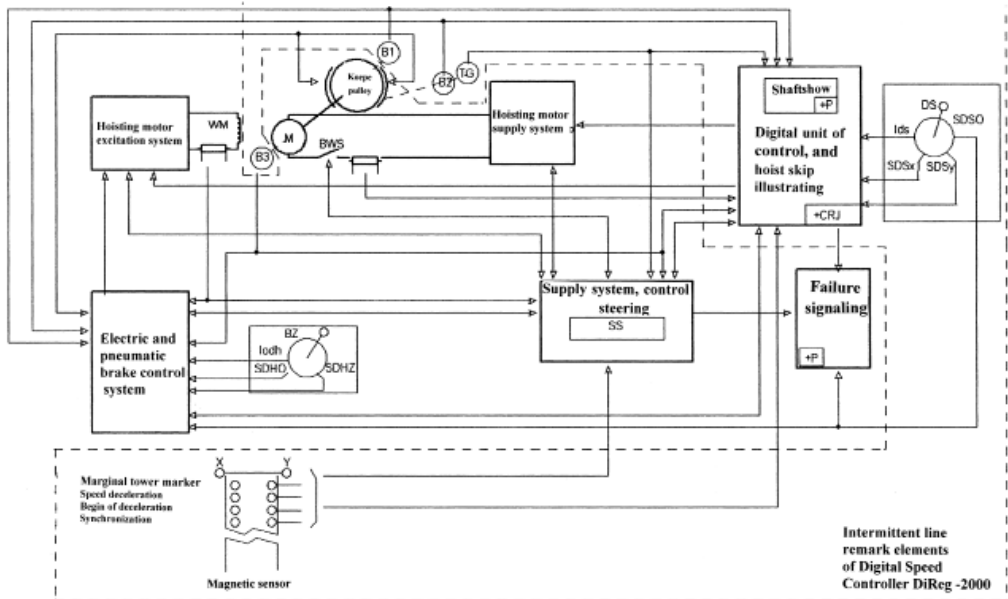Fig. 2. The schema of hoisting-machine driving system with synchronous motor

Fig. 3. The visual schema of the feed system of the winding-machine

filters (static or dynamic), and application of dynamic compensation system of reactive power (Szymański, 2007). To power supply system a motor driving of hoisting-machine one complies system of supply inverters composite from: the single thyristor rectifier, or two symmetrical rectifiers 6T in parallels system. The schema of supply system of hoisting-machine supplied from inverter supply system presented on Fig. 1. On Fig. 2 presented the schema of the supply system of the hoisting-machine driving with synchronous motor. On Fig. 3 presented the visual schema of the supply system of the hoisting-machine with marked of basic elements of executive of electromechanical parts. These system assure reversing work of the hoisting – machine, with application of the electric brake, assuring the energy recuperation to the supply source. The change of direction rotation can be realized by change of direction of current flow in excitation winding of the DC motor, or by the push-pull system of supply circuit in the armature windings of the DC motor. In some solutions of drives of hoisting machines installed on auxiliary shafts, air-shafts, or reserve shaft and people ride shafts one can use hybrid driving system.

That system contains two kinds of the drives: electric motor (DC or AC), and pneumatic drive system composite from the system of gas-turbines and air-compressors. The solution can be installed in methane mines and brings considerable energy savings (to 30%), and improves the circulation of the air. On Fig. 4 presented the visual schema part of the pneumatic hoisting-machine, instead on Fig. 5 the example of the air circulation in hybrid hoisting –machine
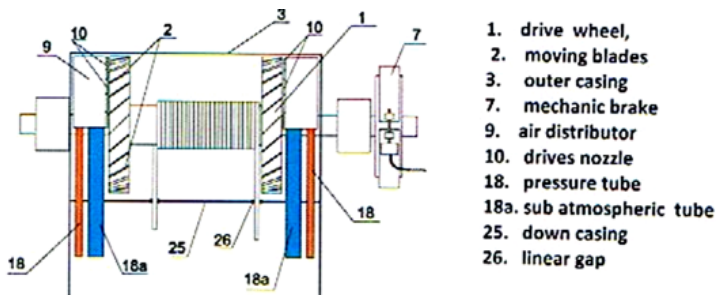

1. drive wheel,
2. moving blades
3. outer casing
7. mechanic brake
9. air distributor
10. drives nozzle
18. pressure tube
18a. sub atmospheric tube
25. down casing
26. linear gap

Fig. 4. The visual schema a part of hoisting-machine with pneumatic drive system

15. accumulation tank
27a. left side drive valve
27b. right side drive valve
28. compressor
29. distributor of air reverse
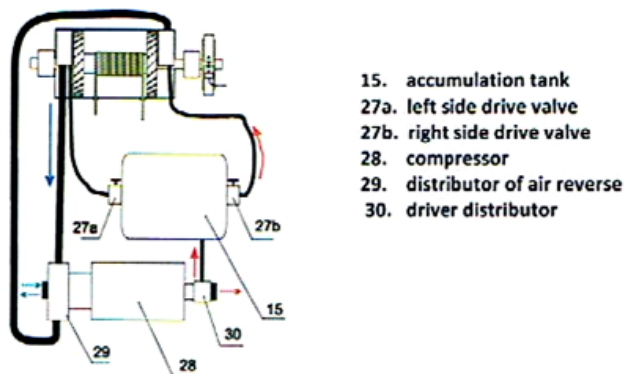30. driver distributor

Fig. 5. The air circulation in hybrid hoisting machine (Szymański, 2007)

(Szymański, 2007). The hoisting pneumatic machine HPM is driven a compressed air which pushes shoulder-blades situated on the circuit of driving circles. HPM is situated in hermetic casing which is simultaneously a silencer of the noise. The air flow takes place bipartitely through distributors of the air to which are connected both pressure tubing as sub atmospheric pressure. If the machine is supplied by pressure pipe this air is taken by the sub atmospheric pressure pipe for obtainment of suitable difference of pressures after both sides of shoulder-blades. The part of expanded, chilled air which returns to the air-compressor one can direct to the shaft and use to aid of ventilation and the air-conditioning of mine. The applying of brake machine is realized by enclosure of opposite circulation of the air, and incurrence of mechanical brake in final phase of slowing down.

3. Microprocessor control system of mine transportation machine

Control system of the hoisting machine work assuring realization of definite transport-task at established times of rides with economic drive, moves to delimitation of changes of electro-magnetic torque in road function or times cycle, travelling speeds, and the acceleration in way function or in cycle time. These sizes should not run away from given values, and energy losses occur at minimization of derivations. The duty cycle of hoisting-machine contains acceleration periods, drives with speed settled, and apply of electric as and mechanical brake system. Changes temporary decisional sizes: driving torque, length of route, travelling speed, weight of the coal, gives realization of energy-saving drive at application of expert systems methods, and adaptive control system of hoisting machine driving motors. The control system can be realized using digital regulators drives constructed basing on industrial computers. On Fig. 6 one introduced
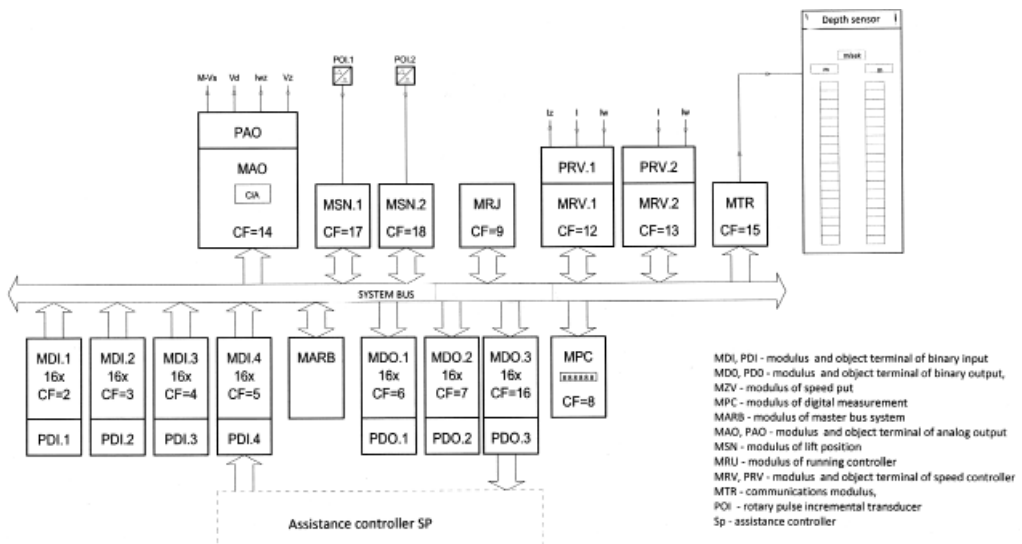

Fig. 6. The block scheme of drive controller type GRZ-00

the block scheme of digital regulator GRZ-00, installed on the cable lift machine in KWK. This system enable control of the machine work, realization of forwarding assignments and affects systems of airbrakes or electro hydraulic (Kowalski, 2006).

An alternative solution is applied a sub optimal control of hoisting-machine. That multi-level control system are applied with multi criteria, high size controller. The sub optimal control system enable a realization of control adaptive algorithms with regard of occurrences anticipatory their pronouncement. The predictive control assuring optimum-control with composition of hoisting machine drive at established functions of aim and multi criteria, determining the proper machine work in compliance with realized technical process. Predictive control system: MPC (model predictive control) or RHC (receding horizon control), are methods of control a non-linear dynamic system, consisting in cyclical resolution of properly formulating assignments of optimum – (ZSO) control. The first part of solution (functions master) is given on input of regulation object, then solve a differential equations systems, describing dynamic model of the object, obtained results of calculations are compared with the real state, then all procedure are repeated again for new established state of object. Mathematical model of predictive control system describes equations system (1):

$$
\begin{aligned}
&x(t) = f\left[x(t), u(t)\right] \qquad x(t) \in X \subset R^n \\
&u(t) \in R \in U \qquad\qquad u_{\min} \le u \le u_{i\max} \\
&u_{\min} < 0, \quad u_{i\max} \ge 0
\end{aligned}
\tag{1}
$$

where:

$x(t)$, $u(t)$ – object control functions,

$f(x, u)$ – functions realizing algorithms of the optimum-control,

Eguation (1) must realize the Lipschitz condition: $f(0,0) = 0$. Quality coefficient of the object control J we can calculate from relation (2):

$$
J_i(u^i, T_i, x(t_i)) = \int_{t_i}^{t_i+T_i} L(x^i, u^i)dt + q(x^i(t_i + T_i))
\tag{2}
$$

where:

$L(x, u)$ – total energy of drive system,

$q(x)$ – individual energy of i element of drive system

Parameters of optimum-regulator described with dependence: $u = k(x)$, can marked dissolving Hamilton-Jacobi-Bellman equations (Golden, 1996; Szklarski & Zarudzki, 2000). Finding of optimum-solution at the predictive control system is largely impossible for composite objects of regulation with non-linear system. At the steady state structure of control system one seeks with gradient methods minimum of quality coefficient $Q(p)$, where p is a vector of parameters of the control system. The gradient of quality coefficient of the visage complying numeric integration of state equations and conjugate equalizations of mining-machine driving system. During realization of optimization calculations are generated procedures of generation and reduction. Practical, are different manners of procedures generating: pins, one-nodal, flat, and multinomial (Driankov et al., 1996; Golden, 1996). The pins generation consists in introduction of additional predictive pulse to control algorithm, and to calculate an optimum-solution. The one-nodal generation consists in the introduction of new node to matrix control system. The flat generation consists

in the introduction of limitations: minimum and maximum to procedures of control system. The multinomial generation causes the enlargement about 2 polynomial meltings ($n + 2$) describing the process of object control system. After the process **generation,** follows structure change of control circuit, and change of dimension a decision space. The research process is continued in new space, to next process **generation,** or to realization of necessary conditions to obtainment of optimum-solution. Procedures of process **reduction** consist in limitations effacement of technical realizations in established procedures. The hoisting-machine can be treated as the non-linear object with non holonomic nodes, described systems of differential non-linear equations (Kowalski, 2006; Pasko & Walczak, 2007).

4. Application of artificial intelligence methods to mine, hoisting machines control systems

The system of mine-transportation this is well ordered internally the harvest of objects being found on the area and in undergrounds of mine, along with relations existing between these objects and their proprieties, whose activity is subordinate to success of established forwarding aim (Szklarski & Zarudzki, 2000). The degree of productive process automations and the diagnostics complex of machines and devices, is in Polish mines considerably limited (Szklarski & Zarudzki, 2000). Practical, are applied a systems of local automatics: stations supplied of transformer, rectifier feeders, courses of belt elevators, hoisting-machines at coal, transport, and system machines cutting: wall combine harvesters, coal planes (Szklarski & Zarudzki, 2000). In the most of mines are practical first of all conventional solutions in which the miner as the operator is necessary to starting and switching off a machines, place of exploitive parameters and to estimation of total regularity work of horizontal and perpendicular transportation machines. The knowledge of operator, and his superiors, leaning on the experience, contracted in directions, and in regulations, and requirements decides about the work quality of mining machines (Szklarski & Zarudzki, 2000). The huge knowledge of technical mine personnel should create the base of intelligent systems of real-time steering – KBS (knowledge based system), leaning on computer databases and knowledge bases. The system KBS will make possible the monitoring of real time processes, diagnostic of hoisting-machine technical state, prognoses of following production cycles and automatic control of all industrial process or his neuralgic elements. To realization of the expert control: superior (SECS – supervisory expert control system), or simple (DECS – direct expert control system) one ought to use systems of the artificial intelligence: ACN (artificial control network) and ANN (artificial neural network) (Golden 1996). To realization of expert systems and optimum-control we can use: fuzzy control (Pasko & Walczak, 2007), neural networks (Golden, 1996), or adaptive control systems containing combination of fuzzy-logic control and neural networks with application of genetic algorithms (Pasko & Walczak, 2007). It demands application of large scale processors, quick and the great memory (Tadeusiewicz, 1993).

The fuzzy logic control system consists in exchange of continuous sizes master on fuzzy leaning sizes on linguistic dependences, to utilization of expert system to conclude decision (conclude machine, rule base, database) and elaboration of continuous signal realizing come to a decision in the real control circuit. The example-schema of the fuzzy regulator FKBC (fuzzy knowledge based control) one introduced on Fig. 7. The input signal of controller is subjected to the standardization process, and is then fuzzyfied in fuzzyfication process. Using the knowledge
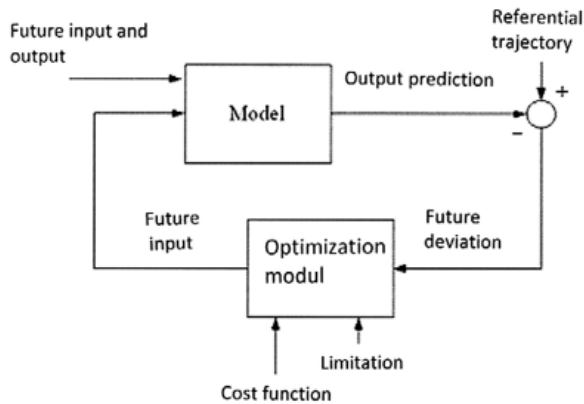
Fig. 7. Structural scheme of predictive FKBC controller

base and variable linguistic one marks sections of variable changes decision and recommended signal level of exit which after sharpening and the denormalization is given on the controller fuzzy-logic exit, and to executive control impromptu rational, enable different unforeseeable situations.
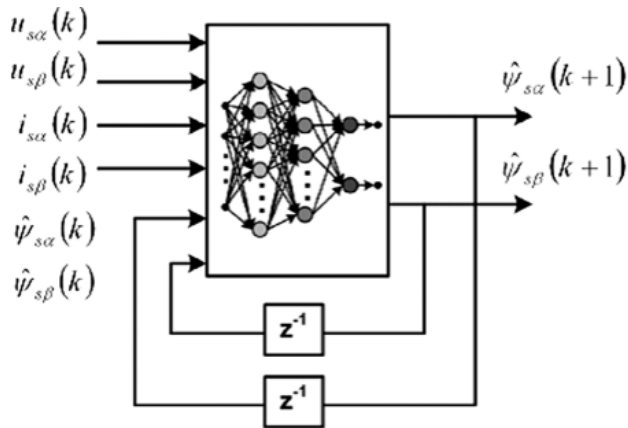

Fig. 8. Simplified scheme of neural net controller

The neural networks control system consists in image of real control system with neurons system (intelligent decisions cells, equipped microprocessor into transducers A/C and C/A and modules of operation memory: RAM, ROM, EEPROM, joint with synapses (two-way-transmission bus connection). The control process consists of two stages:

I stage – education stage (insertion to processor memory an information contracted in knowledge bases and in databases, and forcing of limitations function),

II stage – deduction and decision undertake stage (realization of control process at utilization of knowledge bases). The control system demands usages of processors about the

high speed of calculations and great operation memory, he is practical used to control of very complicated production cycles. The simplified schema of neuronal controller is presented on Fig. 8.

Control with application of genetic algorithms consists in exchange of real control system with genetic system, composite from: cells, tissues, networks of connections of inter cell and superior and local decision units The single cell contains: two microprocessors, transducers A/C and C/A, transmission registers, and operation memory. The cell copies physically definite fragment of real control circuit. Describing according to plan dependences happening among each elements of control circuit, and controller, we build the network of connections among each cells (with genes) of system. It makes possible this model of physical phenomena happening in real control system. The control system require application of more microprocessor drivers and is advisable at the control of extensive and complicated processes technical and productive. The application of expert systems in control systems of mine transportation machines will assure: energy-saving manner of power supply, and control system of the work: belt conveyors and rail transport, running monitoring of exploitive parameters, local and total diagnostics of machines in transportation system, and optimal control with the work of cutting machines.
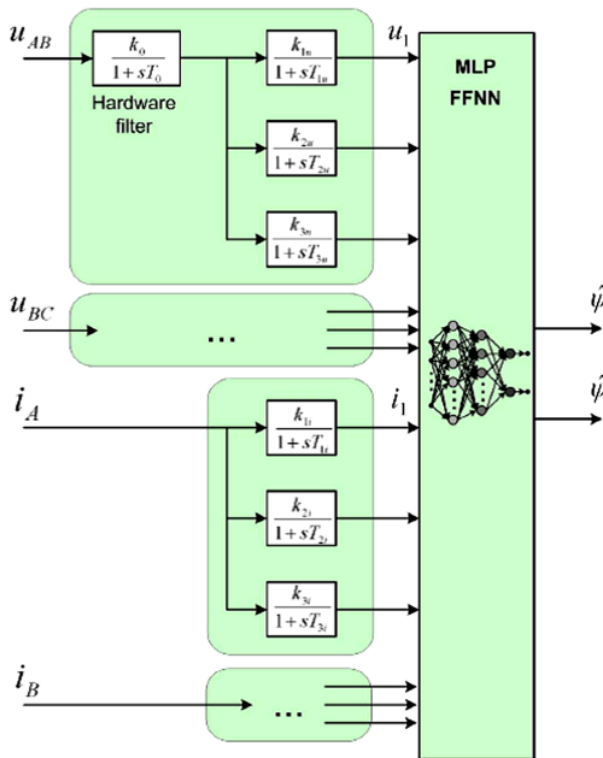

Fig. 9. Visual scheme of the fuzzy logic neuro net controller

5. Hoisting machine microprocessor control system

The hoisting machine control system assured realization of definite transportation system at established rides times, and with economic speed drive, moves to delimitation a changes of electromagnetic torque in function of way, or in function of cycle times and travelling speeds and acceleration in function of way, or in function of way of cycle time. These sizes should not run away from values given, and losses of energy occur at liquidation of deviations should be of minimum. The duty cycle of hoisting-machine contains acceleration periods, drives with speed settled and apply of brake of both electric as and mechanical. Changes temporary decision sizes: driving torque, length of route, travelling speed, weight of output, give realization energy-saving drive at application of expert methods systems and adaptive control of machine driving motors For complexity procedures of adaptive control system (Szymański, 2007; Tadeusiewicz, 1993), one used algorithm of fuzzy steering with driver of neural networks of II degree to marking a value of electromagnetic torque driving machine motor. The block scheme of adaptive fuzzy leaning regulator on object model presented on Fig. 9. At paper a verbal description of input variables and fuzzy rules of inference one uses knowledge base and database of control hoisting-machines. At present, practical are applied different versions of regulators: the regulator celled TDLs (Time Delay Liner) on entry FFNN (Feed-Forward Neural Network), the system with processes repetition, and real-time control. One can also use parley with Wiener identification and approximation of linear of dynamic states and non-linear states.
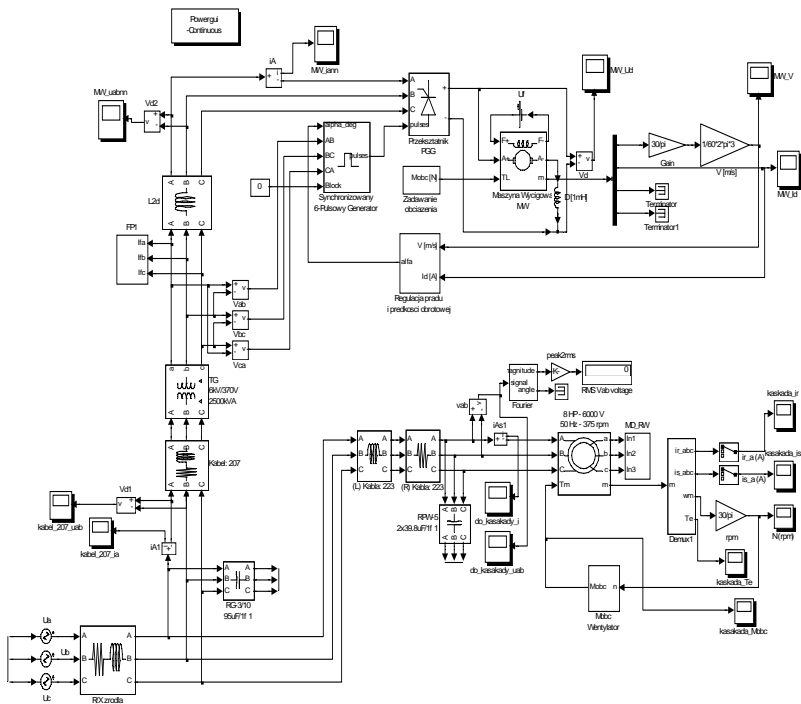

Fig. 10. Block scheme of hosting machine simulation model

On Fig. 10 presented a block scheme of hoisting cable lift machine mathematical model worked out with application of simulation programs: Matlab – Simulink and TCAD. Simulation model was used to validation direct regulators FLNS. Example-results of simulation calculations presented on Fig. 11. Results of calculations confirmed usefulness of ACN regulators in control systems of hoisting-machines.
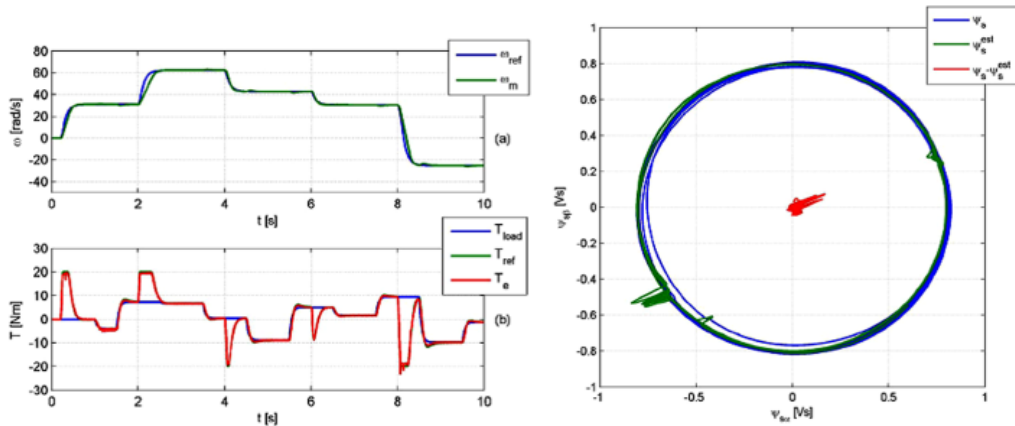

Fig. 11. Temporary courses of changes of the rotational speed of the motor and the driving torque
at the correct work of the drive of hoisting-machine

7. Conclusion

The application of expert steering systems in mine machine control systems, monitoring, and diagnostics of hoisting-machines demands introductions to each circuits of additional sensors and measuring-transducers whose output signals will make possible a realization of optimum-control system, running inspection of machine technical state and detection of possible damage states. The application of fuzzy control system permits to take into account in hoisting-machine control system process a situations not identical in meaning, in which with difficulty to undertake proper decision. Fuzzy- logic control system demands however introductions to control systems of microprocessor system and a special software. Economic impact of introduction an artificial intelligence methods are very profitable for normal economic conditions, can however bring limited advantages in the period of transformation

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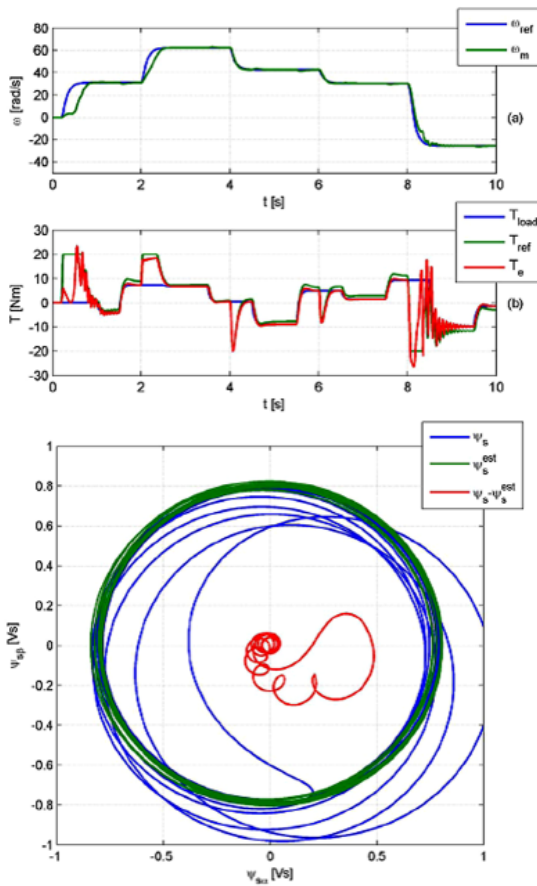
Fig. 12. Temporary courses changes of motor rotational speed and driving torque at the damage work of hoisting-machine drive system

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