UNIVERSITY OF CRAIOVA

FACULTY OF ELECTRICAL ENGINEERING

ENERGY EFFICIENCY ANALYSIS INDUSTRIAL INSTALLATIONS

DOCTOR'S DEGRE PAPER

elaborated by

ing. Nicolae POPESCU

- summary -

Scientific coordinator:

Prof.dr.ing. Ion MIRCEA

Craiova, 2013

In the electrical drives domain, the constant research preoccupation refer to the equipment modernization and, in the same time, to the energy consumtions decrease, trough the most recent technological results application. In the belt conveyors drives domain, trough the implementation of the electrical energy supply of the asynchronous motors from static converters, the present stage obtained allows the obtaining of some satisfactory energy results that leads to the significant electrical energy consumptions decrease, concomitent with the efficient motors operating.

In this context, the present paper is of up-to-dateness, the research theme being centered upon two general directions of study:

- identification of the main possibilities of conveyor belts drives modernization going up to the variours revolutions drives introduction;
- substitution of the old conveyor belts systems drive groups with the new motors of special construction (with reduced revolution 80rot/min controled by static converter of voltage and frecquency), eliminating the revolution reductor from the drive chain.

The placing of the points (zones), in that the energy savings can make, is importantly for the decrese of the industrial energy consuptions and, especial of the electrical energy consumptions for the big capacity conveyor belts drive.

As concerns the proposed objectives obtaining, the research activity was divided on more stages:

- selecting, from the speciality literature, of the mathematical models that stand at the electrical drives energy aspects base;
- adaptation of these models at the short-circuit rotor electrical motor and the realization of some specialized program of energy analyse of these;
- realization of electrical measurements – into the frame of the test stand – for to verify the correctness of drawing up of the mathematical models for the electrical motors analyse;
- effectuation of comparative measurements on different types of conveyors that has – in the drive chain composition – new drive motors (controled by static converter of voltage and frecquency) and old drive motors, through the acquisition of data from the measurement apparatus mounted on the conveyors of the same technological flow and operating in the same work duty.

This paper is structured in seven chapters, during of that as theoretical notions relevant to energy efficiency domain, as numerous mathematical formulas and relationships underlying the models studies are presented. The obtained results are centralized in tabular and graphical shape. This thesis is developed in accordance with traditional methodologies of doctoral reserach and includes a bibliographical list of 96 positions and one annexe .

In **chapter 1**, entitled *„General problems in the industrial energetics"*, it is made an elucidation of the „energy problem" that supposes a differentiating of the manner of study and analyse of this notion, depending on the different stages of conversion and usage. On the base of the definitive aspects of the energy efficiency and through the romanian industry energy

consumption structure variation manner illustration, for to refer to an immediat increase of the energy efficiency.

Having in view that the rational use is a very complex problem been in a strict interdependence with all technics domains (economics, ecology, social development), the rational management of energy must follow:

- primary energy resources saving;
- allowance for investment and expenses of exploitation for the installations of primary energy extraction and of conversion of this into other forms of energy, or for transformations of the various intermediate forms of energy, as well installations of transport and distribution of the fuels, electrical and thermal energy;
- allowance the cost of industrial production, especially of the energy – intensive, where the expenses for energy has an important weight in total spending;
- decrease of the polluting emissions into the environment in the shape of harmful gases resuted from various processes and technological installations.

Chapter 2 is entitled *„The main complex equipment used in the lignite extraction pits from Romania"* and it presents general considerations regarding on the technological process of lignite extraction from the surface pits. The technology used in continuous flow is practiced overall in the world, where there is similar conditions of surface deposits exploitation, and it requires the assimilation of some high productivity equipment such as: bucket wheel excavators, high capacity conveyers, dump trucks etc. Referring only to the coal basin of Oltenia, in this chapter the main functional characteristics are presented for: excavator type ERC 1400 30-7, types of high capacity conveyors used for excavated material transport, dump trucks – type abzeter, belt cart, machines of deposited and refilled excavated material and machine of taking coal from the deposit.

Regarding on the drives used to the belt conveyor gear, from the practice and speciality literature, can observe as to the mechanisms who composing pit equipment, the continuous service is yhe base, while short time service meets at lifting – lowering mechanisms or at displacement – mechanisms, that require a stepped variation of speed. The solution mostly used for driving the conveyor belts is the with squirrel cage induction motor, in variant with dry starting resistance or with liquid rheostat. In the case of these solutions, the starting can be controlled depending on speed, time or current. As modern gear solution, can be proposed the variable speed drives use in large limits, through the squirrel cage induction motor supply from a current inverter with intermediary circuit of current this conveyor belts systems drive manner assurance a speed variation, a good power factor, energy saving and high couple even in hard operating situations too. Because the electrical energy consumptions depend on the supply system configuration too in a certain measure, the methods of electrical energy supply of an extraction pit of low and high capacity are presented schematicly depending on technological flow complexity, in the chapter end.

In **Chapter 3**, entitled *„The energy analyse of the electrical energy consumption from a lignite pit in current situation",* the general theoretical aspects that refer to the energy audits and

analyzes are treated. Based on the speciality literature and on the genearl definitions of the two concepts, the objectives and the types of analysis, respective of audits – underlying the economical and energy efficiency indicators determination – are established in the first part of the chapter. For the energy audits, the main steps that must follow to achieve of such study for an industrial objective are presented succintly on follow-up of the chapter.

The lignite extraction in the surface pits is a complex process during which high consumptions of electrical energy are recorded for the main extraction equipment. The main energy indicators of consumption at the coal extraction pits from Romania - Berbeşti, Jilț Nord, Jilț Sud, Olteț, Peşteana and şi Roşia (actve power, reactive power, power factor, specific consumptions) and their variations are presented comparatively for a period of 12 month of operation, in the last part of this chapter.

Considering the high level of electricity consumptions recorded in the lignite extraction pits, in **chapter 4** entitled *„Mathematical models for determining of the energy efficiency indicators to drive systems"* mathematical models for energy analysis of the conveyor belts systems operation and program for determining of the energy efficiency parameters to conveyor belts drive motors are presented.

The first model, for determining of the energy efficiency parameters to the conveyor belts systems, is based on the algorithm for calculating the electrical power required by motor of driving of a conveyor with belt. The conveyor belts functional parameters variation schemes were performed in own design Matlab – Simulink, based on this algorithm.

The second model, for determining of the energy efficiency parameters to the conveyor belts drive motors, is based on the operating characteristics of the induction motor used for driving of the belt conveyor systems in the lignite pits. Considering that the wast majority of the conveyor belts systems drive motors are older than 15 years, so they have exceeded operation time, these motors must be replaced with some new, energy efficient, for the electrical energy consumption decrease. The new motors implementation, in high capacity conveyor belts drive schemes, leads to energy savings. This aspect is justified through preseting of the energy performance obtained behind of the analysis of functioning of two modernized variants of motors.

For determining of the energy parameters to different grade of load of the conveyor belts system drive motors and for effectuation of a real analysis on electrical energy consumptions of the high capacity conveyor belts drive systems, it was used the complete mathematical model implemented in a computer program developed using Visula Basic programming enviroment. Starting from the equivalent circuit for calculating the induction motor, the calculation program allows - through the 6 calculation windows – the determination of the energy efficiency indicators for squirrel cage induction motor 630kW/1000 rot/min, with a total of 24 poles, type MAB 630, where the power supply by mean a frequency converter that ensures obtaining the nominal torque equivalent with the from shaft of coupling of the reductor type 2KC-P-630.M (75800Nm at a number of revolutions 80 rot/min and at a frequency 16,6 Hz).

In the final chapter, for different coefficients of motor load, the parameters values – obtained with the computer program – are verified both by measurements made in test stand and

the values calculated by Manufacturer. It can be concluded that the calculation program is done correctly and viable for the energy analyzes effectuation, because the variation of active power absorbed and others parameters are included in both the curve obtained with power quality analyzers and the ranges of admitted errors.

Chapter 5 is entitled *„Using of voltage and frequency converters for driving of the high capacity conveyor gear motors"* and it presents the main characteristics of the high efficiency motors, characteristics that make them suitable for variable revolution drive. This chapter refers to aspects of the voltage and frequency convertors compatibility with the motors, to the effects of the abnormal supply system duties and to the harmonious pollution influence, because for operating with variable frequency the motor chooses taking into consideration more informations than are necessary for a motor with a single revolution (as for example: admisible maximum revolutuin, couple limits etc.).

In this chapter, the definitive aspects of the vectorial induction machine control are treated, being presented the information graph and the main structure of the speed control system, the vectorial control principle, the asynchronous machine phase diagram for stationary duty and the main equations that allow the flow control in the systems with orientation according to the rotor flow phase vector.

Taking into account that the induction motors spead control can be realized through more rotational speed modification methods (through the supply voltage modification, through the rotor circuit control, through the supply voltage frequency modification), the strategies presented in the chapter final can be used for the variable rotative speed gear systems control:

- voltage/frequency control – convertor with source of current;
- voltage/frequency control – convertor with source of voltage;
- direct control of the speed – convertor with source of current;
- vectorial flow control with flow transducer – convertor with source of voltage.

The advantages for using of the induction motors supplied from static convertors of voltage and frequency are presented in this chapter. With this end in view, the base principles for speed adjustment through variable frequency and voltage supply, the static convertors structure and the control principles for the harmonic content decrease are presented. From the functional analysis of different convertors types, a general conclusion that can detach is that more frequency static convertors types can be suited in the lignite extraction pits. The used from convertors, it is the static frequency convertor for the control of the squirrel cage induction motors type DCMA-800K-VA06-100 supplied at 6 kV.

In **chapter 6**, entitled *"The energy performance indicators evaluation of a technological flow of lignite extraction"*, the general economical and energy analysis model is presented for a technological flow of transport of the mining mass excavated. This flow is composed from four sections of belts and it disposes of different drive systems (explosion proof squirrel cage induction motor MAB 630kW and static convertor of voltage and frequence CSTF, squirrel cage induction motor of 630 kW with special construction 80 rot/min and static voltage and frequency convertor CSTF without reductor, squirrel cage induction motor MIB 630 kW and static voltage

and frequency convertor CSTF). In the conveyor belts drive motors and on their supply cables, the energy losses could be determined starting from the general diagram of the technological flow of a surface pit, from the particularities showed by the continuous flow excavation, transport and dumping technology used in the surface mining exploatations, from the main (constructive and functional) characteristics of the conveyor belts. This energy losses could be determined on the base of the catalogue, measured and calculated data and of the algorithm for calculating power losses in the network elements and in the electro-technological equipment, too.

For the energy efficincy indicators calculation, it took into account of load grade or every drive motor (grade appreciated through the ratio between the real current and the rated current) and the mathematical relations were used for the calculation of the power factor and of the efficiency, relations presented in the speciality literature. For the currect absorbed of the same motor, at the same load, but supplied with variable frequency and voltage, it was used a values set resulted after measurements effected on motor, on a test stand. Then, for the real analysis of the behaviour of a such motor, it was necessarly to effect measurements on the technological flow of transport of the mining mass, in the real conditions of operating. In this real operating conditions, the conveyor belts motor (motors) absorbs from electrical network a current with a value that was correlated with the electrical power necessary to the belts drive systems and resulted from the simulations realised in Matlab – Simulink program, depending on the flow of material transported and on the technical – constructive characteristics of the belt sections studied. The drive power values resulted from calculation and the values of the current absorbed from electrical network were validated through the measurements effected.

Chapter 7 is entitled *"The economical efficiency calculation of the variable rotative speed drives implementation to the conveyor belts system"* and it represents the part of economical analysis of this paper, part developed on the basis of the economical efficiency indicators specified in the speciality literature (net revenue updated, internal rate of profitability, investment recovery duration, project profitability etc). For the energy efficiency increase, it proposes the conveyor belts drive motors replacement measure with squirrel cage induction motors with control through frequency and voltage convertor, that has as main effect the electrical energy consumptions decrease and, implicit, the realization of some financial savings.

Chapter 8 is entitled „*Conclusions. Personal contributions and possibilities of subsequent development of the researches from domain*" and it presents concisely the main conclusions resulted after researches effected, from that it follows the achievement of the objectives proposed through the research directions. From among these, the next deserve to be mentioned:

- personal contributions brought in the development of the reseraches in the industrial energy consumptions efficiency (these contributions can be structured in theoretical, software and experimental contributions);
- complete mathematical model for determining of the energy indicators that describe the induction motors operating at different load grades of these; this model was adapted to the specific duty of operating of the squirrel cage induction motor 630 kW, 80 rot/min,

controled by static voltage and frequency convertor, permiting the his implementation in a computer program achieved in Visual Basic;

- for determinating of the energy efficiency parameters at the conveyor belts systems, the mathematical model implementation (in modeling diagrams achived in Matlab - Simulink) led to the obtaining of results verified through measurements what concern the variation of the power absorbed from electrical network by the belts gear motors. These values were used afterwards to determination of the useful energy and of the energy losses;
- by comparing the results obtained by means of measurements made on the program of and the data engine catalog, values were obtained in the admissible error range (± 5%) which allowed their validation;
- calculations effectuation made on base of the real values of the flows of material transported and on base of the constructive characteristics of the belt sections. These sections are different depending on the placement of energy section as part of technological flow;
- comparative analysis of the real electrical energy consumptions, for an average number of 300 hours of operating/ month for the sections of conveyor belts T306H, T104H, T101H drove with old motors and that heve rotative speed reductor in the drive chian composition and the belt section T105H drove by a special construction motor controled by a static voltage and frequency convertor without rotative speed reductor. This analysis gave emphasis the efficient operating of this section (electrical energy absorbed and energy losses decreased with until 46%);
- economica; efficiency analysis concerning to the electrical energy consumptions efficientness measurement implementation. This analysis give emphasis the solution of replacement of the winding cage induction motors with the squirrel cage induction motors controled through voltage and frequency convertor. This solution allows the investments recovery in a short time period, making these investments to be attractively from point of financial view.

Doctorand,

Eng. Nicolae POPESCU