REDUCING ELECTRICITY CONSUMPTION AT WINDING MACHINES OPERATED BY INDUCTION MOTOR USING POWER ELECTRONICS

Ilie Uţu - *Associate Professor Eng., Ph.D., University of Petroşani*
Stochiţoiu Maria Daniela - *Associate Professor Eng., Ph.D., University of Petroşani*

ABSTRACT: *The key to the successful achievement of speed regulation of asynchronous motors is the possibility of quick change, efficiently and in a stable manner the voltage and current applied to the motor. Most electric drives used in mining plants are with induction motors due to their robustness, low cost and simple maintenance. The electric drive systems require high performance, high precision and superior function of maintenance. For that are necessary controlled drive systems with frequency converters. Its stable operation and highly precise torque control are implemented through a number of techniques such as CPU system and a Digital Signal Processor (DSP), current detection, and voltage model method.*

KEY WORDS*: electric drive systems, induction motor, PWM converter, Digital Signal Processor.*

1. INTRODUCTION

The drive system of mining equipments has been required to compose of ac motors because of their simple maintenance. Transistor inverters are usually used in small plants. However, they cannot be applied to larger drive systems, such as winding machine drives, because the maximum capacity of those currently available for ac drives is only 200-300 kVA.

Therefore, there has been demand for an inverter with a large capacity to enable ac drive systems to be used for all process lines. On the other hand, high performance, high precision and superior function of maintenance and fault diagnosis are needed to improve the quality of drive system without additional cost. Hence, there is a strong requirement for a fully digital controlled inverter.

In mining plants from Jiu Valley there are many winding machines operated with asynchronous motors, where starting and speed control is achieved by means of a rheostat metallic gear.

In order to ensure winding machine operation speed, we proposed the use of asynchronous motor drives fed by a fully digital, vector controlled GTO PWM inverter for driving induction motors.

This allows operation of the electric drive speed extraction set eliminating loss of electricity rheostat rotor circuit by operating the existing solution. The management system can be realized by means of a microprocessor system intended for such an application.

The relatively low cost, ease maintenance, high performance technical features, require the use of the technical solutions for the new operating conditions of extraction machine.

Of the many issues regarding equipment in mining in this paper deepened use of new types of electric drives by applying power electronics as a measure to reduce electricity consumption.

2. ASYNCHRONOUS ELECTRIC MOTOR DRIVES FED FROM AN PWM INVERTER FOR THE WINDING MACHINES

2.1. General data

Since almost all mines in the Jiu Valley mining facilities are operated motors with rheostat rotor circuit, the problem of finding more efficient ways to achieve the speed setting in being intricate so as to reduce electricity losses [1], [5].

A very modern method is the introduction of electric drives induction motor powered by an inverter, whose calculation is shown below.

In order to highlight the advantages of using such electrical drives, have made some calculations on the operation of the existing plant operation conditions, showing that energy losses occurring in the rotor circuit resistances.

The calculations will take into account the rated motor drive type AKH-2-16-48-12:

- Nominal power: 630 kW;
- Supply voltage: 6000 V;
- Power factor: cos φ = 0.8;
- Stator current: 81 A;
- Rotor current: 466 A;
- Rotor voltage: 810 V;

Features extraction machine are:

- Maximum static load: 176,5 kN;
- Maximum static imbalance: 147,1 kN;
- Maximum weight of equipment carried in or under cage: 102.9 kN;
- The weight of the heaviest machine with special frame cage: 176.5 kN;

- Gear transmission ratio of 1:10.5;
- The extraction rate: 5,8 m / s;
- 4 buildings for 1 m^3 of sterile 1800 Kg / conveyance;
- Extraction time t = 59 s;
- The cycle: T_0 = 119 s;

The method of calculation used assumes a functioning extraction system diagram 3 times to double cages.

Initial data for determining starting resistances are:

a) The ratio of maximum torque and nominal;
b) The nominal voltage of the rotor, E_{2N};
c) The rated rotor I_{2N};
d) Motor efficiency;
e) rated speed n_N and synchronicity, n_0;
f) Theoretical values of M_{min} and M_{max} starting time

To determine the actual values starting rheostat steps can be applied analytical method of calculation or graphical method. I thought the graphic method is most suitable for this application [5].

According to this method, it is necessary to be constructed of natural or artificial mechanical properties formed by the coupling to the rotor circuit of the power levels of the resistance.

It should be given limit values (minimum and maximum) of torque variation during startup. The range of these variations is inversely proportional to the number of steps starting rheostat and can reach 30% of the theoretical starting time.

This should be borne in mind that the higher values of starting torque not reach the maximum moment due to a reduction in blood supply to the engine, leading to decreased torque proportional to the square of supply voltage.

The starting torque lower values may not fall below the static moment resistance as during startup with system acceleration would take place and the phenomenon of slowing appropriate time during descent time starting below the static moment resistant.

2.2. Cinematic and dynamic parameters for extraction plant shareholders

Extraction unit for projecting the drive system is a system of the type 2T-3,5x1,7A extract the following information [5]:

- Static permissible cable extraction: $Q_{st\ max\ adm}$ = 15,000 daN;
- Nominal body wrap: Dt = 3,400 mm;
- Width of the drum: B = 1,700 mm;
- Cable diameter extraction: d_c = 44 mm;
- Maximum depth of extraction: H_{max} = 337 m;
- Cage with 2 floors of 2 buildings on the floor;
- Power drive motor (electric motor type AKH-2-16-48): P_n = 630 kW;
- Synchronous speed: n_0 = 600 rev / min;
- Rated: n_n = 590 rev / min;
- Return drive motor: η = 0.925;
- T2S gear type transmission ratio: i_{red} = 20.

Cinematic extraction facility

Vertical transmission speed is

$$v = \frac{\pi D_t n_t}{60} = 5{,}25 \ \ [m/s] \qquad (1)$$

where:

$n_t = n_n / i_{red}$ = 29.5 rev / min; speed spindle drum.

Diagram elements of the installation of extraction are:

- The period of time that acceleration and deceleration:

$$t_1 = t_3 = \frac{v}{a_1} = 7 \ \ [s]; \qquad (2)$$

with a = 0.75 m / s^2 acceleration or deceleration;

- Space traveled during acceleration or deceleration:

$$h_1 = h_3 = 0{,}5 \cdot v \cdot t_1 = 19 \ \ [m] \qquad (3)$$

$$h_2 = H_{\max} - (h_1 + h_3) = 299 \ \ [m]; \qquad (4)$$

$$t_2 = \frac{h_2}{v} = 57 \ \ [s]; \qquad 5)$$

- Actual time of an extraction:

$$t = t_1 + t_2 + t_3 = 71 \ \ [s]; \qquad (6)$$

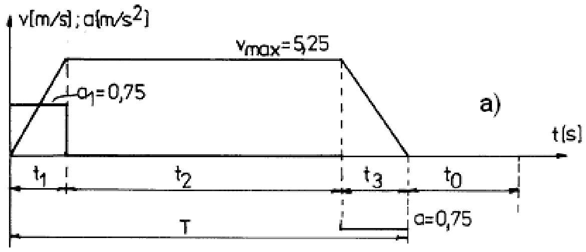

Fig.1.a. Angular velocity variation

- Residence time consists of the time required to introduce two buildings on the floor of the cage and the time needed to change the floor of the cage:

$$t_0 = 60 \ \ [s]. \qquad (7)$$

The diagram of operation of extraction is shown in fig.1.a at another scale the change in angular velocity of the induction motor function of time [5].

Dynamic extraction plant

In order to increase graphics force variation with respect to time (fig.1.b) were determined following forces:

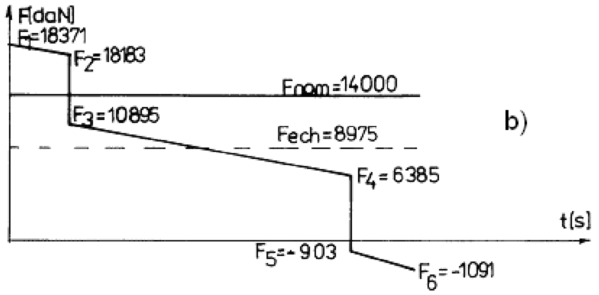

Fig.1.b. Force variation

- Force at the beginning of acceleration:

$$F_1 = k \cdot Q_{ut} + h_{\max} \cdot p_c + + m_{red} \cdot a_1 = 18.371 \ [daN]; \quad (8)$$

- Force at the end of the acceleration:

$$F_2 = k \cdot Q_{ut} + h_2 \cdot p_c + + m_{red} \cdot a_1 = 18.183 \ [daN]; \quad (9)$$

- The beginning of the drive force stabilized:

$$F_3 = k \cdot Q_{ut} + h_2 \cdot p_c = 10.895 \ [daN]; \quad (10)$$

- The end of the drive force stabilized:

$$F_4 = k \cdot Q_{ut} - h_2 \cdot p_c = 6.385 \ [daN]; \quad (11)$$

$$F_5 = k \cdot Q_{ut} - h_2 \cdot p_c - - m_{red} \cdot a_1 = \_903 \ [daN]; \quad (12)$$

$$F_6 = k \cdot Q_{ut} - h_{\max} \cdot p_c - m_{red} \cdot a_1 = = 1.091 \ [daN]; \quad (13)$$

where:

- Aerodynamic drag coefficient k = 1.2;
- Q_{UT} = 7200 kg total payload cage;
- p_c = 7.25 kg / m linear weight of the cable;
- m_{red} = 9717 kg reduced mass of the entire system periphery drums extraction.

With these forces will determine the appropriate power points of interest: P_1=0; P_2 = 818 kW; P_3 = 490 kW; P_4 = 288 kW; P_5 = -41 kW; P_6 = 0; representing the variation with time in fig.1.c. [5]

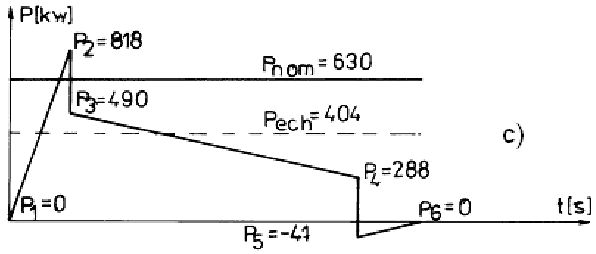

Fig.1.c. Power variation

Torque developed by the engine needed to be shown graphically in fig.1.d.

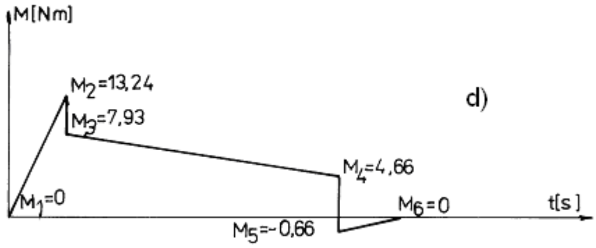

Fig.1.d. Torque variation

The values of the angular velocity and the torque with respect to time are input quantities for the microcontroller (prescribed value), and are previously stored in the micro memory.

Kinematics and dynamics calculations extraction plant were extracted from contract research which aimed at improving the technical and functional parameters of the extraction plants operated asynchronous contract which I was coauthor [5].

2.3. Energy consumption calculation functioning machine rotor resistance extraction steps

We are considering the following parameters that characterize electric drive:

- Nominal torque M_N = 1.229.75 daN;
- Rated slip S_n = 2%;
- Nominal resistance rotor R2N = 1 Ω;
- Rotor resistance, $R_2 = s_N$ x R_{2N} = 0.02 Ω;
- Minimum torque, M_{min} =1.05 M_N = 1,291.22 daN;
- Maximum static force, F_S = 10,588.24 daN;
- Torque resistant, M_{st} = 1,926.02 daN;
- Report, M_{st} / M_N = 1.57;
- Maximum torque M_{max} = 1,755M_N = 2,158.44 daN;

Resistant torque values and maximum starting torque oscillations in the types of transport are given in Table 1.

Resistance values for each step are calculated using:

$$r_i = R_i - R_{i+1}, \quad (14)$$

where i is the step number rheostat.

The results are shown in Table 3.

The total resistance is R_T = 0.897 Ω.

Binding phase two parallel triangles, the total equivalent resistance is $R_{T\Delta}$ = 4.657 Ω.

Resistances on the steps for connecting the star are as follows (see Table 4) [5].

Table 1. Resistant torque values and maximum starting torque oscillations

Version	A	B	C	D	E	F	G	H	I	J	K
M_{st}	1964	641	363	806	1351	286	959	653	2530	1798	1464
M_{min}/M_N	1,05	0,30	0,18	0,38	0,65	0,14	0,46	0,31	1,20	0,86	0,70
M_{max}/M_N	1,57	0,51	0,30	0,64	1,08	0,22	0,76	0,52	2,01	1,43	1,17

The values for the total resistance of the rotor circuit of the motor drive of the plant extract are shown in Table. 2.

Table 2. Resistance of the rotor circuit

Step	R_1	R_2	R_3	R_4	R_5	R_6	R_7	R_8
Value [Ω]	0,917	0,580	0,343	0,231	0,145	0,085	0,052	0,033

Table 3. Resistance values for each step

Step	r_1	r_2	r_3	r_4	r_5	r_6	r_7	r_8
Value[Ω]	0,336	0,237	0,112	0,085	0,059	0,033	0,019	0,013

Table 4.Total resistance values

Step	r_1	r_2	r_3	r_4	r_5	r_6	r_7	r_8
Equation	$1,4R_{2N}$	$0,5R_{2N}$	$0,3R_{2N}$	$0,2R_{2N}$	$0,12R_{2N}$	0,07R	$0,04R_{2N}$	$0,02R_{2N}$
Value [Ω]	1,4	0,5	0,3	0,2	0,12	0,07	0,04	0,02

The total resistance is $R_T = 2.67$ Ω.

The equivalent resistance delta binding is $R_{T\Delta} = 4.619$ Ω.

Existing total resistance is composed of two branches connected in parallel delta of 9.28 Ω. We obtain a total resistance $R_{T\Delta} = 4.64$ Ω.

The operating time is determined on each step bearing in mind that the engine operates on artificial mechanical rheostat. The first feature allows the actual start of the engine, resulting in a slow-motion necessary to carry out the revision of the extraction wire,[2], [5].

Running the engine at a speed of extraction of 5.8 m / s takes place on the fourth stage of resistance at an engine speed of 342 rev / min.

The plant can operate after shorting resistance at a speed of 8.3 m / s.

For the first step of the rheostat, to achieve regime overhaul cable pit mining or choose: $\Delta_{t1} = 0.75$ s.

Intervals between the steps of resistors to meet start time 8 s at a speed of 5.8 m / s are:

$\Delta t_2 = 3.95$ s;
$\Delta t_3 = 2.10$ s;
$\Delta t_4 = 1.20$ s.

The total time between steps will be:

$$\Delta t = \sum_{i=2}^{i=4} \Delta t_i = 7{,}25\ s \tag{15}$$

Times after which engages every one steps will be:

$\sigma_1 = 0.75$ s;
$\sigma_2 = 4.70$ s;
$\sigma_3 = 6.80$ s;
$\sigma_4 = 8.0$ s.

By means of the above-values are determined by setting time of the time relay. Calculate the time of the relay control for the extraction of plants is based on the kinematics of the system, the start time t1 is given size, unlike the calculation method it is necessary to determine in advance the period of acceleration of the motor according the low moment of inertia of the engine shaft.

The methodology for determining the adjustment times of relays is simplified considerably. Knowing the values of time the gear coupling occurs neighboring rheostat resistance and proper time of the engagement of the contactor, t_k, t_{pi} time setting is obtained by the relationship:

$$tp_i = \sigma_i - t_k \tag{16}$$

Embracing the value of t_k = 0.15 s, we obtain the following values:

t_{p1} = 0.6 s;

t_{p2} = 3.2 s;

t_{p3} = 2.0 s;

t_{p4} = 1.1 s.

Then it will calculate the currents on each step. To determine the current value of each step of the starting rheostat is necessary to know the relative coupling length and size of the starting current of the rotor.

The relative length of the coupling for each step is PR_1 = 0.7%, PR_2 = 4%, PR_3 = 6%, PR_4 = 7%.

Starting current of the rotor size is calculated knowing the ratio M / MN for each step. Engine mechanical diagram is determined M_{min} = 1,290.5 daN and M_{max} = 2,158.4 daN and can be considered constant for each step because the variations are small.

The result will therefore:

$$Ip_i = I_2 \cdot \frac{MP_{\max i}}{Mp_{\min i}} \; [A] \qquad (17)$$

Performing calculations resulting I_p = 779 A.

Equivalent amount of current for the rheostat steps is determined by the equation:

$$Ief_i = Ip \cdot \sqrt{PR_i} \; [A], \qquad (18)$$

resulting in the following numerical values:

Ief_1 = 65 A;

Ief_2 = 155 A;

Ief_3 = 190 A;

Ief_4 = 206 A.

Knowing that at a time of driving DA = 15% of the permitted load resistance is about three times larger than the permissible charging DA = 100%, the steps of stress currents are I_1 = 22 A, I_2 = 52 A, I_3 = 63 A, I_4 = 69 A. These currents must be less than the allowable currents of resistance rheostat steps.

Based on the above calculation we made the actual electricity that is lost rheostat rotor circuit of induction motor drive system of extraction. We have the following data:

- Resistance of the rotor circuit at v = 5.8 m / s, R_2 = 2.225 Ω;
- Current in the rotor circuit, I_2 = 330 A;
- TEF - effective operating time of 24 hours at a speed of 5.8 m/s: - often during a cycle, t = 59 s;
- During a cycle, T0 = 119 s;
- K = 0.75 - coefficient ratio of common and rare regimes or breaks

$$t_{ef} = 24 \cdot \frac{t}{T_0} \cdot K \qquad (19$$

The calculations will result - t_{ef} = 8.93 hours

Energy consumed per day:

$$E = \sqrt{3} \cdot R \cdot I^2 \cdot t_{ef} \qquad (20)$$

Substituting the resulting data and performing calculations: E = 3743.3 kWh/day.

Energy consumption per year is calculated by the formula:

$$E_{an} = 300 \cdot E \qquad (21)$$

So, we obtain E_{an} = 1,122,990 kWh/year.

For the consumer, the less shift operation or implement a different pricing system, the equivalent energy consumed on the steps rheostat will refresh accordingly [2].

The entire energy consumption resulting from the above calculations will be saved using asynchronous motor drive system powered by an inverter.

3. DESIGN OF INVERTER SYSTEM

3.1. Main circuit

In figure no.2 is shown the main circuit scheme. The element used in the inverter is a 2500 V, 2000 A reverse conducting GTO. By the use of reverse conducting GTO, the need for a diode, connected in reverse parallel to the GTO, resulted in a simplified circuit. This inverter uses a direct current distribution system [1].

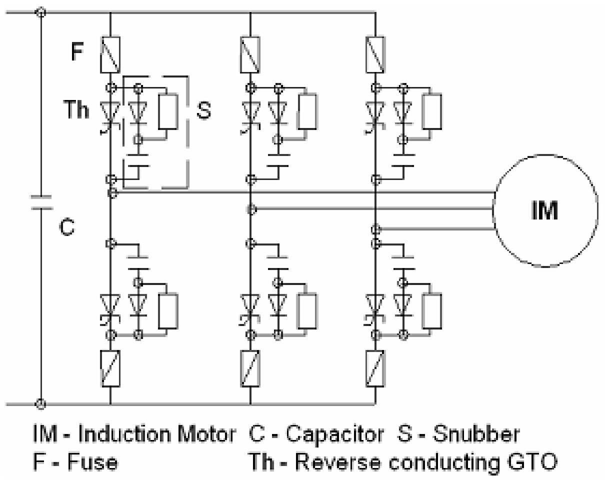

Fig.2. Main circuit scheme of inverter

To realize a larger capacity of the inverter, the parallel-set operation of the inverter was reported.

This method presents the problem of a complex control structure to suppress any cross current between the two inverters.

For solve this problem, it can be used a large capacity system with six-phase motor [3], [4]. In figure no.3 is shown the diagram of the inverter, motor and reactor.

The induction motor stator windings consists in two of three-phase groups displaced by 30 degrees each being supplied by one inverter. The phase current are shifted by 30 degrees between the two inverters.

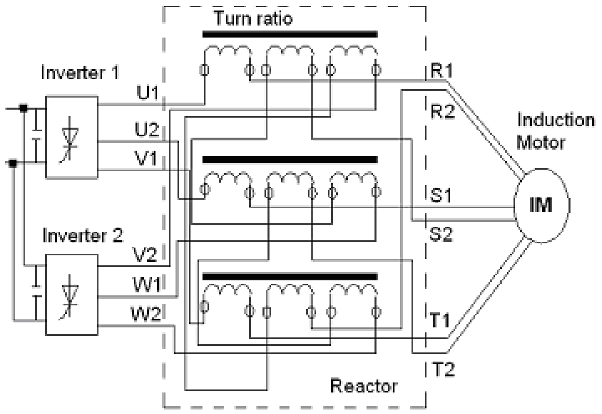

Fig.3. Diagram of the inverter, motor and reactor

3.2. Microsystem block diagram

In figure no. 4 a microsystem block diagram is shown. This diagram can be divided into three parts.

In block no. 1 is a 16-bit microprocessor for the speed control, flux control, slip frequency operation, voltage model operation, and so on.

In block no.2, the Digital Signal Processor (DSP),provides current control and PWM operation at high speed, according to his software.

In block no.3 is shown the discrete circuits for generation the PWM pulse, distribution of the PWM pulse to each GTO, detection of the voltage and current, other interface processing [3], [4].

4. CONCLUSIONS

A fully digital, vector controlled GTO PWM inverter for driving induction motors has been developed. With the techniques described in this paper, this drive system has enabled the following improvements:

1. High precision torque control.
2. High speed response by current detection without the effect of current ripple and decoupling control.
3. Improvement of reliability and maintainability through full digital control.

This inverter system can be applied to driving a bucket wheel of a bucket wheel excavator in an open pit mine. This inverter allows the process to be entirely operated by ac machines.

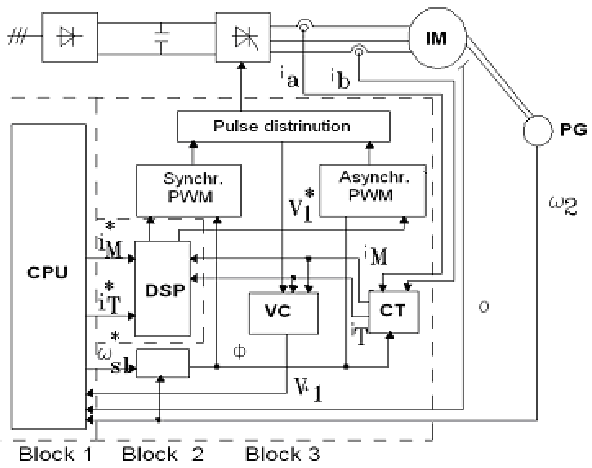

Fig.4. Discrete circuits for generation the PWM pulse

5. REFERENCES

[1]. Bitoleanu, Al., şa. – Convertoare statice. Infomed Publishing House, Craiova, 1997.

[2]. Chiuţă, I. Compensarea regimului energetic deformant. Technical Publishing House, Bucharest, 1989.

[3]. Hashii, K., Kousaka, K. & Kaimoto, M. - New approach to a high power GTO PWM inverter for ac motor drives. IEEE Trans. Ind. Appl., vol IA-23, Mar./Apr. 1987.

[4]. Ohsawa, C. & Ohara, M. A digital control system with grafic language and its applications to variable speed drives. IEEE Conf. Rec. 1988 IAS Annu. Meeting.

[5]. Uţu, I. Reducerea consumului de energie electrică în acţionările electrice de mare putere din industria minieră. Doctoral Thesis, Petroşani 1998.