REALISATION A REAL 24-HOUR ELECTRICITY BALANCE AT LIGNITE COAL MINE

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Abstract: In recent years, reducing energy use and complying with environmental regulations and legislation have become an integral part of the strategy of industrial enterprises. In a lignite quarry, due to the specific nature of the activity carried out, the main objectives (set at European Community level) that the technologies applied must meet are: reduced raw material requirements, reduced energy requirements and the production of reduced pollutant emissions and waste.

Thus, the interest in improving applied technologies is both energy, environmental and economic. For these reasons, I have proposed to present a general model of energy analysis of a quarry outline; in order to establish and prioritize plans of measures to reduce the energy used and the environmental impact.

Keywords: energy balance, energy losses, useful energy, mining excavator.

1. INTRODUCTION

The elaboration and analysis of energy balances is a scientific method for assessing the energy-economic efficiency of all electrical installations of users in a lignite quarry, with the aim of improving energy yields, raising the technical-economic level of their operation and improving electricity supply schemes.

Electroenergy balances are used to:

- determination of electricity losses throughout the installations and their component parts;
- highlighting unused secondary resources from an electroenergy point of view and establishing possibilities for their exploitation;

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- o the rationale for the technical and organisational measures envisaged to increase the efficiency of electricity use in all electrical equipment in the installations;
- o the development of scientifically substantiated standards for specific electricity;
- o determining quality indicators in order to compare actual indicators with those designed or with indicators from other similar companies.

The work in a lignite quarry must be carried out along the following lines:

- o improving the environmental performance of industrial activities;
- o use of clean technologies as a pollution prevention measure; application of efficient processes in the use of natural resources in power generation; taking measures to correct environmental impacts;
- o the use of waste as secondary raw materials and fuels.

For energy-intensive industries (day-to-day exploitation of lignite), energy is an important part of the total production cost within the energy complex.

Lately, lignite quarries have had to implement energy efficiency measures on a large scale, facing tough international competition. Product prices are set on the global market and characterised by high CO_2 per unit of sales.

In the following, we have developed the general concept of an analysis model aimed at energy, environmental and economic assessment of technological processes in a typical industrial contour belonging to an energy complex.

Taking into account what was presented and statistical data of the analyzed Energy Complex, some diagrams and tables we determined electricity losses in some electric networks, electric motors, transformers, i.e. we made real electric balance on some machines.

At the quarry analysed, the contour for which the energy balance is being drawn up is defined as the approved quarry perimeter with 20 kV overhead power lines as inputs, starting from the 110/20 kV transformer station [6].

The main machines supplied with electricity that are components of the technological flow at the quarry are: excavator type ERC - 2000, excavator E01 type ERc 1400 30/7, excavator E02 type ERc 1400 30/7, excavator E03 type ERc 1400 30/7, excavator E04 type ERc 470 15/3,5, excavator E05 type ERc 1400 30/7, excavator E06 type ERc 1400 30/7, bucket A01 type MH 6500/90, bucket A02 type MH 6500/90, bucket A03 type MH 4400/170, belt trolley - MAN 1 type CBS 1200, belt trolley - MAN 2 type CBS 1200, belt trolley - MAN type CDS 1400, stacker type MST-1-T 2053, stacker type MST-2-T 2053, warehouse removal machine type T 2846, belt conveyors of various types and sizes [1].

2. ENERGY BALANCE OF EXCAVATOR TYPE ERC - 1400X30/7

The excavator type ERc 1400 30/7 is designed for excavating tailings and coal and depositing the excavated material on the face conveyor.

Table 1 shows the main technical characteristics of the excavator type Erc 140030/7 required for the energy analysis.

Table 1. ***Technical characteristics of the excavator type ERc - 1400x30/7***

Working arrangements	**long-lasting**	
Nominal cup capacity	1	1400
Diameter of bucket wheel on cutting centre	m	11,5
Number of cups:		
- cutting	buc	9
- filling	buc	9
Theoretical excavation capacity	m^3/h	3280/3860
Cutting speed	m/s	2,6/3,08
Electric motor power to drive the bucket wheel	kW	630
Cutting height above support plane	m	about 30
Cutting depth below support plane	m	about 7
Horizontal swivel range of the bucket wheel arm	degrees	210°
Rubber mat width		
- for conveyor bands	mm	1800
- for dirt bands	mm	2000
Transport speed:		
- for conveyor bands	m/s	3,6
- for dirt bands	m/s	1
Travel speed	m/min	about 6
Average pressure on the ground	daN/cm^2	1,07
Minimum turning radius	m	about 60
Maximum admissible slope		
- during work		1:25
- when changing workplace		1:20
Service table of the installation	t	about 1980
Mass in service	t	about 2050
Power supply voltage and frequency	V, Hz	6000, 50
Installed power	kW	2950

In the technological excavation process, the following equipment is permanently in operation: bucket wheel mechanism, bucket wheel drive (630 kW motor; 6 kV; 104.7 rad/s (1000 rpm)) and the strip plant comprising: strip no. 1 driven by 2 motors of 200 kW at a voltage of 0.4 kV with 104.7 rad/s (1000 rpm), strip no. 2 driven by 2 x 160 kW motors at 0.4 kV at 104.7 rad/s (1000 rpm), strip No. 3 driven by 1 x 250 kW motor at 0.4 kV at 104.7 rad/s (1000 rpm), strip No. 4 driven by 1 x 200 kW motor at 0.4 kV at 104.7 rad/s (1000 rpm) [3].

The energy balance of the ERc-1400 30/7 consists of the following balances:

a) - energy balance of the cupped wheel mechanism,

b) - energy balance of conveyor belts,

c) - energy balance of electric transformers,

d) - energy balance auxiliary electrical installations and own energy services [2], [5], [7].

2.1. Energy balance of excavator type erc - 1400x30/7

The balance is only for active energy, the energy input (E_i) is the energy absorbed from the grid.

In electric drives, the useful energy (E_u) is the mechanical energy developed at the end of the kinematic chain, which is declared as the difference between E_i and the sum ΔE of losses.

The main losses are electrical in the power line ΔE_L, electrical in the motor coils ΔE_{inf}, electrical in the magnetic circuit of the motor ΔE_{Fe}, mechanical in the rotor $\Delta E_{mec.mot.}$, mechanical in the driven mechanism $\Delta E_{mec.mecanism}$.

The (hourly) balance equation is written as:

$$\Delta Ei = E_u+\Delta E = E_u+\Delta E_L +\Delta E_{inf} +\Delta E_{Fe}+ \Delta E_{mec.mot.} + \Delta E_{mec.mecanism} \qquad (1)$$

The following elements were measured for the balance sheet:

- Active energy used in four consecutive half-hours
  E_{i1} = 302 [kWh]; E_{i2} = 304 [kWh]; E_{i3} = 315 [kWh]; E_{i4} = 308 [kWh]
- Average active energy used per hour E_i = 614 [kWh]
- Average reactive energy absorbed per hour E_{ri} = 60,5 [kVArh]
- Length of power cable L = 76 m (from the 6 kV cell, to the hub wheel motor)
- Specific cable resistance R_{sp} = 0,1462 [Ω/km]
- Stator resistance r_1 = 0,5 [Ω]
- Rotor resistance r_2 = 0,019 [Ω]
- Power supply voltage U_i = 6 [kV]
- Voltage between the rotor winding phases with the rotor open U_2= 0,968 [kV]
- Electrical power and current absorbed by the motor with the rotor circuit open:
  $P_{rd} = 14{,}1$ [kW]
  I_{rd} =21 [A]
- the electrical power and current absorbed by the motor when idling (decoupled from the gearbox and the cupped wheel)
  $P_{0\ mot}$ = 22,2 [kW]
  $I_{0\ mot}$ = 26 [A]
- power and electric current absorbed by the motor when idling the bucket wheel (without excavating material)
  P_0 = 541 [kW]
  I_0 =51,14 [A]

It is calculated:

- the average absorbed electric current:

$$I_{med} = \frac{\sqrt{\left(\sum E_{ik}\right)^2 + E_{ri}^2}}{\sqrt{3}\cdot U \cdot \tau} = \frac{\sqrt{614^2 + 60,5^2}}{1,73\cdot 6 \cdot 1} = 59,43 \cong 59 \text{ [A]} \qquad (2)$$

Bucket wheel mechanism

- the form factor of the electric current:

$$K_f = \frac{I_{mp}}{I_m} \cong \sqrt{n}\,\frac{\sqrt{\sum E_{ik}^2}}{\sqrt{E_{ik}}} \tag{3}$$

$$K_f = \sqrt{4}\,\frac{\sqrt{302^2+304^2+315^2+308^2}}{302+304+315+308} = 2\cdot\frac{\sqrt{377709}}{1229} = 1,0001 \tag{4}$$

- motor power supply line resistance [6kV]

L = 76 [m]; S = 3x120 [mm^2]; $R_L = R_{sp}\cdot L$ = 0,1462·0,076 = 1,011·10^{-3} Ω

Calculating losses (τ_f = 1 h)

$$\Delta E_L = 3\cdot K_f^2\cdot I_{med}^2\cdot R_L\cdot\tau_f\cdot 10^{-3} \text{ [kWh]} \tag{5}$$

$$\Delta E_{\inf} = 3\cdot K_f^2\cdot I_{med}^2\cdot R_e\cdot\tau_f\cdot 10^{-3} \text{ [kWh]} \tag{6}$$

K_f = 1,01 in the case of asynchronous ring motors,

I_{med} – the arithmetic mean value of the electric current absorbed by the motor in the range τ_f [A],

τ_f – running time [h],

R_e – equivalent motor resistance [Ω],

r_1 – stator resistance [Ω],

r_2' – reduced rotor stator resistance [Ω],

$$r_2' = 0,98\left(\frac{U_1}{U_{2i}}\right)^2 r_2 \tag{7}$$

r_2 – rotor resistance [Ω],

U_i – voltage between stator phases [V],

U_{2i} – phase-to-phase voltage at the rotor rings (measured with the rotor locked and the circuit open) [V],

$$\Delta E_{\inf} = 3\cdot 1,001^2\cdot 59^2\cdot\left[0,5+0,019\cdot 0,98\left(\frac{6}{0,968}\right)^2\right]\cdot 1\cdot 10^{-3} = 12,69 \text{ [kWh]} \tag{8}$$

$$\Delta E_{Fe} = \left(P_{rd} - 3\cdot i_{1d}^2\cdot r_1\cdot 10^{-3}\right)\tau_f \text{ [kWh]} \tag{9}$$

P_{rd} – is the power absorbed by the motor when the rotor circuit is open [kW],

i_{1d} – stator electric current when the rotor circuit is open [A],
r_1 – stator resistance $[\Omega]$,

$$\Delta E_{Fe} = \left(14,1 - 3 \cdot 21^2 \cdot 0,5 \cdot 10^{-3}\right) \cdot 1 = 13,44 \quad \text{[kWh]} \qquad (10)$$

$$\Delta E_{mec.mot} = P_{0\,mot} \cdot \tau_f - \Delta E_{Fe} - 3K_f^2 \cdot R_e \cdot I_{0mot}^2 \cdot \tau_f \cdot 10^{-3} \quad \text{[kWh]} \qquad (11)$$

$$\begin{aligned} \Delta E_{mec.mot} &= 22,2 \cdot 1 - 13,44 - 3 \cdot 1,0001^2 \cdot \\ &\cdot \left[0,5 + 0,019\left(\frac{6}{0,968}\right)^2\right] \cdot 26^2 \cdot 1 \cdot 1 = 6,27 \end{aligned} \quad \text{[kWh]} \qquad (12)$$

$$\Delta E_{mec.mecanism} = P_0 \cdot \tau_f - \Delta E_{\inf} - \Delta E_{Fe} - 3K_f^2 \cdot R_e \cdot I_0^2 \cdot \tau_f \cdot 10^{-3} \quad \text{[kWh]} \qquad (13)$$

$$\begin{aligned} \Delta E_{mec.mecanism} &= 541 \cdot 1 - 12,69 - 13,44 - 3 \cdot 1,01^2 \cdot \\ &\cdot \left[0,5 + 0,019 \cdot 0,98 \cdot \left(\frac{6}{0,968}\right)\right] \cdot 26^2 \cdot 1 \cdot 10^{-3} = 512,33 \end{aligned} \quad \text{[kWh]} \qquad (14)$$

Useful energy: E_u

$$E_u = E_i - \left(\Delta E_L + \Delta E_{\inf} + \Delta E_{Fe} - \Delta E_{mec.mot} + \Delta E_{mec.mecanism}\right) = 75,53 \quad \text{[kWh]} \qquad (15)$$

2.2. Energy balance sheet of the transportation band

Conveyor belt: drive - 2x motor type MIP 3
The balance equation is:

$$\begin{aligned} E_i &= E_U + \sum \Delta E = \\ &= \Delta E_L + \Delta E_{\inf} + \Delta E_{Fe} - \Delta E_{mec.mot} + \Delta E_{mec.mecanism} \end{aligned} \quad \text{[kWh]} \qquad (16)$$

Loss calculation:

$$\Delta E_L = 3 \cdot 1,1^2 \cdot 146^2 \cdot 0,0148 \cdot 1 \cdot 10^{-3} = 1,145 \quad \text{[kWh]} \qquad (17)$$

$$I_{med} = \frac{\sqrt{E_i^2 + E_{ri}^2}}{\sqrt{3}U\tau} = \frac{\sqrt{18,1^2 + 18,2^2}}{1,73 \cdot 0,4 \cdot 1} = 146 \quad \text{[A]} \qquad (18)$$

K_f = 1,1 – form factor of electric current

$$K_f = \frac{I_{mp}}{I_m} \approx \sqrt{n}\,\frac{\sqrt{\sum E_{ik}^2}}{\sum E_{ik}} \qquad (19)$$

The motor is powered by a 3x50mm² section copper cable, 50 m long.

$$r_{Cu}\left(3\times 50mm^2\right) = 0,37 \ \ [\Omega/\text{km}] \qquad (20)$$

$$R = r_{Cu}\cdot L = 0,37\cdot 0,04 = 0,0148 \ \ [\Omega] \qquad (21)$$

$$\Delta E_{Cu} = 3\cdot 1,1^2\cdot 146^2\left[0,196 + 0,01617\cdot\left(\frac{6}{0,968}\right)^2\right]\cdot \cdot 1\cdot 10^{-3} = 15,62 \ \ [\text{kWh}] \qquad (22)$$

$$\Delta E_{Fe} = \left(10,6 - 3\cdot 7,52^2\cdot 0,196\cdot 10^{-3}\right)\cdot 1 = 10,56 \ \ [\text{kWh}] \qquad (23)$$

$$\Delta E_{mec.mot} = 18,6\cdot 1 - 10,56 - 3\cdot 1,1^2\cdot 0,20\cdot 13,2^2\cdot 1\cdot 10^{-3} = = 18,6 - 10,56 - 0,126 = 7,91 \ \ [\text{kWh}] \qquad (24)$$

$$\Delta E_{mec.mecanism} = 157\cdot 1 - 15,62 - 10,56 - - 3\cdot 1,1^2\cdot 0,2\cdot 220^2\cdot 1\cdot 10^{-3} = 98,92 \ \ [\text{kWh}] \qquad (25)$$

$$E_U = 181 - \left(1,145 + 15,62 + 10,56 + 98,92\right) = 54,75 \ \ [\text{kWh}] \qquad (26)$$

Since the conveyor belt has two 200 kV motors, all losses (as input energy and useful energy) are multiplied by two [8].

2.3. Energy balance of electrical transformers

The excavator type ERc 1400 30/7 supplies users at 0.4 kV from three transformers (Table 2).

Table 2. ***Characteristics of the transformers on the excavator***

S_n kVA	Primary tension kV	Secondary tension kV	ΔP_0 kW	ΔP_{sc} kW	I_0 (% from I_n)	u_{sc} (from U_n)
200	6	0,4	0,45	3,25	3,0	4,0
800	6	0,4	1,85	12,0	2,0	6,0
1250	6	0,4	2,6	18,0	2,0	6,0

Equation of the active electricity balance of a transformer substation:

$$E_i = E_U + \Delta E_T + \Delta E_L \text{ [kWh]} \tag{27}$$

where: E_i and E_u is the sum of the active energy entering the post contour and the useful active energy leaving the contour.

ΔE_T and ΔE_L the sum of the losses of electricity in the substation transformer, i.e. in the lines, busbars and connecting conductors around the substation.

The active power losses in a transformer can be determined using the relationship:

$$\Delta P_T = \Delta P_0 + \beta^2 \Delta P_{SC} \tag{28}$$

ΔP_0 and ΔP_{SC} are the active power losses in the transformer during no-load operation and the active power loss in the transformer during short-circuit operation; β – the average load factor of the transformer.

$$\Delta E_{T200} = 0,45 \cdot 1 + \left(\frac{1,1 \cdot 2,8}{5,78}\right)^2 \cdot 3,25 \cdot 1 = 0,45 + 0,92 = 1,37 \text{ [kWh]} \tag{29}$$

$$\Delta E_{T800} = 1,85 \cdot 1 + \left(\frac{1,1 \cdot 11,4}{23,12}\right)^2 \cdot 12 \cdot 1 = 1,85 + 3,53 = 5,38 \text{ [kWh]} \tag{30}$$

$$\Delta E_{T1250} = 2,6 \cdot 1 + \left(\frac{1,1 \cdot 17,5}{36,1}\right)^2 \cdot 18 \cdot 1 = 2,6 + 5,12 = 7,72 \text{ [kWh]} \tag{31}$$

The other mechanisms, which operate intermittently, can be considered as average hourly energies of up to 30% of the power installed in the transformers mounted on the excavator [2], [4], [6].

$$E_{iserv.aux} = 0,3P_n = 0,3 \cdot S_{mot} \cdot \cos\varphi = 0,3 \cdot 2250 \cdot 0,85 = 573,75 \text{ [kWh]} \tag{32}$$

$$\Delta E_{serv.aux} = 0,4E_{iserv.aux} = 0,4 \cdot 573,75 = 229,5 \text{ [kWh]} \tag{33}$$

$$E_{Userv.aux} = 0,6 \cdot E_{iserv.aux} = 0,6 \cdot 573,75 = 344,25 \text{ [kWh]} \tag{34}$$

The calculation of total energy losses is summarised in Table 3.

Table 3. ***Calculation of total energy losses***

Component name	[kWh]	[%]
Energy input	1688,0	100,000
Energy output		

1.Useful energy (transport of mining mass)	592,93	35,126
2. Losses		
- in the supply line	11,57	0,685
- in engine windings	98,21	5,818
- in the engine iron	61,86	3,66
- mechanical in engine	54,5	3,228
- mechanical in gearboxes and moving parts of conveyors	625,66	37,07
- auxiliary and internal services	229,5	13,617
- in transformers	14,47	0,857
Total losses	1095,07	64,94
Total	1688,0	100,000

On the basis of these calculations it is possible to construct the Sankey diagram for the large excavator ERc - 1400 (Figure 1).

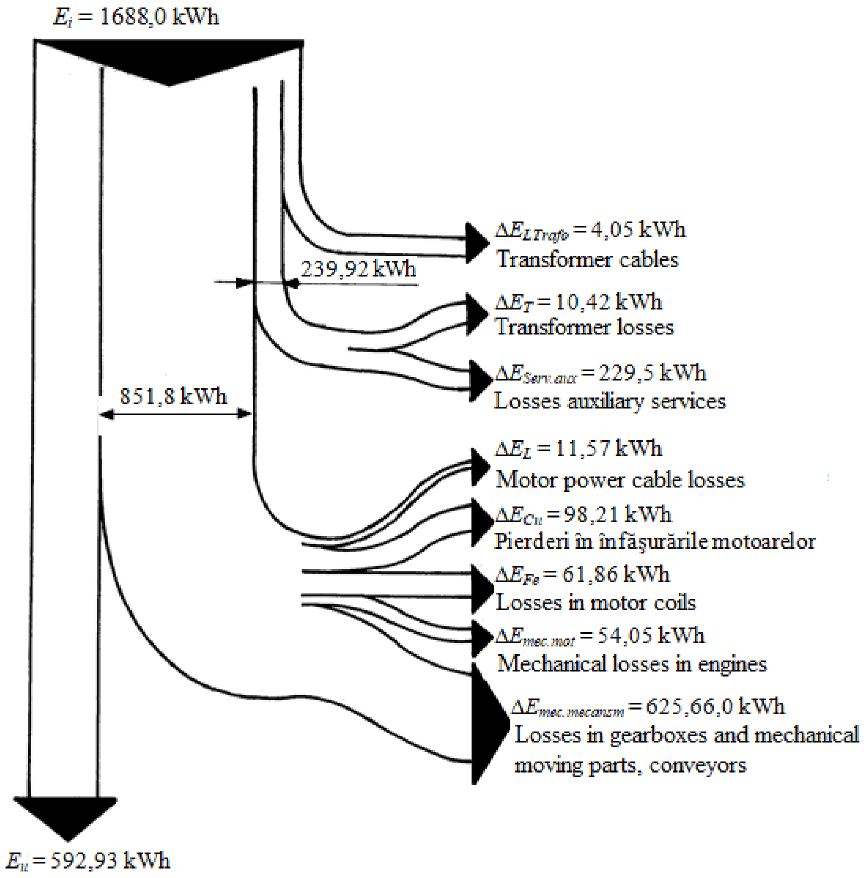

Fig. 1. Sankey diagram for excavator ERc 1400

3. CONCLUSIONS

The elaboration and analysis of energy balances is a scientific method for assessing the energy-economic efficiency of all electrical installations of users in a lignite quarry, with the aim of improving energy yields, raising the technical-economic level of their operation and improving electricity supply schemes.

For quarry mining operations, energy is an important part of the total production cost within the energy complex.

In recent times, quarries have been applying energy efficiency measures on a large scale, facing tough international competition. Product prices are set on the global market and characterised by high CO_2 per unit of sales.

We have developed the general concept of an analysis model aimed at energy, environmental and economic assessment of technological processes in a typical industrial contour belonging to an energy complex.

Taking into account the theoretical aspects and on the basis of real statistical data we determined the electricity losses in some electric networks, electric motors, transformers, i.e. we made the real electric balance on significant machines in the quarry.

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