ENERGY METERING FROM THE LONEA COLLIERY COMPRESSORS

Susana ARAD, Leon PANĂ**, Florin POPESCU****

Abstract: ATLAS Copco compressors and Ingersoll Rand, from Lonea II Station and Valea Arsului, measurements were conducted during October to November 2012 with the PowerQ Plus energy analyzer in order to draw up an energy audit of compressors station. It is useful for the analysis of power quality that energy parameters to be monitored and tracked: voltage U, current I, active power P, reactive power Q, apparent power S and power factor cos φ. To determine the balance of power from the asynchronously engine components a simplified mathematical model was used together with the extended model based on measurements and calculation formulas. From the records obtained were drafted load curves and their parameters were determined.

Keywords: energy, energy audit parameters, compressors, mining, coal.

1. Introduction

National Hard Coal Company (CNH) Petrosani has as main activity the extraction and preparation of hard coal from the Jiu Valley. Mining perimeters (Lonea, Livezeni, Lupeni, Uricani, Petrila, Paroseni, Vulcan) are organized in SNH Petrosani and SNÎM Petrosani. Viable mines (Lonea Livezeni Vulcan, Lupeni) formed in SNH Petrosani are integral part of the Hunedoara Energy Complex. Lonea Colliery is in the development plan of the company, is part of mines economically viable.

The viable mining exploitations (Lonea, Livezeni, Vulcan, Lupeni) within SNH Petroşani is necessary to implement a comprehensive programme of modernization and investment to maintain existing capacity, enabling:

- physical labour productivity growth;
- reducing the cost of coal energy production;
- increase the quality of coal energy supplied to beneficiaries

The Lonea Colliery there are two compressors stations: Lonea II with 3 ATLAS Copco screw compressors and one compressor, Ingersoll RAND type put into function in 2005 and Arsului Valley Station, where station operates six ATLAS Copco compressors, that has been put into function in 2006. Screw compressors are functioning in two compressors stations in Lonea Colliery: Lonea II and Valley Arsului in the normal function for the specific operating conditions require a constant flow on variable pressure or reverse, and also to reduce the energy consumption in compressed air producing. [7]

2. Energy parameters metering

Electrical plant and generating machines are examined further. When setting the stroke he had in mind the outline of the system they considered themselves the entrances and exits of electricity.

Contour energy consumers are three-phase electric engine compressors ATLAS Copco GA 250 FF 250 kW and Ingersoll RAND compressors SSR M 800 288 kW cooling and auxiliary engines 2 x 4,5 kW for Atlas Copco and 15 kW for Ingersoll RAND.

The four compressors of Lonea II station is supplied with electricity by the three from the Lonea II, from the two transformer 6/0.4 kV, 1000 kVA transformer 1 and transformer 2 of 1600 kVA from one cell type CIIL 6 kV. ATLAS Copco compressors and Ingersoll RAND Lonea station II and ATLAS Copco of Valley Arsului Station, measurements were carried out from October to November 2012 with energy analyser PowerQPlus, Fig. 1. The PowerQ Plus device is a portable device due to its small size and simple operation, it is ideal for evaluating a routine or complex power quality in heavy industrial environments.

It is useful in the simultaneous analysis of power quality parameters that basic parameters, voltage U, current I, active power P, reactive power Q, apparent power S and power factor cosφ to be monitored and recorded. Recording, reporting and quality assessment of power network is performed in accordance with EN 50160 [1].

Data taken from measurements were analyzed and centralized and give the values for line voltages, phase currents, apparent power, active and reactive absorbed motor power factor cosφ/PF and the type circuit (capacitive C or inductive I). These measurements were performed at "full load" and "null" task for each type of compressor in the two stations, and the results to be extrapolated to all station compressors.

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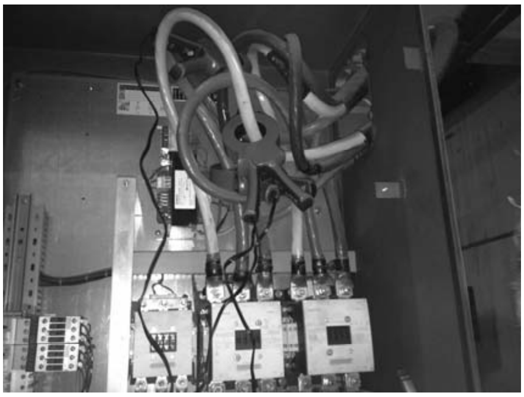

Fig. 1 *Energetic parameters to measure the distribution of the Lonea compressors II*

It was recorded with the help of the device PowerQ Plus-Metrel, the voltages and currents variation for ATLAS Copco compressor engine at nominal load and load "null" appear in the graphs in Figure 2. [2]

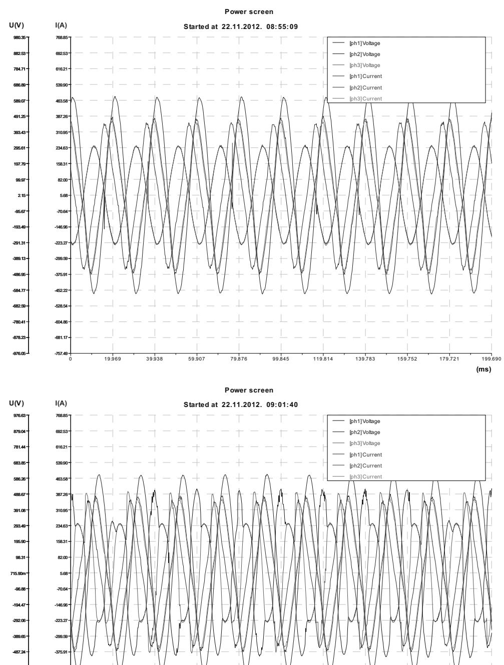

Fig. 2 *Records of U, I, ATLAS Copcocompressor engine [2]*

Records from the engine compressor Ingersoll RAND with nominal and minimum load are displayed in Fig. 3 and then the engine compressor Ingersoll RAND and ATLAS Copco after a download electrical load.

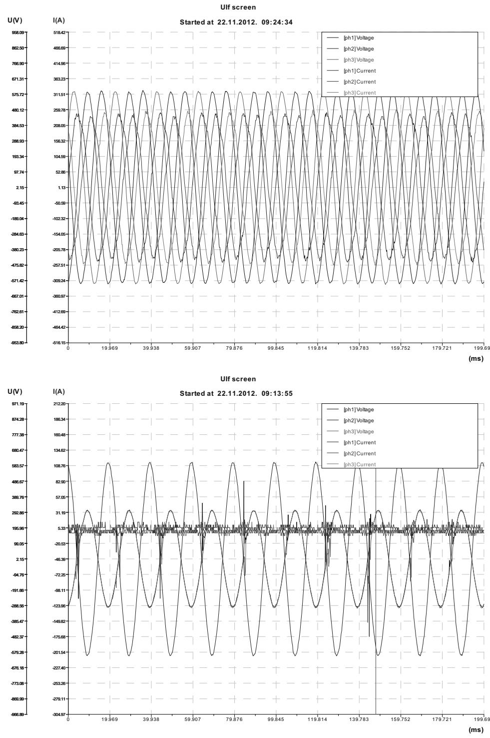

Fig. 3 *Records of U, I compressor Ingersoll RAND motor [2]*

In Figure 4 are recordings of energetic parameters for ATLAS Copco compressor engine. Both are registered as voltage and current on all three phases of the motor compressor.

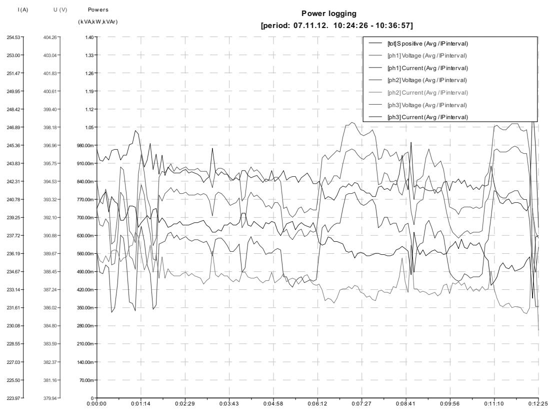

Fig. 4 *Entries for ATLAS Copco compressor engine at rated load [2]*

3. Determination of the components of the balance of powers

The energy balance of the compressors, in the case of a remote control, it boils down to determination of total active energy consumed and the various losses in the motor and compressor. To determine the components of the balance of powers at an asynchronous motor used the simplified model.

This model was used for low-voltage engines of low power under 100kW to not know all electrical parameters (auxiliary engines). Because the experimental determination of operating conditions is difficult, to characterize the regime has adopted the use of other indicators, namely:

- The degree of loading with active power: $\beta_p = \eta_n \cdot {P_A}/{P_n}$;
- The degree of loading with current: $\beta = {I_S}/{I_n}$;

Where I_s (P_A) is the current (power) absorbed by the motor, and if a system variable their average values during the running τ_f considered.

If we use the β_I are variation curves of the efficiency η and the power factor cosφ depending on the degree of loading or using the following relationships:

$$\eta \cong \frac{\beta_P - A_\eta}{\beta_P \cdot B_\eta}; \ \cos\varphi \cong \frac{\beta_P}{A_\varphi + \beta_P \cdot \beta_\varphi} \qquad (1)$$

The coefficients, A_η, B_η, A_φ, B_φ, depend on the value of the nominal yield of nominal power factor. Their average values are taken from the literature [5].

Engine power losses P_m will be calculated with relation (2),

$$P_m = (1-\eta) \cdot P_A \qquad (2)$$

and the loss of active energy ΔW_{am} shall be determined as follows:

$$\Delta W_{am} = P_m \cdot \tau_f \qquad (3)$$

where τ_f represents the running time.

Reactive absorbed power Q_A is obtained,

$$Q_A = P_A \cdot \sqrt{\frac{1}{\cos^2\varphi} - 1}\,. \qquad (4)$$

Thus, the three phase electrical engines for cooling, engines (Motors below 100 kW) to load active power for nominal yields of the two auxiliary engines have the coefficients: A_η = 0.0459, B_η = 1,115; for GA 4,5 at rated power factor we have A_φ= 0,4, B_φ= 0,898, but at SSR A_η= 0,0479, B_η = 1,099 at rated power factor we have A_φ= 0,196, B_φ= 0,941.

The degree of loading with active power:

- GA 4,5kW, $\beta_p = \eta \cdot {P_A}/{P_n} = 0{,}95$,
- LS160 15 kW, β_p= 0,83,

$$\eta_{4,5} = \frac{0{,}95 - 0{,}0459}{0{,}95 \cdot 1{,}115} = 0{,}853 \quad (3{,}3\ \%),$$

$$\cos\varphi_{4,5} \cong \frac{0{,}95}{0{,}4 + 0{,}95 \cdot 0{,}898} = 0{,}758$$

(within 2%)

$$\eta_{15} = \frac{0{,}83 - 0{,}0479}{0{,}83 \cdot 1{,}099} = 0{,}857 \quad (-3{,}15\%),$$

$$\cos\varphi_{15} \cong \frac{0{,}83}{0{,}196 + 0{,}83 \cdot 0{,}941} = 0{,}849$$

(within 3%)

Were calculated in the same way, for GA 250 engine and SSR M250 yields and the power factor to load active power for nominal yields of the two motors and nominal power factor, where the coefficients, Bη, Aη Aφ Bφ are taken from the literature [5].

For **GA 250** $\beta_{p\,AC}$= 0,90; A_η= 0,039, B_η = 1,00; A_φ= 0,202, B_φ= 0,948;

$\eta_{AC} = 0{,}956$, $\cos\varphi_{AC} \cong 0{,}89$ (a deviation of 3% compared to the full model and by 0.6 percent compared to the nominal).

For **SSR M250** $\beta_{p\,Ing}$= 0,864; A_η= 0,039, B_η = 1,00; A_φ= 0,218 B_φ= 0,944.

$\eta_{ing} = 0{,}954$, $\cos\varphi_{ing} \cong 0{,}83$ (deviation 4% compared to the full model and by 0.6 percent compared to the nominal).

4. Balance charts

The electrical power input W is the hourly consumption of power distribution network of the propulsion system consisting of a proper wiring clearing system of reactive power, power transformer and electric motors. According to the equation of balance sheet

$$Wi = Wu + \Delta\ Wp \qquad (5)$$

where: W_i-is the energy brought into the contours of the balance; W_u is the energy consumed to achieve useful process (developed by the energy of the SEA is ML); ΔW_p-energy losses within the boundaries, which correspond to the loss of energy from the SEA:

$$\Delta Wp = \Delta W_{DA} + \Delta Wme + \Delta W_{OT} + \Delta W_{ML} \qquad (6)$$

where: ΔW_{DA} is the loss in power and control device, ΔW_{me}-losses in the electric motor, ΔW_{OT}-body transmission losses and casualties in car ΔW_{ML} (compressor).

Contour balance shall be deemed null and void in particular losing power and command structure, as the transmission losses. Power balance equation for a SEA of the compressor becomes according to equation (7), [4].

$$W_u = W_i - \Delta W_p \qquad (7)$$

Energy losses in the windings shall be calculated with the relationship (8), [5]

$$\Delta W_{cu} = 3 \cdot {k_f}^2 \cdot I_{med}^2 \cdot R_e \cdot \tau_f \qquad (8)$$

where: k_f-current form factor; I_{med}-average value of the intensity of the current in the time interval τ referred to the balance sheet; τ_f- running time; R_e- the equivalent resistance of the motor windings ME with the following values:

$$R_e = \frac{P_A - P_{Ao}}{3(I_A^2 - I_{AO}^2)} \quad (9)$$

where: P_A-active power absorbed by ME at a certain task; P_{AO}-active power idling coupled with the equipment trained; I_A-the current absorbed in the task P_A, I_{AO}- the corresponding load $P_{A0.}$

$$\Delta W_k = \Delta W_{fe} + \Delta W_{mot} = (P_0 - 3I_0^2 \cdot R_e) \cdot \tau_f \quad (10)$$

where: P_0-the active power absorbed by the engine idling; Io-power absorbed in load. [2]

Corresponding to a time period T, the balance is expressed through:

$$W_a = W_u + \Delta W_{ac} + \Delta W_{am} \quad (11)$$

where: Wa - energia activă la intrare în contur (înregistrată în punctul de măsurare); Wu-the energy output of the engines, ΔWac-active energy loss on the power cord, ΔW_m-energy losses in the motor group.

To determine the components of the balance sheet, the group of motors is tantamount to an equivalent engine, characterized by:

- nominal power

$P_{ne} = \sum_{i=1}^{n} P_{ni}$, where N is the number of engines , in this case N=5, P_{ni} the nominal power of engines;

- nominal yield

$\eta_{ne} = \frac{1}{P_{ne}} \sum_{i=1}^{N} P_{ni} \cdot \eta_{ni}$, where η_{ni} – represent the nominal yield of engines;

- nominal power factor

$\cos\varphi_{ne} = \frac{1}{P_{ne}} \sum_{i=1}^{N} P_{ni} \cdot \cos\varphi_{ni}$, where $cos\varphi_{ne}$ represents the nominal power of the engines.

They calculated the various components, as follows:

P_{ne} = 562kW
η_{ne} = 95%
$cos\ \varphi_{ne}$= 0,86

Total energy balance components for compressors that are analyzed as a group of engines are displayed in table 1. Towards balance components determined from measurements and complex mathematical model it is observed that there are differences of 1.8% for output power,- 3.6% for useful energy and 36.2% for losses.

Table 1 *Components of the balance of power of engines*

The name component of the balance sheet	Active energy kWh/h	%
Output energy	**562**	100
• Useful energy	514,08	91.47
• Losses	47,92	8,53
- in the motor windings	17,26	3,07
- in the magnetic circuit and the motor mechanic	29,19	5,19
- technological losses	1,47	0,26

The engine power losses are calculated using the relation 2.

The balance results for the compressor engine group are shown in table 2.

Table 2 *Table group on balance of compressors*

The name component of the balance sheet	[kW]	%
Input active power	560,905	100
Useful power	533,178	95,05
Losses P_m	27,727	4,94

One can appreciate that the analysis of the balance sheet performed on each engine and highlights loss measurements with 36.2% what causes us to appreciate that there are technological losses greater than those shown in table 1 and that the losses highlighted in table 2 results of simplified model calculations are undersized.

5. Results and measurements

Records obtained from the developed load curves and parameters have been determined. Load curve builds on a period of 24 hours, and the number of meter readings is n_d=25 intervals. The actual construction is carried out starting at 7 where active and reactive energy meters index is deemed to splits from the call sign 0, and then it counts every hour, with a specific step.

In this case calculate the characteristic load curve sizes. The power installed on transformer 2 is P_i= P_{ne} +P_{aux} = 562 + 51 = 613 kW what are the two main engines power, fan motors and auxiliary of installed power station.

It also prompted active hourly energy $W_{a,m}$ = W_a/T_{uP} and reactive energy hourly $W_{q,m}$ = W_r/T_{uQ} and they like the curves of a task, indicators are shown in table 3.

Table 3. *Indicators of load curves*

Wa,$_{\textbf{med hourly}}$ [kW]	**Wr,**$_{\textbf{med-hourly}}$ [kVAr]	**S**$_{\textbf{med}}$ [kVA]	**P**$_{\textbf{max}}$ [kW]	**Q**$_{\textbf{max}}$ [kVAr]	**S**$_{\textbf{max}}$ [kVA]	**K**$_{\textbf{c}}$	**Kf**	**ki**	**ku**
213,58	114,74	242.45	361,47	234,42	430,82	0,58	1,08	0,27	0,35

- form factor of the load curves
- $K_f = P_{med, p}/P_i = 1{,}08$
- the duration of use of the active maximum load (P)
- T_{uP} = 3840.72 ore,
- the duration of use of the reactive maximum load (Q)
- T_{uQ} = 3181.57 ore
- apparent power per lifetime
- S_{med} =242.45kVA
- duration of use, Tu = 6500 hours
- the losses at full load τ = 1677.89 hour
- application factor $Kc = P_{max}/P_i = 0.589$
- coefficient of flatness
- $K_{apl} = P_{med}/P_{max} = 0{,}59$
- coefficient of use of electricity α = 0,79
- installed power utilization coefficient
- $K_u = P_{med}/P_i = 0{,}35$
- coefficient of uniformity of the graph of the task
- $K_{unif} = P_{min}/P_{max} = 0{,}24$
- coefficient of flatness of the load curves
- $K_d = P_{med,p}/P_{med} = 0{,}59$

Data taken from the beneficiary on the basis of reading the counter, on the energy consumption in Compressor Station Lonea II on the transformer 2, which feeds two compressors (Atlas Copco M3 and M4 Ingersoll), constitute the basis for calculating the load curves.

Values of quantities, in particular energy consumption obtained for a period of time T = 10 months (7320 hr) are played on schedule in the annual load curves presented in Figure 5 for active power range of 10 months and Figure 6 for reactive power in the same interval of time.

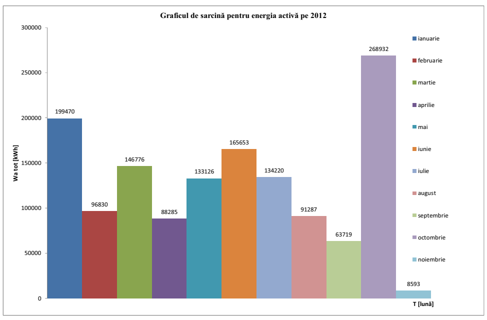

Fig. 5 *Load Graph for active energy*

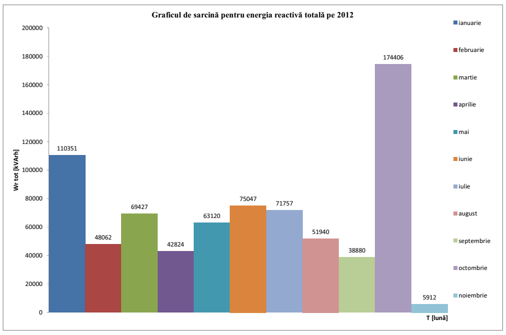

Fig. 6 *Schedule task for reactive energy*

The overall average power factor is determined by the relation:

$$\cos\varphi_m = \frac{W_a}{\sqrt{W_a^2 + W_t^2}} = 0{,}88 \qquad (12)$$

Comparing the power factor value of the global environment with the power factor value determined motor group in the balance sheet $\cos\varphi_{ne} = 0{,}86$

It can be said that the group, one of the five engines comes with a decrease in the power factor by 2%. It is proposed that enterprises the power factor to be practically constant and equal to the neutral power factor 0,92 while the resources for improvement of power factor.

The measured data it can be concluded that active energy measurement device registered by PowerQ Plus-Metrel an Atlas Copco compressor reported in an hour is **Wa**$_{\textbf{reg}}$ **= 5,257 kWh.**

For t = 24 hours active energy consumed is Wa = 126,168 kWh, value is comparable to the average energy value zones on the first 10 months of the year of Wa_{med} = 213.58 kWh for two compressors suplied from transformer 2.

He also executed a set of measurements and for the energy absorbed by the compressor engine. Such recordings were made of the energy consumed in the engine compressor Atlas Copco GA 250 M6 Arsului Valley Station on a time interval of 10 seconds, appear in Table 4.

Table 4 *Results of energy from compressors*

Time	Wa reg [W s]	Wr (+) [Var s]	Wr (-) [Var s]	Wa reg/ hour [kWh/hr]
00:00:10:00	14,605	5,985	6,981	5,2578

Are also centralized operating hours at the 2 ô compressors fueled on Trafo2.

Load times on the two compressors on the first 10 months, are distributed thus, Atlas Copco τ_{AC}= 675 hr what are the hours of operation, 83. 64% on Ingersoll τ_{ING} = 482, i.e. 16. 35% with an average working day for both compressors τ_f= 17.9 hr.

Atlas Copco compressor operates with maximum load τ_{maxAC} = 91,23 %, and Ingersol compressor with full load, , τ_{maxING} = 99,8 %. The total running time of the compressor Atlas Copco works in startup, and τ_{pAC} = 26,7 %.

Operating daily averages τ =17.91 hours from Atlas Copco compressor works 14.98 hours and compressor Ingersoll 2.93 hours.

6. Conclusions

The balance of the electrical system of the actuator is to highlight the various components of energy losses in order to determine the possibilities of their reduction.

Internal power supply line to the compressor was considered null and loss of energy W_{lin} = 0.

You have neglected the losses the power electronics modules at both compressors.

It is found that there are differences in the operation of the engine load, based on simplified mathematical model, it has thus been obtained a higher yield (3-4)% compared to values obtained from measurements and appreciated from the data engines.

Based on data collected and calculated the balance chart (Sankey) corresponding to the two types of compressors on the E. M. Lonea.

One can appreciate that the analysis of the balance sheet performed on each engine and highlights loss measurements with 36.2%. What causes us to appreciate that there are technological losses greater than those shown in table 1 and that the losses highlighted in table 2 results of simplified model calculations are undersized.

The measured data it can be concluded that active energy measurement device registered by PowerQ Plus-Metrel a Atlas Copco compressor reported in an hour is **Wa_{reg} = 5,257 kWh.** For t = 24 hour active energy consumed is Wa = 126,168 kWh, value comparable to the average energy value zones on the first 10 months of the year for the two compressors, supplied by 2 Units.

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