PAPER MACHINE INFLUENCE ON INDUSTRIAL ENERGY SYSTEM

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This paper present influence of low power factor on electricity system and influence of paper breaking on heat system. For that, a mathematical model and a case study for a paper mill are realised.

Keywords: energy system, paper machine.

1. Introduction

Energy use reduction can provide cost savings, often with low capital investment.

The main energy forms that are needed in the production process are electricity, steam, water and natural gas, [1].

Electric power in paper industry is mainly consumed for the operation of various motor. The power factor is low and electricity losses on the cables and on the transformers is height. If capacitors are used on the low voltage for maintain power factor at neutral value, 0.92, energy saving can be realized.

In the machine operating appears paper breaking when steam consumption of the dryer cylinders is cutting down automatically. Load of the steam boilers must be reduced corresponding. But, often these breaks are repeated and short and determine a variable regime of the steam boilers and its efficiency decrease. Thus, more fuel is consumed for steam generation

2. Energy supply system of paper machine

Electrical energy is used to drive the paper machine, pumps, ventilating fans et cetera on medium voltage or on low voltage.

The steam is used on different locations in the paper making process. The steam flow in the paper mill is coming from the CHP plant on low pressure. The CHP plant delivers electrical energy, too. When the CHP plant produces too little electrical energy the difference will be bought from the public grid on height voltage. Transformers on 110/6 kV and on 6/0.4 kV are used usually. The diagram of the energy flow is presented in the fig.1.

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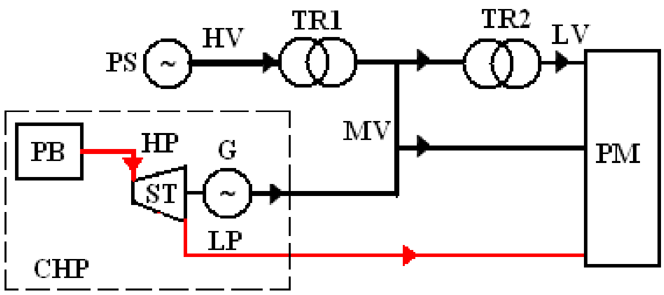

Fig. 1. The diagram of the energy flow: CHP- combine heat power plant; PB – power boiler; ST – steam turbine; G – generator; PS – power system; TR – transformer; PM – paper machine; HP – height pressure; LP – low pressure; HV – height voltage; MV – medium voltage; LV – low voltage

3. The mathematical model

To study paper machine influence on power system is developed a mathematical model.

Induction motors are used to drive pumps and fans of water and air circuits of the paper machine. This leads to a low power factor. To highlight the influence of machine operation with a low power factor on power system, we calculate energy losses in cables and transformers depending on power factor.

Maximum apparent power, S(cosφ) in kVA, is a function of power factor, [2]:

$$S(\cos\varphi) = P \cdot \cos\varphi \qquad [\text{kVA}] \qquad (1)$$

where P – is the maximum active power, in kW, T during analysis, in h/year; cosφ - power factor.

Maximum current, I(cosφ), is:

$$I(\cos\varphi) = \frac{S(\cos\varphi)}{\sqrt{3} \cdot U} \qquad [\text{A}] \qquad (2)$$

where U is voltage, in V

Lifetime maximum power, TSM(cosφ), is a function of power factor, [3]:

$$TSM(\cos\varphi) = 1.03 \cdot \frac{\sqrt{W_a{}^2 + W_r(\cos\varphi)^2}}{S(\cos\varphi)} \qquad [\text{h/year}] \qquad (3)$$

where W_a is active energy consumption during T, in [kWh/year], and W_r (cosφ) is reactive power, in [kVar/year]

Duration of maximum loss, τ(cosφ), is:

$$\tau(\cos\varphi) = TSM(\cos\varphi)\cdot\frac{10000+TSM(\cos\varphi)}{27520-TSM(\cos\varphi)} \quad \text{[h/year]} \qquad (4)$$

Active power losses in cables, ΔW(cosφ) are, [4]:

$$\Delta W_c(\cos\varphi) = 3\cdot R\cdot I(\cos\varphi)^2\cdot\frac{\tau(\cos\varphi)}{1000} \quad \text{[kWh/year]} \qquad (5)$$

where R is the resistance of cable, in Ω.

Active power losses in transformers, ΔWT(cosφ) are determined by the relationship:

$$\Delta WT(\cos\varphi) = \Delta W_{Fe} + \Delta W_{Cu}(\cos\varphi) \quad \text{[kWh/year]} \qquad (6)$$

where ΔW_{Fe} are losses of iron, in [kWh/year], which is determined by the relationship:

$$\Delta W_{Fe} = \Delta P_0\cdot T \quad \text{[kW]} \qquad (7)$$

where ΔP_0 are iron losses in the transformer, in kW, and ΔW_{Cu}(cosφ) – copper losses in the transformer is determined by a relationship of form (5)

Total energy losses in power supply system are:

$$\Delta W(\cos\varphi) = \Delta W_c(\cos\varphi) + \Delta WT(\cos\varphi) \quad \text{[kWh/year]} \quad 8)$$

Relative loss of energy, wr, is defined as:

$$w_r = \frac{\Delta W}{W}\cdot 100 \quad [\%] \qquad (9)$$

Energy savings, WS, which is obtained by compensating power factor neutral value, is calculated with relation:

$$WS = \Delta W_{\cos\varphi} - \Delta W_{0.92} \quad \text{[kWh/year]} \qquad (10)$$

where $\Delta W_{\cos\varphi}$ is energy losses in case of power factor cosφ and $\Delta W_{0.92}$ represents energy losses in case of neutral power factor, cosφ=0.92.

A paper tear on the paper machine means a sudden reduction in steam flow on boiler.

To highlight the boiler efficiency variation with load, the boiler is modeled by the characteristic energy, B(D), which is considered a form of analytic functions of degree two, [5]:

$$B(D) = C_0 + C_1 D + C_2 D^2 \qquad [\mathrm{Nm^3/h}] \qquad (11)$$

where: B is the fuel consumption, in $\mathrm{Nm^3/h}$, D – boiler load, in t/h, C_0, C_1, C_2 - unknown coefficients.

Values for steam flow and fuel consumption are determined experimentally for the operation of the steam boiler at nominal parameters, in three regimes. It introduced the numerical values of the independent variable and dependent variable in the equation corresponding to model and obtains a determined system of equations of the form:

$$\overline{B}_j = f(\overline{C}, \overline{D}_j) \qquad , j=1...3 \qquad (12)$$

where $\overline{C}$ is the coefficients vector, $\overline{D}_j$ - independent variable vector, the flow of steam and $\overline{B}_j$ - vector output measurements, fuel flow, j - number of operating regime.

Efficiency of boiler depending on its load, $\eta(D)$, is calculated with relation:

$$\eta(D) = \frac{D \cdot (i_{ab} - i_{ap})}{P_i \cdot B(D)} \cdot 100 \qquad [\%] \qquad (13)$$

where i_{ab}, i_{ap} are enthalpy of steam and of water supply, respectively and P_i is the lower calorific value of fuel.

4. The case study

The paper machines influence on energy supply system was studied in a paper mill. The maxim power and energy consumption for a newsprint paper machine (PM1), for a toilet paper (PM2) and for auxiliary installations which are necessary for water supply and steam technology that is water filters and CHP, are presented in table 1.

Table 1

The maxim power and energy consumption

Installation	Power, [kW]	Energy, [kWh/year]
PM1	9330	54492100
PM2	400	1957800
CHP	500	3280000
WF	400	2460000

Table 2

Transformer parameters

Parameter	Simbol	U.M.	TR1	TR2
Copper power losses in Cu	ΔP_{Cu}	kW	180	12
Iron power losses	ΔP_{Fe}	kW	52	1.85
Primary nominal voltage	U_{1n}	kV	110	6
Secondary nominal voltage	U_{2n}	kV	6	0.4
Nominal power	S_n	MVA	40	1
Resistance	RT	Ω	0.004	0.002

Table 3

Resistance power cable network

Cablul	Rezistenta, [Ω]
LES SRA – PM1	0.06
LES SRA – PM2	0.01
LES SRA - CHP	0.02
LES SRA - WF	0.03

Table 4

Energy losses to cos f=0.75

Network elements	Symbol loss	Energy loss, [kWh/year]	Weight loss energy, [%]
LES SRA – PM1	ΔW1	318108	26.38
LES SRA – PM2	ΔW2	2938	0.24
LES SRA - CHP	ΔW3	1447	0.12
LES SRA - WF	ΔW4	1502	0.12
TR1	ΔW5	567276	47.05
TR2	ΔW6	314622	26.09
Total	ΔW	1205893	

In fig.2 and in table 4 is seen as the largest energy losses occur in the transformer 110 / 6 kV, 47.05%, followed by 6/0.4 kV transformer, 26.09% and cable LES RAS - PM1, 26.38%.

Energy losses can be reduced if capacitors batteries are installed for power factor compensation for the 0.4 kV to neutral value, table 5.

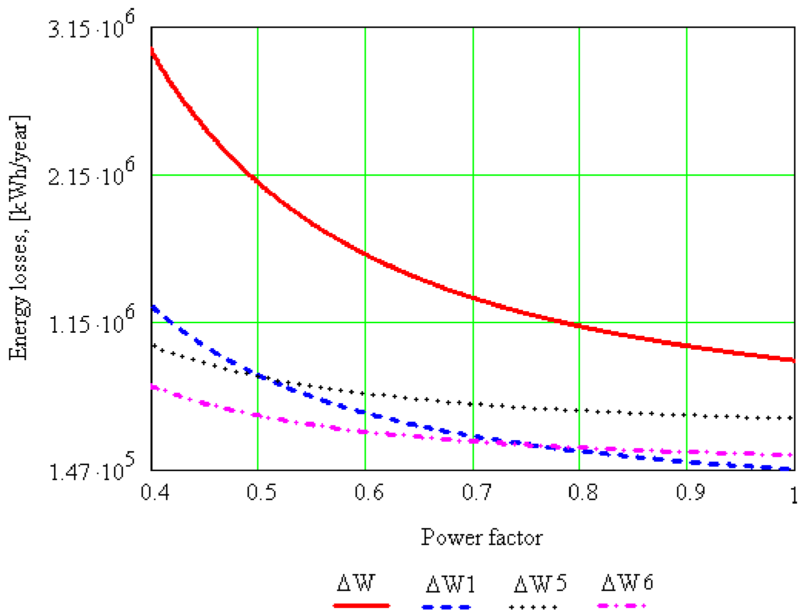

Fig.2. Variation of energy loss depending on power factor

Table 5

Reduce energy losses

Network elements	Symbol energy savings	Reduce energy losses, [kWh/year]	Weight of reduce energy losses, [%]
LES SRA – PM1	SW1	128693	53.08
LES SRA – PM2	SW2	1398	0.57
LES SRA - CHP	SW3	617	0.25
LES SRA - WF	SW4	675	0.28
TR1	SW5	57783	23.84
TR2	SW6	53246	21.98
Total	SW	242412	

From Table 5 it is apparent that the greatest weight of reduce energy losses, 53.08%, is in cable LES SRA – PM1 supply newsprint machine, although the greatest weight of loss is in 110 / 6 kV transformer. This is due to iron losses which remain constant in the transformer.

For operation at power factor neutral relative energy loss is reduced to 1.55% against 1.94% in operation with a power factor cosφ=0.75.

To see the influence of paper breaking on efficiency of steam boilers, it was determined the energy characteristics of the CHP boiler for 3 operating regimes which are presented in table 6.

Table 6

Boiler operating regimes

Operating regime	Steam flow, [t/h]	Fuel flow, [Nmc/h]	Efficiency, [%]
1	26	3043	72.63
2	38	3739	86.40
3	45	4361	89.79

Analytical expression of the boiler characteristic is given by rel.14 and its graphic representation is shown in fig.3.

$$B(D) = 2398 + 2.179 \cdot D + 0.872 \cdot D^2 \tag{14}$$

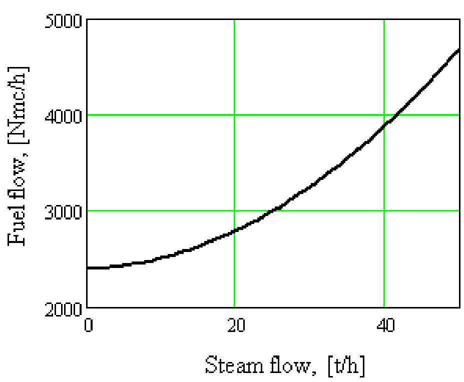

Fig.3. Boiler energetical characteristic

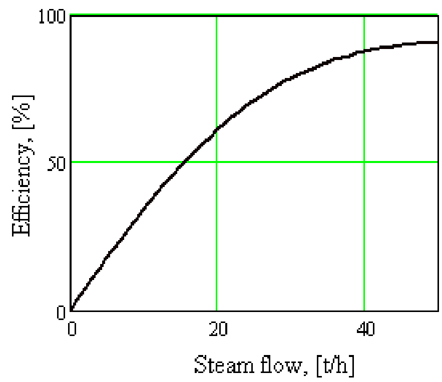

Fig.4. Boiler efficiency

Variation of boiler efficiency depending on its load is shown in fig.4.

In summer, a single boiler CHP work with a maximum load of 40 t / h and in winter, 2 boilers works in parallel with a maximum load of 60 t / h. In case of breaking paper on paper machine, boiler load drops sharply to 25 t / h. This reduction of boiler load may take several minutes and can be repeated several times and may take several hours or days depending on the issues that determine break of paper web on the paper machine. Such variation of boiler load causes an additional thermal application of boilers and decreases their yield. For example:

- in the summer, the efficiency decreased from 87.66% as corresponding to the load of 40 t / h, to 48.55% as corresponding to the load of 15 t / h.
- in winter, in case of equal loading of the two boilers, the efficiency decreased from 78.54% as corresponding to the load of 30 t / h, to 55.05% as corresponding to the load of 17.5 t / h.

5. Conclusions

Low power factor due to AC motors influence electricity quality and lead to energy losses.

Using the mathematical model presented in this paper, in the case study were established variation of energy losses depending on power factor. For an average power factor of 0.75 achieved in the factory, were calculated energy losses in cables and transformers. Important losses are in the transformer and in the supply cables of paper machine which has the highest consumption of energy. Increasing power factor from 0.75 to 0.92 reduce energy losses up 242 MWh/an, that mean 20,000 $/year.

The operating regime of the paper machine influences steam boilers efficiency.

Breaking of paper leads sudden drop of the boiler load thus a decrease of its efficiency. With proper maintenance works and following the technological process also breaks can be eliminated. Such a paper machine operation could lead to fuel savings, during the breaks eliminated by 1253 Nm3 / h - in summer and 544 Nm3 / h – in winter.

R E F E R E N C E S

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