OPPORTUNITY STUDY FOR HEAT RECOVERY FROM LARGE POWER TRANSFORMERS IN SUBSTATIONS

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Rezumat. Transformatoarele de putere pot reprezenta surse importante de căldură în stațiile electrice. Lucrarea aceasta studiaza oportunitatea recuperării acestei călduri din punct de vedere energetic, exergetic și economic. Sunt studiate două cazuri de recuperare : cu un schimbător de căldură ulei-apă și cu o pompă de căldură cu compresie din care se poate obține apă caldă menajeră sau pentru incalzira unor cladiri. În final, este prezentat un exemplu numeric pentru un transformator de putere aflat în funcțiune într-o stație electrică.
Cuvinte cheie: transformator de putere, recuperare caldură, exergie, beneficiu.

Abstract. The power transformers can be important sources of heat in substations. This work studies the heat recovery opportunity in terms of energy, exergy and economy. We studied two cases of recovery: with an oil-water heat exchanger and with a compression heat pump that can provide domestic hot water or hot water for building heating. Finally, a numerical example is presented for a large power transformer in operation within a substation.
Keywords: power transformer, heat recovery, exergy, benefit.

1. INTRODUCTION

In the substations of the national energy system there are a lot of large power transformers. They are usually cooled by the forced circulation of oil through the transformer tank and through the oil cooler. The oil cooler is usually an oil-air heat exchanger, [1]. The forced circulation of air is provided by fans located on the cooling batteries. The oil temperature frequently reaches the 40-60 ^{0}C temperature range.

Cooling systems have been proposed with classical heat exchangers, [8], or with heat pipes, [9].

This work studies the heat recovery opportunity in terms of energy, exergy and economy for a recovery system with a heat exchanger and another with a compression heat pump. Consumers for the recovered heat were proposed. For a numerical example a large power transformer operating in a substation was considered.

2. OPPORTUNITY STUDY OF HEAT RECOVERY FROM THE LARGE POWER TRANSFORMERS IN SUBSTATIONS

Opportunity study of heat recovery from the large power transformers is made for transformers with forced cooling of oil, in two cases, Figure 1:

-case 1 – the use of an oil-water heat exchanger (HE), 4;

-case 2 – the use of a compression heat pump (CHP), B, for domestic hot water or for heating.

The transition from one case to another is done using three-way valves, 2 și 3.

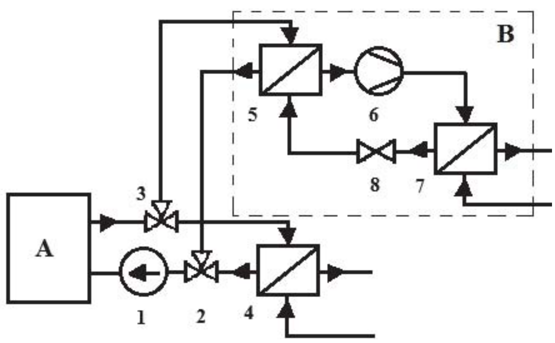

Fig.1. *Heat recovery scheme: A-transformer; B-compression heat pump; 1-oil pump; 2, 3 - three-way valves; 4-oil-water heat exchanger; 5-evaporator; 6-compressor; 7-condenser; 8- expansion valve*

2.1. Recoverable heat flux from the transforme

Recoverable heat flux, Φ_r, from the oil transformer can be calculated using thermal balance equation, [5]:

$$\Phi_r = \Delta P_t + \Phi_s - \left(\Phi_p + \Phi_o\right) \qquad (1)$$

where: ΔP_t represents electrical losses in the transformer, in [W]; Φ_s – the heat received from the sun, in [W]; Φ_p – the heat lost through the walls of the tank to the environment, in [W]; Φ_o – heat flux received / given by the oil from the transformer tank, in [W]

Electrical losses in the transformer depend on the load of the transformer, [1], and heat flux received from the sun depends on the location of the transformer, [6], the season and time of day.

Heat losses in the environment depend, mainly, on the temperature of the oil from tank and the ambient temperature, [2].

Heat flux received / given by the oil from the transformer tank depends on the recovery system used, [7]. In case of maintaining a constant temperature of oil, this flux is zero.

Recoverable heat flux, as shown in the balance equation, depends on the load of the transformer, the transformer location, season, time of day, the recovery system used..

2.2. Energy recovery study

Aim of the energy recovery study is to determine the useful heat flux, ie heat flux transferred to consumer and heat flux consumed by the recovery system.

These heat fluxes depend on the heat recovery system used. The useful heat flux is determined by the following equation:

- in case 1 of using oil-water heat exchanger:

$$\Phi_{us} = \eta_s \cdot \Phi_r \qquad (2)$$

where η_s is the efficiency of the heat exchanger.

- in case 2 of using compression heat pump, [4] :

$$\Phi_{up} = \eta_{cd} \cdot \left(\eta_v \cdot \Phi_r + \eta_c \cdot \eta_m \cdot P_c\right) \qquad (3)$$

where η_v, η_{cd} is the efficiency of the evaporator, respectively, of the condenser of the heat pump; η_c, η_m - the efficiency of the compressor, respectively, of its engine; P_c – electrical power consumed by the compressor engine, in [W].

Heat flux consumed by the recovery system is:

- in case 1:

$$\Phi_{cs} = P_p \qquad (4)$$

where P_p electrical power consumed by the oil pump engine, in [W].

-in case 2:

$$\Phi_{cp} = P_p + P_c \qquad (5)$$

2.2. Exergy recovery study

To assess the quality of recovered heat is calculated exergy fluxes of useful heat. For the recovery system with heat exchanger, it is determined by the relation, [3]:

$$E_{us} = D_w \cdot \left[\left(i_{w,e} - i_{w,i}\right) - T_0 \cdot \left(s_{w,e} - s_{w,i}\right)\right] \qquad (6)$$

where : D_w is the water flow heated by the heat exchanger, in [kg/s] ; $i_{w,e}$, $i_{w,i}$ – output water enthalpy, respectively, input in the heat exchanger, in [J/kg] ; T_0 – the reference temperature for the exergetic calculus, in [^{0}K] ; $s_{w,e}$, $s_{w,i}$ - output water entropy, respectively, input in the heat exchanger, in [J/(kg ^{0}K)].

With a relation of the form (6) is determined and useful exergy of water obtained from the condenser of heat pump.

Exergy consumed are considered equal to heat fluxes consumed, because that they are given by the electric power.

2.3. Economic recovery study

Economic evaluation of recovery system is done by determining the cost, revenue and the benefit obtained. Thus, for the recovery system with heat exchanger, they are:

$$\begin{aligned} C_S &= p_e \cdot \sum_{h=1}^{24} P_{p,h} \\ R_S &= c_{tr} \cdot p_h \cdot \sum_{h=1}^{24} Q_{us,h} \qquad (7) \\ B_S &= S_S - C_S \end{aligned}$$

where: C_s is the cost of electricity consumed, in [lei/day]; R_s – revenue, that is value of the recovered heat, in [lei/ day]]; B_s - benefit obtained, in [lei/day]; p_e – electricity price, in [lei/Wh]; p_t – heat price, in [lei/Gcal]; c_{tr} – conversion factor of units of measurement, in [Gcal/Wh];, $P_{p,h}$ – hourly average power consumed by the engine of oil pump, in [W]; $Q_{us,h}$ – hourly average useful heat flux, in [W]. This flux is determined by the relation (2).

With relations of the form (7) is made the economic evaluation of the use of heat pump.

3. NUMERICAL RESULTS

Opportunity study for heat recovery from large power transformers, according to the algorithm described above, is performed for a transformer of 250 MVA, 400/100 kV, that operating in a substation. Hourly measurements of electrical parameters related to transformer load - active and reactive power, and thermal parameters related to oil temperature and the tank wall and ambient air temperature were made in May 2013.

In case of using compression heat pump, with R21 agent, were considered two situations:

- obtaining domestic hot water
- obtaining hot water for district heating.

To exergetic calculus, was considered reference temperature of 15 ^{0}C.

Water parameters are shown in Table I, the results of energy and exergy study - in Table II and the economic study - in Table III.

In case of HE and CHP for domestic hot water, cold water is introduced into the system with the same temperetură of 15 ^{0}C. In case of CHP for district heating, water introduced into the system is the water from the return of heating system, with high temperature of 70 ^{0}C. At the output of recovery system, is obtained water with a variable temperature, in case of HE, Figure 2, and with constant temperature in case of CHP. The amount of water produced daily is highest in case of CHP for district heating.

From Table II it is noted that in case of CHP for district heating, there are obtained maximum values for exergy flux and heat flux but and for electricity consumed, for the same recoverable heat flux in the transformer.

From economic study, Table III, t is observed that the greatest benefit is obtained in case of HE, where the cost of electricity consumed is the lowest.

Table I
Water parameters

Parameter	U.M.	Value for :		
		Heat exchanger	Compression heat pump	
			Domestic hot water	Hot water for heating
Water temperature input	^{0}C	15	15	70
Water temperature output	^{0}C	35.8-average	45	90
Amount of hot water obtained	m^3/zi	82.9	59.3	112.6

Table II
Results of the study energetic and exergetic

Parameter	U.M.	Value for :		
		Heat exchanger	Compression heat pump	
			Domestic hot water	Hot water for heating
Recoverable heat	kWh/day	2027	2027	2027
Electricity consumed	kWh/day	23.7	137.2	652
Heat obtained	kWh/day	1987	2056	2550
Exergy of heat obtained	kWh/day	68.8	102.8	470.7

Table III
Results of the economic study

Parameter	U.M.	Value for :		
		Heat exchanger	Compression heat pump	
			Domestic hot water	Hot water for heating
Electricity cost	lei/day	14.2	81.7	388.6
Revenue from heat obtained	lei/day	444.2	459.7	570.3
Benefit obtained	lei/day	430.0	378.0	181.7

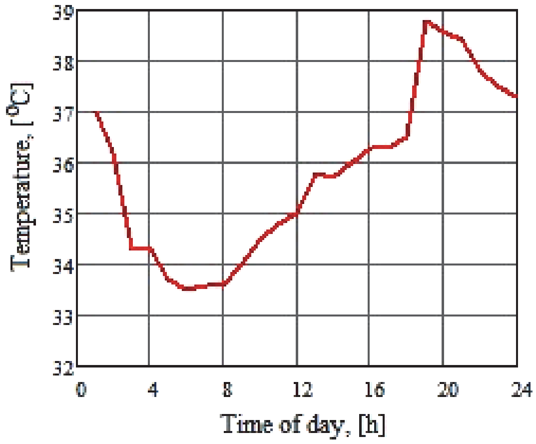

Fig.2. *Variation of water temperature obtained from the heat exchanger*

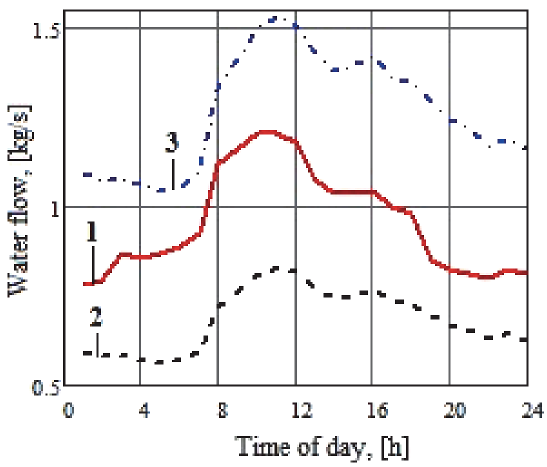

Fig.3. *Variation of water flow obtained in: 1 - HE, 2 - CHP for domestic hot water, 3 - CHP for district*

Figures 3, 4 and 5 show the variation of hot water flow, useful heat flux, exergy flux of useful heat, during the day, for the three cases studied.

It is observed variation about the same shape but different values.

The largest flow of hot water is obtained in case of CHP for district heating and the lowest - in case of CHP for domestic hot water.

In Figure 4 it is observed that values of useful heat flux, in case of HE and CHP for domestic hot water are close, only with 3.3% higher for CHP for domestic hot water and heat flux, in case of CHP for district heating, is with 22 % higher than in the case of HE.

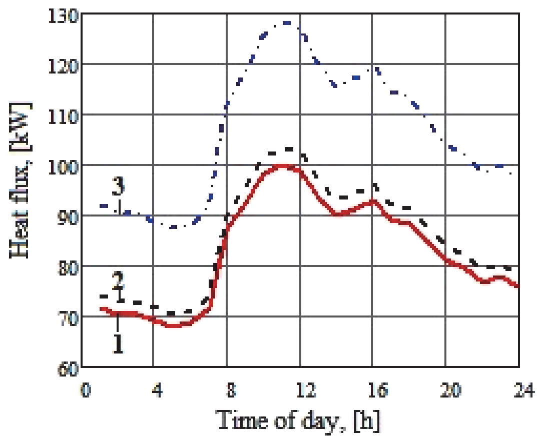

Fig.4. *Variation of useful heat flux obtained in: 1 - HE, 2 - CHP for domestic hot water, 3 - CHP for district heating*

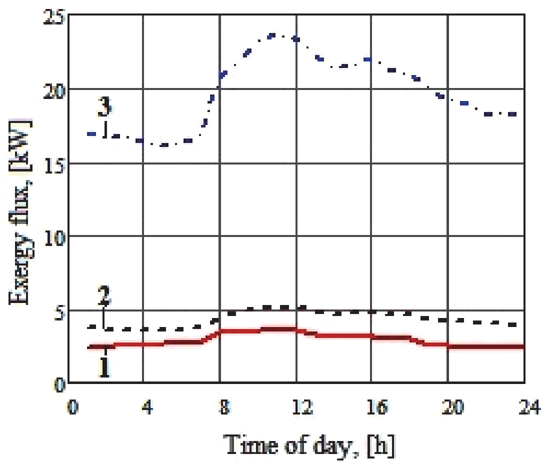

Fig.5. *Variation of exergy of useful heat obtained in: 1 - HE, 2 - CHP for domestic hot water, 3 - CHP for district heating*

Exergy flux of heat obtained from CHP for district heating is significantly higher, with 85%, than in case of HE and with 78% higher than in case of CHP for domestic hot water. This difference is due to the high thermal level of water for district heating, of 90 ^{0}C vs 45 ^{0}C in case of CHP for domestic hot water and vs an average value of 35.8 ^{0}C, in case of HE.

4. CONCLUSIONS

From the numerical results of the oportunity study for heat recovery the following conclusions can be drawn:

- the use of an oil-water heat exchanger for the production of hot water is the simplest and most cost-effective solution. But, the thermal level of the water is low (35.8 ^{0}C daily average) and may be used only as domestic hot water for the operating staff of the substation. In terms of the quantity of water produced, it is too much for the operating staff (enough for about 600 people). This makes the HE solution not opportune.

- the use of a CHP for domestic hot water allows heating water for about 420 people, at a thermal level close to that of a domestic hot water network (45 ^{0}C) and with a 12% lower benefit than in the HE case. The solution is opportune only if it is possible to connect the recovery system to a domestic hot water network.

- the use of CHP for district heating is the most economically disadvantaged but the best in terms of quality (exergy). The solution is opportune only if the recovery system can be connected to a district heating network, (90/70 ^{0}C).

If the heat price would also take into account its quality, the results of the economic study would be different.

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