SOLUTION HEAT RECOVERY FROM THE POWER TRANSFORMER OIL

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REZUMAT. Recuperarea caldurii uleiului de racire a transformatoarelor de putere este in atentia specialistilor atat din domeniul electric cat si termic. O solutie de recuperare a acestei calduri pentru obtinerea unui agent termic cu temperatura ridicata ce poate fi utilizat atat pentru incalzire, racire, cat si pentru apa calda menajera, este propusa in aceasta lucrare. Sunt prezentate modelul termic al transformatorului si modelul analitic al pompelor de caldura cu compresie si cu absorbtie. In final, este aratat un exemplu numeric.

Cuvinte cheie: transformator de putere, pompa de caldura, flux de caldura, recuperare

ABSTRACT. Heat recovery from cooling oil of power transformers is in the attention of specialists from both electrical and thermal field. A solution of this heat recovery to getting a high temperature of thermal agent which can be used both for heating, cooling and domestic hot water is proposed in this paper. The thermal model of transformer and analytical model of compression heat pumps and absorption heat pumps are presented. Finally, a numerical example is shown.

Keywords: power transformer, heat pump, heat flux, recovery

1. INTRODUCTION

The power transformers are used in a power system, being a very important component.

Power transformers with forced cooling of oil can be sources of heat for heating and domestic hot water, both inside station buildings and the ones beyond.

Different models have been carried out involving transformer thermal heat transfer equations of the winding, oil from oil to air environment in transient or steady, [1], [2], [3].

The heat generated by electrical losses in iron and windings is taken by cooling oil that can get in operation, currently, at 45-60 ^{0}C. Given the low level of oil heat, using heat exchangers to recover heat can not get an agent heated to a high temperature. But, the use of a heat pump permits, [5]. In addition, maintaining the oil at a low temperature by using of the heat pump has the advantage of increasing the life of the transformer insulation.

Such a solution is proposed in this paper. A scheme of heat recovery and thermal model of the transformer and of compression heat pumps and absorption are presented.

Finally, a study is conducted on a transformer in operation at a substation and the numerical results are shown.

2. SOLUTION HEAT RECOVERY FROM THE POWER TRANSFORMER OIL

The solution proposed for heat recovery from the transformer oil is shown in Figure 1.

This solution is to recover heat from the transformer oil, A, with a compression heat pump, B, and apply only in case of forced cooling of transformers. Thus, in the oil cooling circuit are introduced two three-way valves, 2, that enabling the delivery of oil in both the cooling batteries 3, as well as in the heat pump evaporator, 5. Heat generated in the heat pump condenser, 7, is in the form of hot water with parameters similar to those of external heating network, E, which serves as a backup heat source or storage.

From the hot water distributor 11, is fed:

- during the cold season - the water network of conditioning installation, 23 and domestic hot water network, 22
- during the warm season - an absorption heat pump, C that cools water in the conditioning network 23, in the evaporator 17 and provides domestic hot water from the condenser 15 and absorber 17.

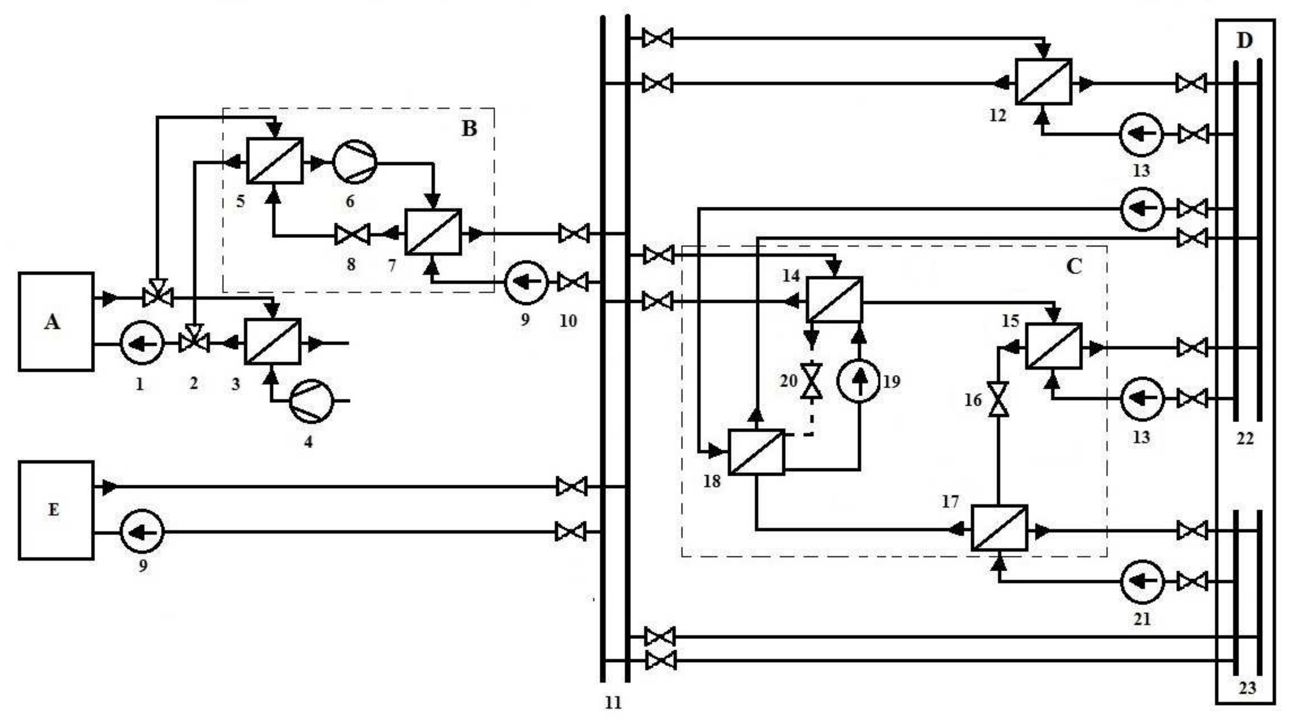

Fig. 1. Scheme of heat recovery from transformer: A-transformer, B-compression heat pump (CHP), C-absorption heat pump (AHP), D-building, E-district heating network: 1-oil pump, 2-three-way valve, 3-cooling batteries, 4-fan air atmospheric, 5-evaporator of CHP, 6-compressor of CHP, 7-condenser of CHP, 8-expansion valve of CHP, 9-water pump, 10-valve , 11-heating water dispenser, 11-hot water distributor, 12-water-to-water heat exchanger, 13-domestic hot water pump, 14-generator of AHP, 15-condenser of AHP, 16-expansion valve of AHP thermal agent, 17 - evaporator of AHP, 18-absorber, 19- solution pump, 20-expansion valve of solution , 21-cold water pump in the conditioning installation, 22-domestic hot water network, 23-water network of conditioning installation

3. ANALYTICAL MODEL

Thermal model of the transformer

In a forced cooling of transformer oil, heat generated by electrical losses in the transformer core and windings is taken by cooling oil and, at steady, is discharged into the environment through cooling batteries and through tank walls, by convection and radiation. If it is a transient, some of this heat will be accumulated or released from the oil, causing its temperature variation. If transformers located in the environment, it takes into account the heat received from the sun. The heat balance equation for the transformer is:

$$\Delta P_t + \Phi_s = \Phi_b + \Phi_p + \Phi_u \tag{1}$$

where ΔP_t represents electrical losses in the transformer, [7], in [W]; Φ_s – the heat received from the sun, in [W]; Φ_b – the heat transferred from the cooling batteries into the environment, in [W]; Φ_p – the heat lost through the walls of the tank to the environment, in [W]; Φ_u – heat flow received / given oil, in [W]

The heat received from the sun, Φ_s, is determined by the following relationship, [2]:

$$\Phi_s = 0{,}5 \cdot S \cdot A \cdot G \cdot f \tag{2}$$

where: S – surface of tank, in [m^2]; A=0,75, solar radiation absorption coefficient; G – solar radiation , in [W/m^2], $f = 0{,}047 \cdot k_c$ - part of solar radiation transmitted oil tank; k_c=1,5 – transmissivity coefficient of heat through the wall of the tank.

Heat flux transferred from the cooling batteries in the environment is calculated using the equation, [4]:

$$\Phi_b = n_b \cdot D_u \cdot c_{pu} \cdot (t_{uib} - t_{ueb}) \tag{3}$$

where: n_b – number of cooling batteries; D_u – oil flow in the batteries, in kg/s]; c_{pu} – specific heat of oil, in [J/(kg.^{0}C)]; t_{uib}, t_{ueb} – inlet oil temperature, respectively, outlet from the cooling batteries, in [^{0}C].

Heat flux lost to the environment is:

$$\Phi_t = \Phi_c + \Phi_r \tag{4}$$

where: Φ_c is the heat flux lost by convection, in [W]; Φ_r is the heat flux lost by radiation, in [W].

$$\Phi_c = k \cdot S \cdot (t_u - t_{air}) \tag{5}$$

where: k is the overall heat transfer coefficient, in [W/m^2]; t_u si t_{air} are the oil temperature in the tank, respectively, the temperature of the ambient air, in [^{0}C];

$$\Phi_r = C \cdot \varepsilon \cdot S \cdot \left[\left(\frac{T_p}{100} \right)^4 - \left(\frac{T_{air}}{100} \right)^4 \right] \tag{6}$$

where C=5,67 Planck's constant, in [W/m^2 ^{0}K^4]; ε-emission factor of the tank wall; T_p and T_{air} are the oil temperature in the tank, respectively, the temperature of the ambient air, in [^{0}K].

Heat flow received / given oil is determined from the balance equation (1).

Analitical model of the compression heat pump, [6].

The characteristic points of compression heat pump are:

- 1 – input in the compressor, at the pressure p_v;
- 2 – adiabatic compressor output, corresponding to entropy of state 1 and to the vapor pressure in the condenser, p_c;
- 2p – real output from the compressor, which takes into account the internal efficiency of the compressor, η_i
- 3 – outputfrom the condenser - the saturated liquid state, at the pressure p_c;
- 4 – input in the evaporator, at the pressure p_v and output enthalpy from the condenser, h_3.

Corresponding to these points, there are determined the enthalpy of agent from the pump circuit and the specific heat:

- taken in evaporator

$$q_v = h_1 - h_3 \tag{7}$$

- given in condenser

$$q_{cd} = h_{2p} - h_3 \tag{8}$$

- the mechanical work consumed in compressor

$$l_c = h_{2p} - h_1 \tag{9}$$

Flow of thermal agent in the pump circuit, D_{ag}, in [kg/s], is:

$$D_{ag} = \frac{\Phi_d \cdot \eta_v}{q_v} \tag{10}$$

where: Φ_d is the available heat flow, in [W]; η_v – evaporator efficiency.

To determine the available heat flow, maximum oil temperature is considered constant, t_{ur}. Heat pump starts when the oil temperature at the top of the tank is, $t_{usup} > t_{ur}$.

Heat flow taken in the evaporator, Φ_v, in [W] is:

$$\Phi_v = D_{ag} \cdot q_v \tag{11}$$

With a relation of the form (5), is determined the flow of heat given to the condenser, Φ_{cd},, and compressor power, P_c.

Heat flow received / given oil is determined from the balance equation (1).

Analitical model of the absorption heat pump

Depending on the thermal agent and the solution enthalpies of absorption heat pump circuit, are determined the specific heat:

- taken in evaporator

$$q_{v,a} = h5 - h4 \tag{12}$$

- given in condenser

$$q_{cd,a} = h_2 - h_3 \tag{13}$$

- given in absorber

$$q_{ab} = h_5 - h_7 + fc \cdot (h_7 - h_{6a}) \tag{14}$$

- received in generator

$$q_g = h_2 - h_7 + fc \cdot (h_7 - h_1) \tag{15}$$

where:

- 1 – input of the solution in generator
- 2 – input of the agent vapor in condenser
- 3 – output from the condenser
- 4 – input in the evaporator
- 5 – ouput from the evaporator
- 6a – output of the solution saturated, in the liquid state, from the absorber
- 7 – output of the liqui solution from the generator

Circulating factor fc is determined from the relationship:

$$fc = \frac{1 - \xi_m}{\xi_M - \xi_m} \tag{16}$$

where: ξ_m, ξ_M – represents the minimum concentration, respectively, the maximum of solution in the pump circuit.

The flow of the thermal agent from the evaporator pump absorption, $D_{ag,a}$, in [kg/s], is determined by the relation:

$$D_{ag,a} = \frac{\Phi_{cd} \cdot \eta_{cd} \cdot \eta_{v,a}}{q_g} \tag{17}$$

where: η_{cd} – efficiency of the compression heat pump; $\eta_{v,a}$ – efficiency of the absorption heat pump.

With a relation of the form (5) are determined heat fluxes in the absorption heat pump circuit.

4. NUMERICAL RESULTS

The analytical model described above was applied to a transformer of 250 MVA, 400/110kV, in operation in a substation. The technical characteristics of the transformer are shown in Table 1.

Table 1

The technical characteristics of the transformer

Name	Symbol	U.M.	Value
Rated power	S	MVA	250
Rated voltage	U_{1n}/U_{2n}	kV	400/121
No-load losses	$\Delta P_{Fe,c}$	kW	90
Losses in the windings	$\Delta P_{Cu,c}$	kW	510
Impedance voltage	u_{sc}	%	16.4
No-load current	I_0	%	0.5

Table 1

Data of heat pump

Name	Symbol	U.M.	Value
Compression heat pump, R21 thermal agent			
Vaporization pressure	p_v	bar	2.53
Vaporization temperature	t_v	^{0}C	22
Condensation pressure	p_c	bar	12
Condensation temperature	t_c	^{0}C	95
Absorption heat pump, water- ammonia thermal agent			
Vaporization pressure	$p_{v,a}$	bar	6.15
Vaporization temperature	$t_{v,a}$	^{0}C	10
Condensation pressure	p_c	bar	17.82
Condensation temperature	t_c	^{0}C	45

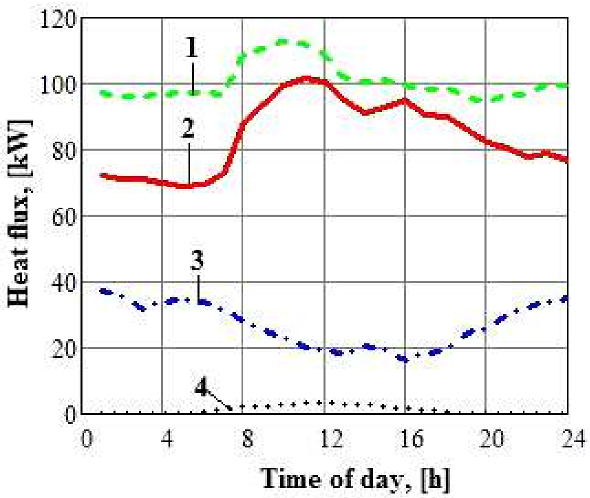

Fig.2. Variation of the heat flux of transformer: 1 – electric losses; 2 – available heat flux; 3 – heat flux lost by convection and radiation; 4 - heat flux of solar radiation;

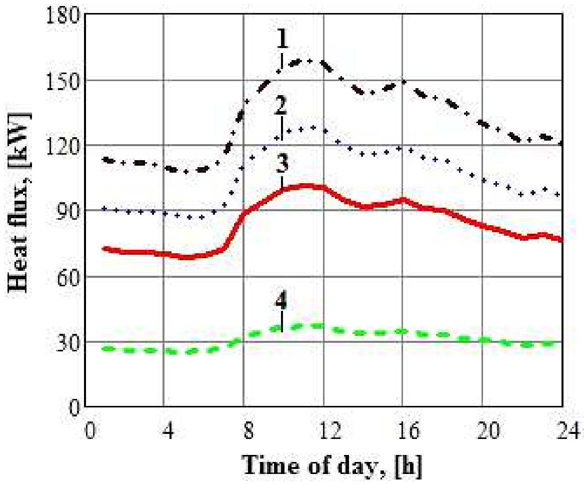

Fig.3. Variation of the heat flux: 1 – of warm water; 2 – available from compression heat pump; 3 – available from power transformer; 4 – of cooling air from air conditioning

Pressure and temperature of vaporization and condensation of heat pumps are presented in Table 2.

The top temperature of oil that starts compression heat pump is 35 ^{0}C.

With the data measured in one day in June 2013, were obtained the heat fluxes shown in the graphs in Figures 2 and 3.

From Figure 2 it is observed that the heat flux available to be taken from the cooling oil of transformer follows the same shape of variation as the power losses in the transformer. Its share in power losses vary between 70 and 93%. The difference between these heat fluxes grow morning and evening, when the air temperature is lower and the heat loss by convection and radiation to the environment are higher. The share of heat flux due to solar radiation is small, reaching 2.5% in mid-day.

From Figure 3 it is observed that the heat flux available in the condenser of compression heat pump is higher than the heat flux taken from the transformer oil due to thermal equivalent of electrical power of the compressor.

In case of the absorption heat pump, the heat flux of domestic hot water obtained from the condenser and absorber increases over the heat flux available in compression heat pump due to the heat flux taken from the air conditioning.

5. CONCLUSIONS

✓ The proposed solution heat recovery of cooling oil of power transformers with compression heat pump and absorption heat pump allows obtaining:

- hot water for heating and domestic hot water, in the cold season
- cold water for cooling of air conditioning and domestic hot water, in the warm season

✓ In case of accidental or planned shutdowns of the transformer, as in the case of a surplus heat, can be used external heating network which serves as a backup heat source or storage.

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