STUDY OF PVT SYSTEM INTEGRATION IN AN INDUSTRIAL COMPANY

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REZUMAT. In lucrare se propun diferite scheme de integrare a unui sistem fotovoltaic-termic într-o unitate industrială. Aceste scheme sunt analizate din punctul de vedere al posibilităţilor de utilizare a energiei electrice şi a căldurii, al fiabilităţii sistemului, al aspectelor economice. Sunt prezentate relaţiile de calcul a diferiţilor indicatori analizaţi şi, în final, este realizat un studiu numeric pentru integrarea unui PVT într-o unitate industrială.

Cuvinte cheie: PVT, fiabilitate, durata de recuperare.

ABSTRACT. The paper proposes various schemes to integrate a photovoltaic-thermal system in an industrial company. These schemes are analyzed in terms of possible use of electricity and heat, system reliability and economics. Calculation relations are presented for the various analyzed indicators and, finally, a numerical study is realized for the integration of a PVT in an industrial company.

Keywords: PVT, reliability, payback period.

1. INTRODUCTION

A hybrid photovoltaic-thermal system is a combination of a photovoltaic system that generates only electricity and a heat system, which generates only heat. Efficiency of the simultaneous generation of electricity and heat in PVT is superior to the separate generation of these two forms of energy, [1]. However, the investment cost is high and leads to a long payback period, which is a disadvantage of this system, [2]. Using such a system implies a heat consumer. If this heat can be taken continuously, as is solar radiation, it can get a better cooling of the panel which leads to increased production of electricity. Such a consumer can be found in industry, where there are technological processes that can use hot water with temperature obtained from the PVT or can use the PVT system in the preheating stage.

The present paper studies how a PVT system can be integrated in an industrial company which consumes electricity and heat generated by PVT. Two schemes for taking heat from the PVT system are analyzed: continuous through the heat exchanger and discontinuous, with storage tank. Another case studied is that of a supply engine for pumping the water through panels, heat exchanger or storage tank, in DC and / or DC and AC.

The reliability of the PVT system affects the operational continuity and thus, the energy production of the system. An analysis of the system is therefore made in terms of reliability.

The payback period is a global indicator that helps us make a decision on wether or not to implement it. Therefore, this work includes an economic analysis of the PVT system that generates the necessary data to determine the recovery period.

The numerical study presented below, helps us to draw some useful conclusions refering to the PVT system integration in an industrial company.

2. CONFIGURATION ANALYSIS

A PVT system can be used in an industrial company for supplying electricity to consumers in DC and/or in AC and for supplying hot water to the technological process.

To take the heat of a PVT system a heat exchanger can be used, as shown in Figure 1, or a storage tank. If we are interested in maintaining a higher water temperature and discontinuous usage, then the storage tank is recommended.

Electricity generated by the PVT can be used to supply, in DC, the PVT water pump motor and, in AC, the engine pump in the secondary heat exchanger; the remaining electricity is delivered into the grid, as in Figure 1. Or, the electricity generated by the PVT can all be delivered into the grid and both motors can be supplied in AC with energy from the grid, figure 2.

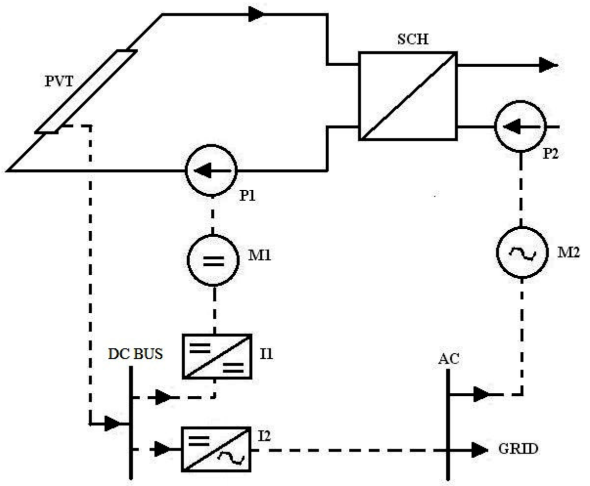

Fig. 1. PVT with heat exchanger and DC and AC engine; *PVT* – photovoltaic-thermal panels; *SCH* – heat exchanger; *P1, P2* – pumps; *M1* – DC engine *M1* – AC engine; *I1* – DC controller. *I2* – DC/AC inverter; *DC* – DC connection box; *AC* – AC connection box.

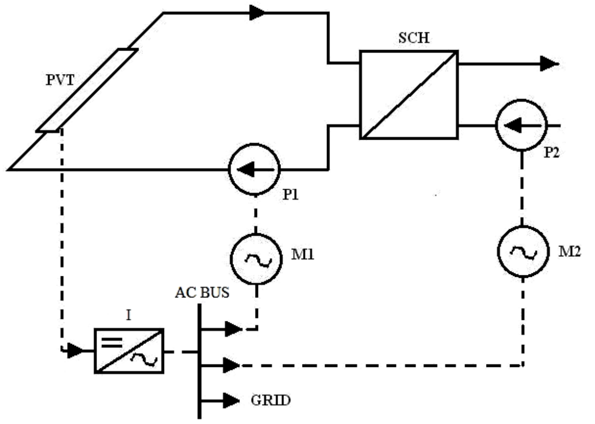

Fig. 2. PVT with heat exchanger and AC engine; *PVT* – photovoltaic-thermal panels; *SCH* – heat exchanger; *P1, P2* – pumps; *M1, M2* – AC engine; *I* – DC/AC inverter; *AC* – AC connection box

3. RELIABILITY ANALYSIS

Reliability is determined by the reliability of the components and by the system configuration. In terms of reliability, the elements in schemes Fig.1 and Fig.2 are in series, except for the AC/DC inverter components, which are in parallel with the grid, [3]. After calculating the equivalent rate of failure, λ_e, and the equivalent rate of repair, μ_e, [4], for the entire system, the reliability indicators are evaluated so as to help us to determine energy losses.

- The yearly mean number of interruptions eliminated through repairs, [5], [6]:

$$N_{intr} = \frac{\lambda_e \cdot \mu_e}{\lambda_e + \mu_e} \cdot T \quad \text{[interruptions]} \qquad (1)$$

where $T=8760$ h/year, reference duration.

- The mean duration of one interruption eliminated through repairs:

$$T_{intr} = \frac{1}{\mu_e} \text{ [h/interruption]} \qquad (2)$$

- The yearly mean duration of interruptions eliminated through repairs:

$$T_{intr,an} = N_{intr} \cdot T_{intr} \text{ [h/year]} \qquad (3)$$

4. ECONOMICAL ANALYSIS

The economic analyses performed in this study are based on the simple payback period. The investment cost and yearly savings are calculated using the following relations:

- Investment cost, C_t , [7]:

$$C_t = C_e + C_i + C_r \text{ [lei]} \qquad (4)$$

were: C_e is equipments cost, [lei]; C_i – installation cost, [lei]; C_r - replacement cost of used equipment (pump, glycol, etc..) [lei];

- Yearly savings, E_t :

$$E_t = E_u - \Delta C_w - C_p \text{ [lei/year]} \qquad (5)$$

where E_u value of useful energy, [8]:

$$E_u = Q_u \cdot p_Q + W_u \cdot p_{reg} + n_{cert} \cdot V_{cert} \cdot W_u \text{ [lei/year]} \quad (6)$$

where: Q_u – useful heat delivered to consumer, in [kWh/year]; p_Q – price of heat delivered, in [lei/kWh]; W_u – useful electricity delivered into grid, in [kWh/year]; p_{reg} – price of electricity delivered, in [lei/kWh]; n_{cert} – number of green certificates issued for electricity generated by a photovoltaic system; V_{cert} – value of one certificate, [lei/cert]; ΔC_w – cost of energy losses due to yearly interruptions, in [lei/year]. These losses are calculated as:

$$\Delta C_w = Q_l \cdot p_Q + W_l \cdot p_{reg} + n_{cert} \cdot V_{cert} \cdot W_l \text{ [lei/year]} \quad (7)$$

where: Q_l – heat losses, in [kWh/an], W_l – electricity losses, in [kWh/year] which are calculated with the following relation:

$$Q_l = \Phi_m \cdot T_{intr,an} \cdot 10^{-3}$$
$$W_l = P_m \cdot T_{intr,an} \cdot 10^{-3} \text{ [kWh/year]} \qquad (8)$$

where: Φ_m is yearly mean heat flux, in [W]; P_m – yearly mean power, in [W].

C_p is cost of electricity consumed for pumping:

$$C_p = W_p \cdot p_g \text{ [lei/year]} \qquad (9)$$

where W_p is electricity consumed for pumping, in [kWh/year]; p_g – price of electricity consumed for pumping, in [lei/kWh].

- Payback period is evaluated with the following relation:

$$T_{rec} = \frac{C_t}{E_t} \quad \text{[years]} \qquad (10)$$

5. NUMERICAL STUDY

Based on the above theoretical analysis, the numerical simulation was conducted for a PVT consisting of 12 modules of 190W-power, respectively, in 2320 Wh/day - heat, each. The modules are arranged on two rows, each with 6 modules per row. The configurations shown in Figures 1 and 2 are analyzed. The numerical results are presented in the following tables and graphs.

Table 1 and Figure 3 show reliability indicators. Equivalent failure rate is higher, both for the exchanger scheme and for the storage tank, in case of DC+AC because there is an element, in series, in the reliability scheme - the DC controller. The equivalent failure rate is higher in the scheme with the heat exchanger, because it has a higher failure rate than the storage tank.

Table 1

Reliability indicators

Indicator	Symbol	U.M	Heat exchanger		Storage tank	
			DC+AC	AC	DC+AC	AC
Equivalent rate of failure *10^-4	λ_e	h^{-1}	5.323	5.209	5.266	5.152
Equivalent rate of repair	μ_e	h^{-1}	0.035	0.035	0.039	0.038
Yearly mean number of interruptions	N_{intr}	inter/year	4.6	4.5	4.6	4.5
Mean duration of one interruption	T_{intr}	h/inter	28.3	28.9	25.9	26.5
Yearly mean duration of interruptions	$T_{intr,an}$	h/year	130	130	118	118

Table 2

Production indicators

Indicator	Symbol	U.M	Heat exchanger		Storage tank	
			DC+AC	AC	DC+AC	AC
Useful electricity of the system	W_u	kWh/year	3420	3528	3297	3391
Loss of electricity due to interruptions	W_l	kWh/ year	95	98	83	85
Yearly mean power	P_m	W	730	753	703	723
Useful heat of the system	Q_u	kWh/ year	8586	8586	5355	5355
Loss of heat due to interruptions	Q_l	kWh/ year	238	238	135	135
Yearly mean heat flux	Φ_m	kW	1832	1832	1142	1142
Electricity consumed for pumping	W_p	kWh/ year	104	104	50.8	50.8

Table 3

Economical indicators

Indicator	Symbol	U.M	Heat exchanger		Storage tank	
			DC+AC	AC	DC+AC	AC
Value of useful energy	E_u	lei/year	6833	6984	5905	6036
Cost of electricity consumed for pumping	C_p	lei/year	0	47.8	0	23.3
Cost of energy losses due to yearly interruptions	ΔC_w	lei/year	195	199	152.3	155.8
Yearly savings	E_t	lei/year	6833	6936	5905	6013
Replacement cost	C_r	lei	24460	24460	24460	24460
Equipments cost	C_e	lei	158100	151800	156200	149900
Installation cost	C_i	lei	96	96	96	96
Investment cost	C_t	lei	182656	176356	180756	174456
Payback period	T_{rec}	years	26.7	25.4	30.6	29.0

- The significance of the notations in tables and graphs is: *DC+AC,S* – case of heat exchanger with DC and AC engines that are feeding from the PVT system; *AC,S* – case of heat exchanger with AC engines that are feeding from the grid; *DC+AC,R* – case of storage tank with DC and AC engines that are feeding from the PVT; *AC,R* – case of storage tank with AC engines that are feeding from the grid.

The yearly number of interruptions is about the same in the case of the heat exchanger and that of the storage tank, but higher (4.6) for DC+AC than for AC (4.5).

The duration of interruptions is higher for the heat exchanger, AC (28.9) than the storage tank, AC (26.5).

The yearly mean duration of interruption is higher by 9.2% for the case of the heat exchanger.

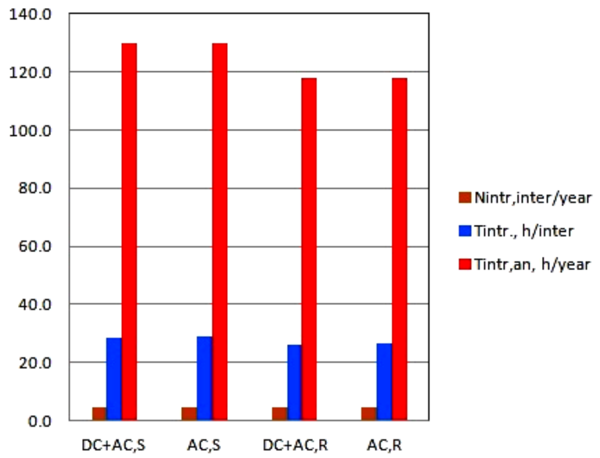

Fig. 3. Variation of reliability indicators: N_{intr} – yearly mean number of interruptions; T_{intr} – mean duration of one interruption; $T_{intr,an}$ – yearly mean duration of interruptions.

Table 2 and Figure 4 show the variation of the PVT system production indicators. Useful energy is higher in the case of the heat exchanger, of 3.9% for AC power and of 37.8% - heat. Energy losses due to interruptions in operation have the same trend - higher in the exchanger, of 13.3%, AC-power and of 43.3% - heat.
Electricity consumption for pumping is 51.2% higher in the case of the heat exchanger, taking into account that pumps operate continuously during solar radiation rather than operating only in short burst when solar radiation ends for a given day, as is the case with the storage tank.

Economical indicators can be seen in Table 3 and Figure 5. The highest value for the useful energy is obtained in the case of the heat exchager, AC (6984 lei/year) and the smallest - in the case of the storage

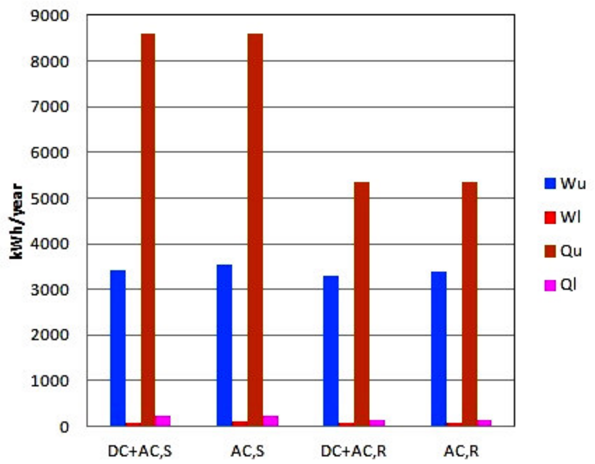

Fig. 4. Variation of production indicators: W_u – useful electricity of the system; W_l – loss of electricity due to interruptions; Q_u – useful heat of the system; Q_l – loss of heat due to interruptions.

tank, DC+AC (5905 lei/year). The cost of pumping electricity occurs only in the AC case, when engines are feeding from the grid. It is higher for the case of the heat exchanger. This cost represents only a small share of the total savings (0.69% in the case of heat exchanger and of 0.39% in the case of the storage tank).

The biggest energy losses unproduced due to interruptions are in the case of the heat exchanger, AC (199 lei/year), their share of the total savings is of 2.9% as opposed to 2.6% for the storage tank, DC + AC.

The total savings are maximum in the case of the heat exchanger, AC (6936 lei/year) and minimum in the case of the storage tank,DC + AC (5905 lei/year).

Total cost is the highest in the case of the heat exchanger, DC + AC, with 4.5% more than the cost in the case of the storage tank, AC.

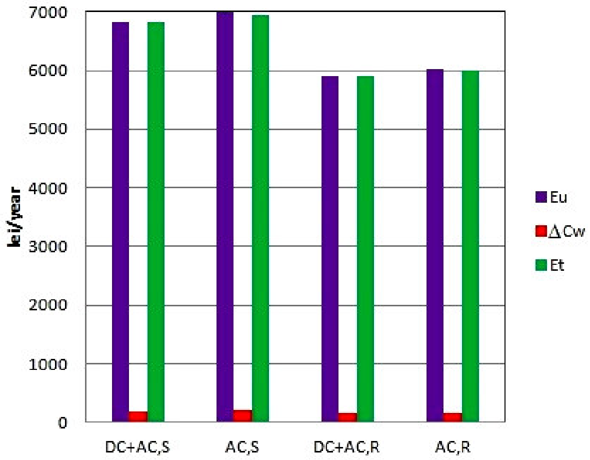

Fig. 5. Variation of economical indicators: E_u – value of useful energy; ΔC_w – cost of energy losses duet o yearly interruptions; E_t – yearly savings.

The payback period, fig.6, is lower in the case of the heat exchanger than in the case of the storage tank. It has the lowest value for the heat exchanger, case AC (25.4 years) and the highest for the storage tank, case DC + AC (30.6 years).

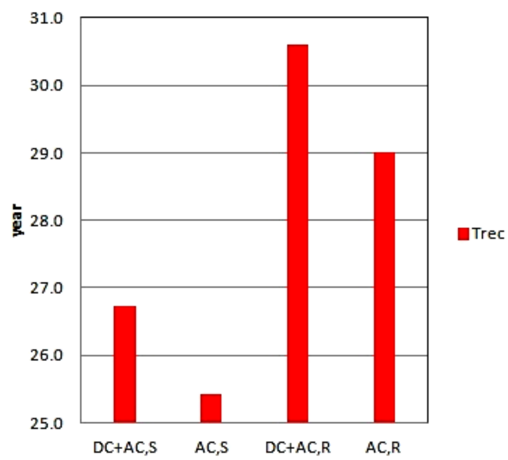

Fig. 6. Variation of payback period, T_{rec}.

6. CONCLUSIONS

The studies made in this paper conduct to the following conclusions:

- In terms of reliability, the PVT system with a storage tank, case DC + AC, is the best;
- In terms of useful energy, the system with the heat exchanger, AC case, is the best;
- In terms of yearly savings, the system with the heat exchanger, AC case, is the best;
- In terms of total cost, the system with the storage tank, AC case, is the best;
- In terms of the payback period, an indicator which gives general information on the PVT system, the system with the heat exchanger, AC case, is the best.

These conclusions may be useful for choosing an integrated PVT system in an industrial company in which heat can be used in the technological process, during the entire solar radiation interval.

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