EVALUATION OF ENERGY AND EXERGY PERFORMANCES OF A THERMODYNAMIC ELECTRO-SOLAR PLANT

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ABSTRACT

The thermodynamic electro-solar plant, installed by the firm BELGONUCLÉAIRE at the "Centre de Physique et d'Energétique" of the INRST consists of plane solar collectors (750 m^2), a storage tank (50 m^3) and a Turbo-Generator-Group (TGG) (10 kW) (fig. 1).

During the running of the plant, some insufficiencies appeared. They were mainly related to the limitations of the efficiency and of the production time. We show in this communication a critical study of the present managing of the plant as well as suggestions to optimize the efficiency.

The exergy approach, based on both the First and Second Laws of thermodynamics, will be applied in order to show the link between managing and the thermodynamic irreversibilities. A new exergy efficiency will be defined and introduced. An on line parametric identification method as well as an hybrid model will be conceived and introduced. We finally propose a fast prediction method of performances.

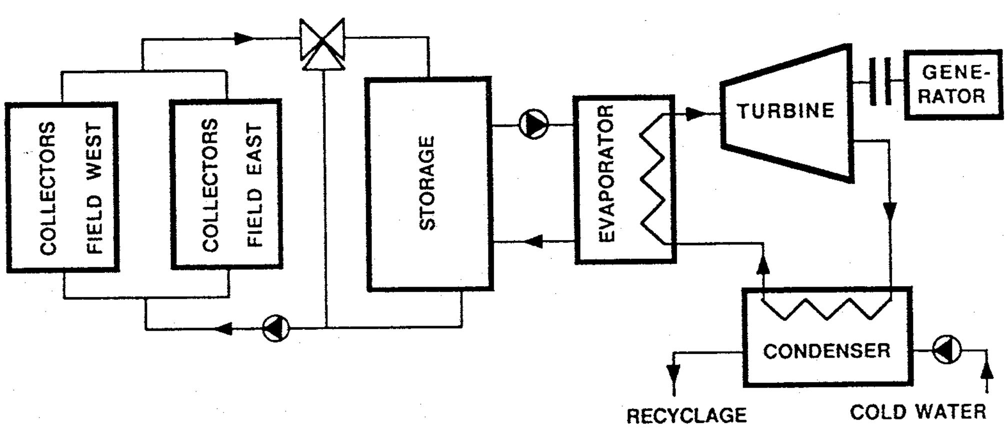

Fig. 1. Principle of the thermodynamic electro-solar plant of the INRST (Tunisia)

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1 ENERGY AND EXERGY ANALYSIS OF THE SOLAR COLLECTORS' FIELD

1.1 Methodology

The analysis of the behaviour of the entire field has not been done. The corresponding model would have been very impractical to manipulate. In this paper, we show a steady state hybrid model based on a Hottel-Whillier-Bliss model usually applied to a single collector. Let us point out that a model is called hybrid when it is based on both the thermodynamics (energy balances) and the experimental data (in and out) [2]. In this study, the computation of the parameters is relative to a specific interval of numerical data.

1.2 Hypothesis

a) the flow is constant ; b) the loss conductance is independent of the temperature ; c) all the collectors are equally irrigated.

1.3 Basic model

$$(\tau\alpha)\cdot F'\cdot E_n\cdot dS(x) = U_L\cdot F'\cdot (T(x)-T_a)\cdot dS(x) + \dot{m}\cdot c_p\cdot dT(x) \qquad (1)$$

This model is presented in the following new form in order to apply the least squares method :

$$y(n) = \theta\cdot\varphi^T(n)+\zeta(n,\theta) = \dot{\bar{W}}_{cc} = [\theta_1\ \ \theta_2]\cdot[1\ \ (T_a-T_e(n))]^T+\zeta(n,\theta) \qquad (2)$$

where : $\theta_1 = \dfrac{\dot{m}\cdot C_p\cdot(\tau\alpha)}{U_L}\cdot\left(1 - e^{-\frac{F'\cdot U_L\cdot S}{\dot{m}\cdot C_p}}\right)$, and $\theta_2 = \dfrac{U_L}{(\tau\alpha)}\cdot\theta_1$

1.4 Identification

The result issued from the least squares method is the parameters'vector $\hat{\theta}(N)$: $\hat{\theta}(N) = [\phi^T(N)\cdot\phi(N)]^{-1}\cdot\phi^T(N)\cdot Y(N)$ (3)

where : $\phi(N) = [\varphi^T(1)\ \ldots\ \varphi^T(N)]^T$, and $Y(N) = [y(1)\ \ldots\ y(N)]^T$

1.5 Loss conductance and efficiency

The real value found for the loss conductance is far from the one relative to a field of selective collectors which was the essential data for the dimensioning of the plant.

$(F'\cdot U_L)$ measured = **7.37 W/(K m²)**

$(F'\cdot U_L)$ constructor of the plant = **4.25 W/(K m²)**

Moreover, for the equinox conditions, the real efficiency of the system is about **28 %** instead of **46 %** which is the estimated value in the study relative to the plant [2,4].

1.6 Comparison between the results obtained with our model, the data of the designer of the plant and the experimental data

This comparison showed that it is possible to describe with great precision the behaviour of the whole field of 396 collectors with a model used in general for a single collector [2].

Let us point out that the collectors are connected according to a Tickelman loop. Figure 2 shows the results of this comparison.

1.7 Prevision model

The instantaneous efficiency of the whole field of collectors is as follows :

$$\varepsilon_{cc} = \frac{\dot{m}\cdot c_p}{SE_n} \cdot \left(\left(\frac{(\tau\alpha)}{U_L} \cdot E_n + T_a\right) - T_e\right) \cdot \left(1 - e^{-\frac{F'\cdot U_L\cdot S}{\dot{m}\cdot c_p}}\right) \tag{4}$$

We have verified experimentally that it was possible to predict the output temperature for a period smaller than the holding time of the fluid in the collectors. The output temperature is as follows :

$$T_s(t+\Delta t) \cong T_e(t) + (T_\infty(t) - T_e(t)) \cdot \left(1 - e^{-\frac{F'\cdot U_L\cdot S}{\dot{m}\cdot c_p}}\right) \tag{5}$$

The maximum relative error is about **1 %.**

1.8 Critical review of the control system and practical recommendations

We have determined that the output temperature T_s varies very little compared to its index value relative to the supply of the storage. The output temperature is often very close to the value T_∞. The ratio dT_s/dt is very small and consequently the effective working time of the plant gets smaller. This is due to the type of collectors chosen, which is not adapted to its utilization (temperature level round 100 °C). We therefore recommend the introduction of an autoadaptive index value which will depend on the minimum threshold radiation.

1.9 Exergy efficiency

The usual efficiency based only on the First Law of thermodynamics is insufficient to evaluate the real energy performances of a system whereas the exergy efficiency makes such evaluations possible. This new type of efficiency is defined on the basis of a new approach called the "exergy approach" which relies on both the First and Second Laws of thermodynamics [3].

Let us point out that only very few studies introducing this new approach have been made for solar systems up until now. Moreover, the hypothesis used in these studies, for determining the coheat-power $\dot{E}_{qs}$ relative to the solar radiation, are ill adapted.

Our work was based on the exergy approach. It has led to the computation of all the thermodynamic internal irreversibilities in the collectors. The most important cause of entropy creation is the devaluation due to the internal heat-transferr with decrease in temperature. The main parameters which had to be determined for this study are the following : the intrinsic characteristics of the collectors and the ambient temperature. We have shown that the exergy efficiency is as follows :

$$\eta_{cc} = \frac{\dot{E}^{-}_{wcc}}{\dot{E}^{+}_{qs}} = \frac{\dot{m} \cdot c_p \cdot (T_s - T_e) - \dot{m} \cdot c_p \cdot T_a \cdot \ln(T_s/T_e)}{E_n \cdot \iint_o^S \left[1 - \frac{T_a}{A + BT(s)}\right] dS} \qquad (6)$$

The value of the exergy efficiency obtained is small (smaller than the value of the usual efficiency). This means that the system contains many sources of entropy creation. This also confirms the fact that the initial choice made for the collectors is bad. Figure 3 shows some results of the exergy approach.

2 ENERGY AND EXERGY ANALYSIS OF THE TGG

The way of approach of this part is similar to the one shown for the collectors. Therefore, we shall not detail it in this paper. Let us point out that the important steps will be presented in the poster and the practical recommendations are included in the following paragraph.

CONCLUSIONS AND RECOMMENDATIONS

Through this work we could emphasize the fact that this plant is not well enough valorized. Indeed, by mastering its management as well as the choice of its flow and temperature commands, we would be able to improve its performances.

The conclusions of the present study are :

- In connection to the flow and the temperature, it appears that the behaviours of the collectors' field and of the TGG are contradictory. Therefore, the electric power, the global efficiency and the global exergy efficiency are not optimal.
- The TGG operates even if the index value relative to the supply of the storage (100 °C) is not reached. We therefore recommend a new connection method which consists of by-passing the storage in order to link directly the field of collectors to the TGG. This would lengthen the working time of the whole plant (now an average of 2 hours daily).
- The choice of the technology of the collectors is not appropriate. The TGG would have a longer working time with another more appropriate technology [1,2].

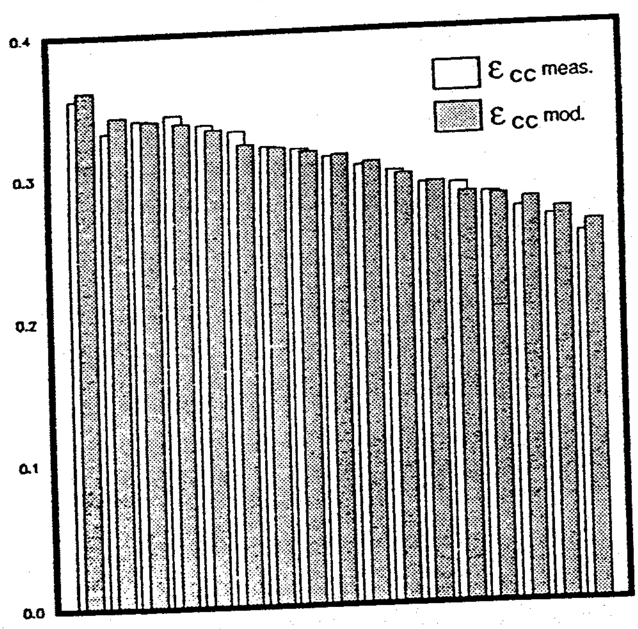

Fig. 2 Comparison between the measured and the modelised field collectors efficiencies.

Te	$\dot{m}$ \ En	700	800	900	1000	
80	4.8	19 21 133	22 32 191	22 32 191	25 53 300	η_{cc} $\dot{E}_{\overline{w}cc}$ $\dot{W}_{\overline{c}c}$
80	7.9	20 22 141	23 33 203	23 31 203	25 54 327	
94	4.8	10 12 62	16 23 121	16 23 121	22 48 238	
94	7.9	11 12 66	17 24 128	17 24 128	22 49 252	

Fig. 3 Exergetic performances evaluation table of the field collectors.

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