THERMAL CALCULATION METHOD OF COGENERATIONAL SOLAR CONVECTOR

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ABSTRACT

The purpose of this article is to describe simple method for fast evaluation of structural adjustments of pv. converters, mainly their influence on operating temperature of such converter. The article is splited into two parts. The own method is described in a first part and there is a short example of its application in second part. At the end is discussed the use and accuracy of the calculation.

1 INTRODUCTION

In today's society are visible efforts for more effective using of accessible energy sources and for increasing of efficiency of electric power generation. The reasons are in limited resources and increasing price of conventional (classical) sources of electric energy. Another reason is to reduce their bad influence on environment. The alternative (no-conventional) sources are possible solution. To these belong as well such types, which use sunlight incident on surface of the Earth in recent period (water, wind etc).

One of the possibilities is direct energy conversion of the solar radiation into electricity. We assume using of solar radiation in pv. converters with concentrators of this radiation to increase their utilization. This concept assumes forced cooling, while it leads to simultaneous production of electricity and low potential heat. On the mentioned collector system, witch produces electricity and low potential heat, can connect heat pump with a heat accumulator. The assumed heat system is suitable, for example, for air heating. It is possible to provide this electric energy to power network or accumulate it in suitable accumulator.

2 THERMAL BALANCE OF PV. AIR-COOLED GENERATOR

We will use so called thermal-resistant schemes for estimation of heat permeability and temperature difference between frontside and backside of the pv. generator composed of several layers [1][3]. These allow us to use procedures well known from circuit theory, when we calculating it. Following scheme describes general group of combined solar converters with front glass cover. The backside also has cover and conventional transfer of heat is provided by coolant. This medium flows between backside of the converter and the cover as in Fig. 1: The area of the absorber here is not fully covered by photovoltaic cells (pv. cell). Cover glass in the front also demands solar radiation permeability as high as possible. The area among absorber, photocell and glass is often filled by foil with corresponding optical characteristics. On the other hand area between cover and absorber is proper to use for heat transfer by coolant. The corresponding thermal resistant net, for calculation of heat flux, is visible on Fig. 2:. Each structural change on solar converter is corresponding with change in its resistance net.

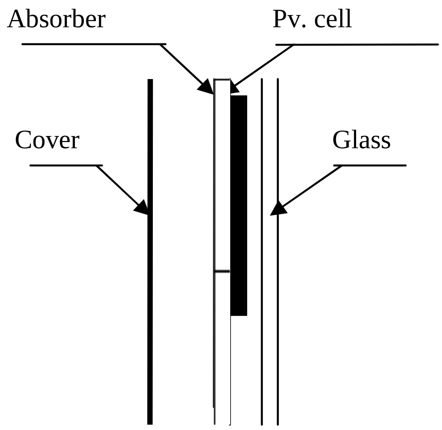

Fig. 1: *Basic profile of Solar Converter*

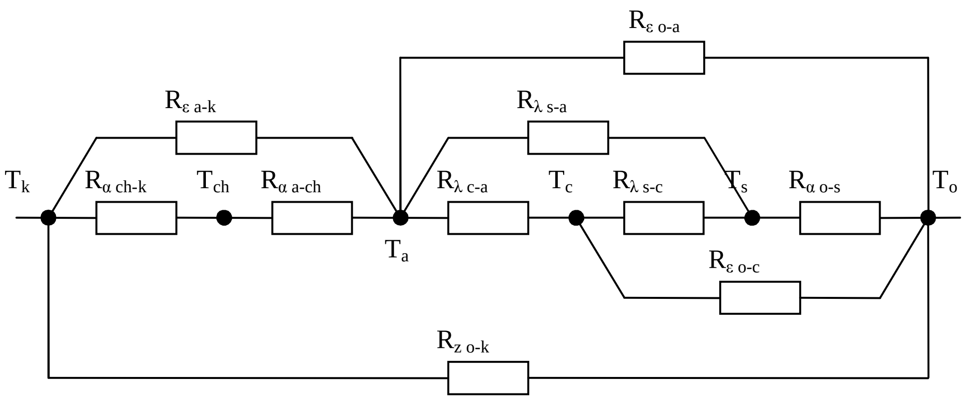

Fig. 2: *Basic thermal-resistance scheme (net) of Solar Converter.*

Where:
T – Temperature
R_λ – Thermal conductivity resistance
R_ε – Thermal radiation resistance
R_z – Radiation loss permeability resistance
R_α – Heat transfer resistance to surroundings

Lower indexes:
o – surrounding
s – glass,
c – pv. cell.
a – absorber
ch – coolant
k – cover

We will use this scheme, after modification, for calculation of total thermal balance in varying cases of solar converters. During calculation we will use following equations, which are derived from theoretical derivation and also from empirically set equations describing behavior of cooling media [2].

2.1 CALCULATION OF THERMAL RESISTANCE

The easiest task is to determine thermal resistance of solid particles with an area S_p and thickness δ. The coefficient of thermal conductivity λ is constant at temperature range at which solution appears. We will calculate thermal resistance according to following equation:

$$R_\lambda = \frac{\delta}{\lambda \cdot S_p}\ [K \cdot W^{-1}] \qquad (1)$$

The thermal resistance determination of heat transfer by convection among surface parts of the panel and exterior air or coolant is more complicated task.

$$R_\alpha = \frac{1}{\alpha \cdot S_p} \, [K \cdot W^{-1}] \tag{2}$$

The heat transfer coefficient α depends on temperature of surroundings or coolant. We estimate it from Nusselt Number, calculated from relations by using numbers of similarity [3]. In a case of forced cooling is the heat transfer coefficient for coolant influenced mainly by speed of coolant. The least favorable case of thermal resistance determination is heat removal by radiation, where thermal resistance strictly depends on surface temperature.

$$R_\varepsilon = \frac{1}{\varepsilon \cdot \sigma \cdot S_p \cdot \left(T_p^2 + T_o^2\right) \cdot \left(T_p + T_o\right)} [K \cdot W^{-1}] \tag{3}$$

For calculation of thermal resistances we have to determine very precisely initial conditions or use iteration calculation.

2.2 SOLUTION OF RESISTANCE SCHEME

For solution of resistance scheme we will use analogy to electrotechnics circuits [4] [5] [6]. For thermal fluxes entering the node applies:

$$\sum \dot{Q} = 0 \tag{4}$$

The system of equations emerging from equation (4) we can after adjustment rewrite to matrix shape:

$$\underline{G} \cdot \overline{T_x} = \overline{\dot{Q}} + \underline{G}_o \cdot \overline{T}_{ox} \tag{5}$$

G – The matrix of inner conduction bonds. Matrix G is symmetrical according to main diagonal. Members in a first diagonal are composed from summary of all members' conduction G_{xy} entering the node. Other members of the matrix are negatively taken conductivities among particular nodes (as in following calculations). Holds: $G_{xy} = 1/R_{xy}$

G_o - *The matrix of conductional bonds to surroundings*. The matrix G_o represents bond of resistance net to the surroundings. The members of the matrix gain the value only when the corresponding node of the matrix has direct bond to the surroundings. Other members of the matrix are zero value. The number of rows in the matrix is given by the number of the scheme nodes and number of the columns corresponding to different temperatures in surroundings.

T_x – *The vector of node temperatures*. The vector of the unknown variables, which we want to calculate. For the example from Fig. 2: These are temperatures: T_k, T_{ch}, T_a, T_c, T_s.

T_{ox} – *The vector of the surrounding temperatures*. The temperatures represent different temperature regions in surrounding environment. Each stands for average temperature T_{ox}.

Q – *The vector of energy entries*. Estimates volume of the energy from incident solar radiation, which enters the system at each node. For example from Fig. 2: we assume only entry of energy at the point where sun heat incidents upon pv. cell or absorber.

For the scheme from Fig. 2: is final system of the equations (5) composed according to following:

$$\begin{pmatrix} G_{ak}+G_{chk} & -G_{chk} & -G_{ak} & 0 & 0 \\ -G_{chk} & G_{chk}+G_{ach} & -G_{ach} & 0 & 0 \\ -G_{ak} & -G_{ach} & \begin{matrix} G_{ak}+G_{ach}+G_{ca}+ \\ +G_{sa}+G_{oa} \end{matrix} & -G_{ca} & -G_{sa} \\ 0 & 0 & -G_{ca} & G_{ca}+G_{sc}+G_{oc} & -G_{sc} \\ 0 & 0 & -G_{sa} & -G_{sc} & G_{sc}+G_{sa}+G_{os} \end{pmatrix} \cdot \begin{pmatrix} T_k \\ T_{ch} \\ T_a \\ T_c \\ T_s \end{pmatrix} = \begin{pmatrix} 0 \\ 0 \\ Q_{ina} \\ Q_{inc} \\ 0 \end{pmatrix} - \begin{pmatrix} 0 \\ 0 \\ -G_{oa} \\ -G_{oc} \\ -G_{os} \end{pmatrix} \cdot (T_o)$$

3 PRACTICAL EXAMPLE OF SOLAR CONVERTOR STRUCTURE AND ITS RESISTANCE SCHEME.

For simplicity of the example we will choose a pv. generator without additional constructional modifications, which is not forced-cooled (for ex. TGM750-12V). For the estimation of resistance scheme we will come out from basic scheme (Fig. 2:), which we will extend with thermal resistance corresponding to transfer of the heat from collector to the surroundings. Introduced version is only one from several structurally similar solutions, which is sufficiently representative (acc to Fig. 4:). Detailed and modified scheme of relevant resistance net is in picture Fig. 3:, where index f represents PVB foil, d (z) represents lower (back) side and h upper side (other indexes such as in Fig. 2:).

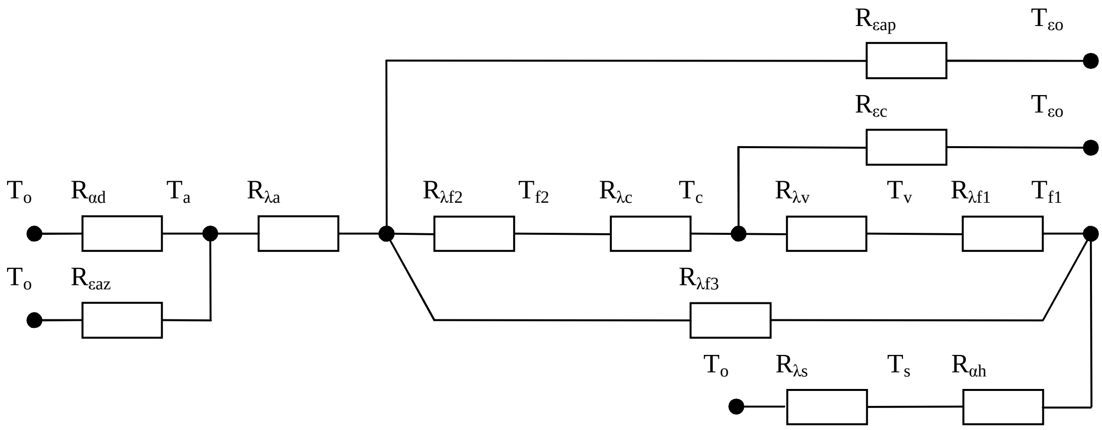

Fig. 3: *Detailed resistance scheme*

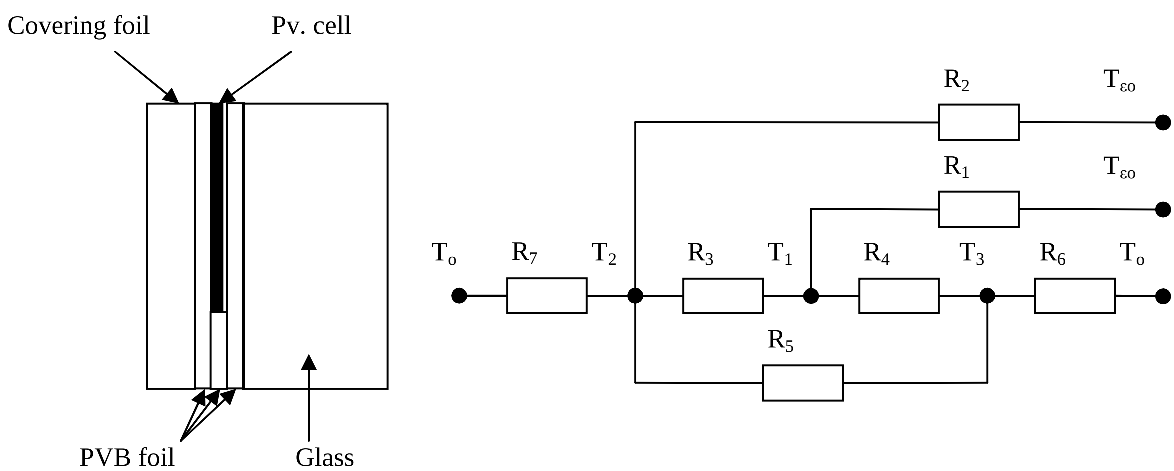

Fig. 4: *Section of panel and its simplified thermally-resistant scheme*

The resistance net corresponding to given structural version of pv. convertor. We can modify by method of progressive simplifying to configuration as in Fig. 4:.

Resistances R_1 a R_2 represents radiation from pv. converter, resistances R_6 a R_7 represents heat transfer by free convection, resistances R_3, R_4 a R_5 inner conductivity bonds and temperatures T_1, T_2, T_3 surface temperatures of panel (T_1, T_3) resp. the surface temperature of pv. cell (T_2). At the calculation of thermal scheme we assume all thermal resistances are given.

The only unknowns here are temperatures T_1, T_2, T_3. For their estimation by calculation we will compose system of equations that are based on resistance schemes according to equation (5). The outcome is system of three independent linear equations with three unknowns T_1, T_2, T_3:

$$\begin{pmatrix} G_1+G_3+G_4 & -G_3 & -G_4 \\ -G_3 & G_2+G_3+G_5+G_7 & -G_5 \\ -G_4 & -G_5 & G_4+G_5+G_6 \end{pmatrix} \cdot \begin{pmatrix} T_1 \\ T_2 \\ T_3 \end{pmatrix} = \begin{pmatrix} Q_{in1} \\ Q_{in2} \\ 0 \end{pmatrix} + \begin{pmatrix} G_1 & 0 \\ G_2 & G_7 \\ 0 & G_6 \end{pmatrix} \cdot \begin{pmatrix} T_{o\varepsilon} \\ T_o \end{pmatrix} \tag{6}$$

4 CONCLUSION

The presented procedure of calculation gives us information about the least convenient operational condition - the highest operational temperature, which can possibly occur. Nevertheless it is suitable for qualitative analysis of structural modifications, because these modifications directly influencing operational temperature of pv. converter. The difference between real measured and calculated temperature will be cause by significant factor – a move of surrounding atmosphere (wind, rising currents alongside the facade, etc), which is very variable and problematical for mathematical description.

REFERENCES

[1] Garg H. P., Adhikari R. S.: Performance analysis of a combined photovoltaic/thermal (PV/T) collector with integrated cpc troughs, CES IIT New Delhi, 2000

[2] Lienhard IV John H.: A heat transfer textbook, third edition, Cambridge (Mass.), Phlogiston Press 2005

[3] Hloušek J.: Termomechanika, FSI VUT Brno 2000, ISBN 80-214-1720-X

[4] Brančík L.: Elektrotechnika I, FEKT VUT Brno Elektronické texty

[5] Matuška T.: Stanovení účinnosi plochého solárního kolektoru, www.tzb-info.cz

[6] Čambala P., Gregor J.: Možnost vývoje kogeneračních měničů sluneční energie, Elektrotechnika a informatika 2003. ZUČ Plzni, 2003, s. 22 - 25, ISBN 80-7082-994-X

[7] Čambala P., Mastný P.: Power balance of photovoltaic generators. Sborník konference EEICT, Brno 2003, s. 20 – 24, ISBN 80-214-2379-X