THERMAL MODELLING AND COOLING SYSTEM DESIGN OF PV POWER CONVERTERS

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REZUMAT. Managementul termic şi determinarea frecvenţei de comutaţie maximă admisibilă sunt două probleme importante în funcţionarea invertoarelor panourilor folotoelectrice (PV). Lucrarea analizează modelarea termică a invertoarelor folosind modele analitice ale dispozivelor, dependente de temperatură. Fenomenul termic este studiat folosind circuite RC. Este analizată o metodă de răcire pasivă a invertoarelor. Eficienţa invertorului scade odată cu variaţia temperaturii. Temperatura de funcţionare în prezenţa lichidului de răcire permite reducerea scăderii eficienţei.

Cuvinte cheie: modelare convertor, model termic, PV, sistem de răcire

ABSTRACT. The thermal management and determination of maximum allowable switching frequency are two important challenges in operating PV converters. The paper deals with the thermal modelling of inverters based on temperature-dependent analytical device models. The thermal phenomenon is studied with equivalent RC circuits. A passive cooling solution for PV power converters is considered. The efficiency of the converter reduces with the temperature variation. The lower operating temperature reached by the liquid cooled inverter allows to strongly reduce the efficiency decrease.

Keywords: converter modelling, thermal model, PV, cooling system

1. INTRODUCTION

The thermal management of PV inverters operating in high environmental temperature conditions represents an important challenge. In order to guarantee an efficient operation of power electronic converters, a cooling process of the electronic devices is required [1].

The converters are also very susceptible to humidity and particles. Hence, the electronic devices are placed in external protection casings realizing a compromise between the heat dissipation and the necessity to block the entrance of particles, gas or water. The use of external protection casings is not always sufficient for the protection function and for the heat dissipation. In these cases, the electronic devices are placed in ventilated protection casings, with additional investments costs and internal energy consumptions. Placing the electronic devices in a ventilated environment leads to their oxidation, reducing in this way their lifetime and functionality [2].

2. THERMAL MODELLING OF THE PV INVERTER

The equivalent thermal circuit for PV inverters is elaborated. The PV three phase inverter is shown in Fig. 1. It is composed of 6 switches, driven by a three phase PWM signal, with an anti-parallel diode. The total power loss of the inverter is 6 times the power loss of each switch with anti-parallel diode. Different control strategies of the inverter influence the power losses of the converter [3].

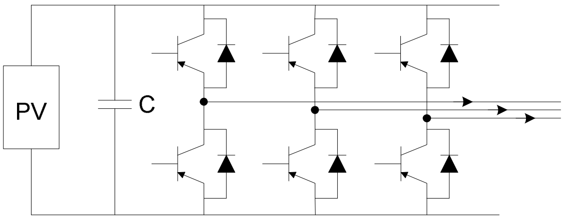

Fig. 1. Layout of a standard three phase PV inverter

The thermal modeling of each switch can be developed using RC parallel block elements. Fig. 2 presents the equivalent circuit of the thermal problem.

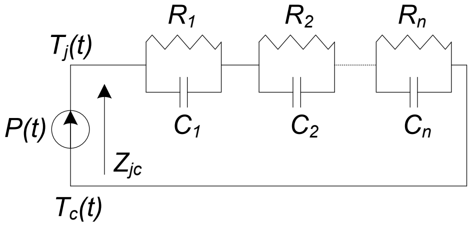

Fig. 2. Equivalent circuit of a junction-casing thermal problem

Based on Fig. 2, the impedance is given by:

$$Z_{jc}(s)=\frac{R_1}{1+s\cdot\tau_1}+\frac{R_2}{1+s\cdot\tau_2}+.....+\frac{R_n}{1+s\cdot\tau_n} \qquad (1)$$

where $\tau_i = R_i{\cdot}C_i$ and junction-case thermal resistance $R_{jc}=\sum_{i=1}^{n} R_i$. Using the equivalent system of Fig. 2, the thermal model of the inverter can be obtained (see Fig. 3).

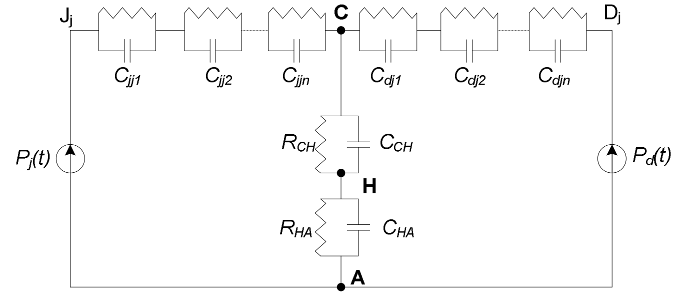

Fig. 3. Equivalent circuit of a junction-casing thermal problem

The variables $P_j(t)$ and $P_d(t)$ are the total power losses generated by the electronic switch and, respectively, by the diode. The switch and diode are considered placed on the same heatsink. The power losses are flowing to the case and afterwards through the heatsink to ambient. The resistance $R_{jcs}=\sum_{i=1}^{n} R_{jjc}$ is the junction-casing thermal resistance of swtich, and $R_{jcd}=\sum_{i=1}^{n} R_{jd}$ is the junction-casing thermal resistance of the diode. The resistance R_{ch} is the thermal resistance casing-heatsink, and R_{ha} is the thermal resistance heatsink-ambient.

The transfer functions of each element can be expressed as:

- switches junction to casing:

$$Z_{jjc}(s)=\frac{R_{jj1}}{1+s\cdot\tau_{jj1}}+\frac{R_{jj2}}{1+s\cdot\tau_{jj2}}+.....+\frac{R_{jjn}}{1+s\cdot\tau_{jjn}} \qquad (2)$$

- diodes junction to casing:

$$Z_{djc}(s)=\frac{R_{dj1}}{1+s\cdot\tau_{dj1}}+\frac{R_{dj2}}{1+s\cdot\tau_{dj2}}+.....+\frac{R_{djn}}{1+s\cdot\tau_{djn}} \qquad (3)$$

- casing to ambient:

$$Z_{ca}(s)=\frac{R_{CH}}{1+s\cdot\tau_{CH}}+\frac{R_{HA}}{1+s\cdot\tau_{HA}} \qquad (4)$$

Experimental verification of the models by comparing model simulations against laboratory tests need to be further conducted.

3. COOLING SOLUTION OF THE PV INVERTER

The cooling solution consists in submersing the converter in a refrigerating liquid i.e. the DOW CORNING 561 Silicon fluid, in a sealed casing.

In Fig. 4, the device (1) represents as a whole an electronic apparatus. This one is composed of an outer sealed casing (2) containing an electrically insulating and cooling liquid. The electrical circuit (3), composed of various electronic circuits (4) and electrically connecting elements (5), is directly submersed in the cooling liquid.

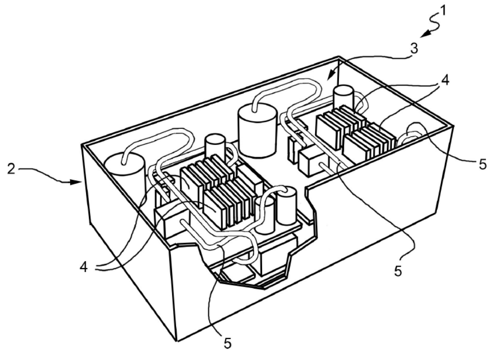

Fig. 4. Layout of the electronic apparatus

The refrigerating liquid is the polydimethyl silicone fluid [4], having the characteristics: thermal conductivity between 0.10 and 0.20 W/m·K.; liquid dissipation factor at 25°C and 50Hz between 0.00009 and 0.00015. The fluid fire point is higher than 350°C, and has a low heat power as compared to other class K insulating liquids.

The used refrigerating liquid is non-toxic and environmentally friendly. In addition, as the liquid is chemically homogenous, it can be subjected to very high temperatures without creating excessive vapor pressure or corrosive by-product. The refrigerating liquid is nonvolatile and does not evaporate to the atmosphere, thus contamination entry points are limited. The various components, submersed in the refrigerating liquid, are directly transferring their generated heat.

4. EXPERIMENTAL RESULTS

An experimental test is performed analyzing the operating temperatures of a converter in air and of a converter submersed into the refrigerating liquid. The analyzed converter is realized using SEMIKRON SKM100GB123D components.

The components are mounted on a single heat-sink and connected to realize an inverter (see Fig. 5). The inverter is placed in a metal sealed casing filled with refrigerating liquid.

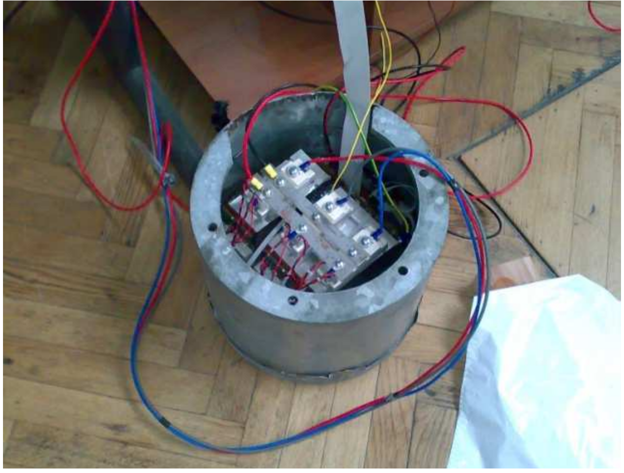

Fig. 5. Experimental setup of analyzed equipment submersed in refrigerating liquid.

A set of tests for measuring the inverter operating temperature are performed. The inverter, supplied with 300 Vdc, is feeding a load composed from a resistor of 6 Ω and an inductor of 5 mH. Thus, the load condition of the realized inverter with respect to the current is 10% with an optimum cooling system, and almost 50% for the proposed cooling system. Fig. 6 illustrates the setup laboratory prototype. The experiments are carried out for 1 hour. The load is supplied with an electrical current of 7.65A. The variations in time of measured temperature with respect to the 25ºC ambient temperature are illustrated in Fig. 7. As shown in Fig. 7, the presence of refrigerating liquid determines, at the end of investigation time, a temperature variation of 1/3 with respect to the condition without refrigerating liquid [5]. For analyzing converter's efficiency, the inverter input and output power are measured.

Fig. 6. Experimental setup of analyzed equipment submersed in refrigerating liquid.

The variations in time of converter's efficiency with/without the use of refrigerating liquid, for the two conducted experiments, are illustrated in Fig. 8. As shown in Fig. 8, the efficiency of the converter submersed in refrigerating liquid varies in time for about 1%.

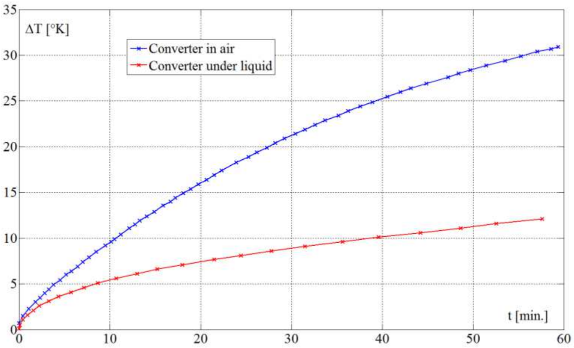

Fig. 7. Measured temperatures for converter in air and converter submersed in the refrigerating liquid.

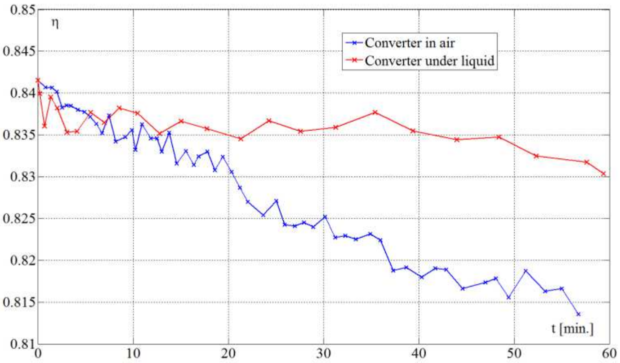

Fig. 8. Measured efficiency for converter in air and converter submersed in the refrigerating liquid.

The efficiency of the converter in air decreases during the investigation time for about 3%. This reduction is determined by the increase of converter's operating temperature. For a photovoltaic system, an efficiency increase of 2% is very important from energy point of view. In fact, the inverters for photovoltaic systems are operating at ambient temperatures exceeding 40ºC. In general, the maximum power production is achieved in case of maximum ambient temperatures.

5. CONCLUSIONS

In this paper, the elaboration of a thermal dynamic model of PV converter was conducted for counting their heating. A possible solution for facing the self-hetaing of the device is to use a refrigerating liquid by immersing the inverter within it. The temperature of converter in air is a third of the temperature of converter in air. Using the cooling liquid, the converter effcieiency remains almoust constant during the simulation period.

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