J. Automation & Systems Engineering 13-1 (2019): 11-17

Regular paper

Adding a cooling system to improve the efficiency of a static converter

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Abstract-A cause of the continuing increase in the power dissipated by components and electronic systems is always looking to improve the performance of static converters. The idea studied in this paper is the addition of a cooling system for semiconductor to improve performance of the converters. In the first part we present the principle of operation of a cooling system. Next, we describe the results of the simulation (with PSpice software) and compare them with those obtained without cooling system. Finally, we present the improvement obtained when adding a cooling system in a DC-DC converter.

Keywords: cooling system; power electronic; pspice.

1. INTRODUCTION

The growing power needs contribute to the growth of power electronics, also called electronic conversion of energy. Conversion devices used to control the transfer of electrical energy available within a particular kind of the same nature or of different nature, for use for example by electric actuators. These uses of the power switches based on semiconductors which modulate the input electrical signal by a succession of loops statements or block the transition from one state to another corresponding to the switching. These conversion devices, called power electronic converters for inverters must have a near 100% conversion efficiency. Therefore, it is necessary to minimize losses compared to the converted energy. The losses generated by the semiconductor must be extremely low regardless of their status, even during switching. The voltage and / or high frequency cutoff intensity is filtered or stored by passive dipoles and reagents, which must also have minimal losses [1]. The performance of power electronic converters depends on solving a number of problems on the components that constitute them. who must also have minimal losses [1]. The performance of power electronic converters depends on solving a number of problems on the components that constitute them. who must also have minimal losses [1]. The performance of power electronic converters depends on solving a number of problems on the components that constitute them.

2. COMPONENT COOLING

The energy dissipated due to the conduction and switching losses induces a heating of the components. The rise in the junction temperature can alter their operation or even destroy them. The dissipated energy must be extracted by means of cooling systems. Fig.1 shows the assembly structure of a power electronics component. The evacuation of the power emitted by the component is done through the different assembly layers. Each of these layers is associated with a thermal resistance Rthi which limits the power extracted. For the thermal equilibrium to be realized, the power extracted must be equal to the power dissipated by the component. The junction temperature of the component as a function of the various thermal resistances and the power dissipated by the component is written [2]:

$$T_j = \sum_{i=1}^{n} R_{thi}.P_{losses} + T_a \tag{1}$$

In this expression n and Ta respectively represent the number of layers constituting the overall system going from the component to the cooler and the temperature of the medium in which the latter is placed.

In the case of the system illustrated in fig.1, the overall heat resistance Rth j-a can be likened to the summation in series of three distinct thermal resistances, all quantifiable as a function of the layers that the heat flow passes through.

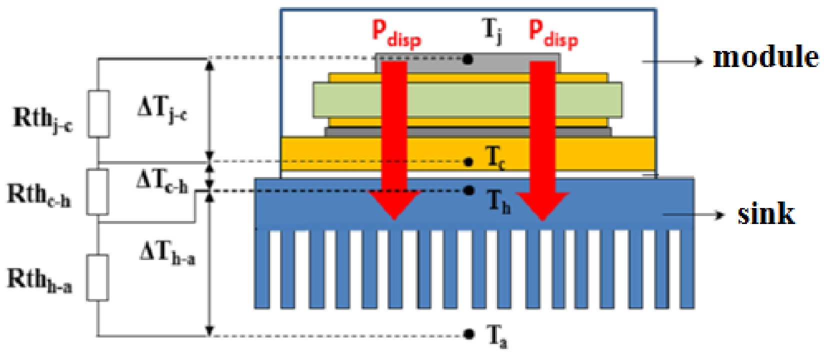

Fig.1. Assembly of a power component mounted on heatsinks and equivalent thermal model.

At first, we find the thermal resistance Rth, j-c (Junction to -case thermal resistance) of the power module, defined between the junction temperature Tj and that of the sole Tc. Note that Tj is a mean temperature unlike that of the sole which is a localized temperature, taken directly above the semiconductor (in or on the surface of the sole). This thermal resistance is indicated by the semiconductor manufacturers in the datasheets of the components. Then comes the thermal resistance between the sole and the cooler, denoted Rth, c-h (case-to-heatsink thermal resistance). This is actually the thermal resistance of the interface material used for the improvement of heat transfer between these two regions. The latter is defined between the base temperature of the module and that of the cooler Th. if the value of this resistance comes mainly from the interface material used, it depends strongly on the mounting conditions that affect the parameter "thermal contact resistance" of the thermal resistance. Finally, the last thermal resistance, denoted Rth, h-a (heatsink to ambient thermal resistance), corresponds to that located between the dissipator and the ambient air temperature Ta. Just like that of the power module, its value is also provided by the manufacturer. However, its value may vary over time with the fouling of fins (air sink) or hydraulic lines (water box).

3. CHILLER SIMULATION

In this part, we present the modeling of the cooler using the Pspice software specialized in the simulation of electronic systems. We simulate the case where the flow density is uniform at the surface of the cooler. We also neglect the heat exchanges taking place at the cooler's outlets. We can then simulate the chiller by studying only one channel. By symmetry, we model only one half-channel of the cooler and apply a uniform heat source over the entire upper surface (Fig.1).

In order to improve the switching of the studied module, the overvoltage's due to these parasitic elements and the switching losses must be minimized. These depend on many factors; the junction temperature (Tj) and the duty cycle. In this part, we will study the influence of these parameters on switching overvoltages and losses of the chopper used as a case study.

▪**Losses by switching**

For switching losses, the transition phases corresponding to the opening and closing of the component cannot be approached in the same way.

Indeed, the use of different combinations of loss calculation approximation models, and approximations in the parameter identification lead us to large errors in the prediction of power losses. This can have an impact important for the choice of converter components and the design goals approach for energy efficiency and reliability [2,4].

The switching losses are due to the initiation and blocking phase, because the current, as well as the voltage, must vary over a wide range, to reach the quantities imposed by the sources between which the converter is inserted. They are written in a general way:

$$E_{on} = \int_0^{ton} V_{ceon} \times I_{ceon} dt \tag{2}$$

$$E_{off} = \int_0^{toff} V_{ceoff} \times I_{ceoff} dt \tag{3}$$

Relationships (2) and (3) clearly show that switching losses are the product of the voltage across the transistor and the current flowing through it. In these relations, E_{off} and E_{on} are the switching losses, respectively at closing and opening. These switching losses, as well as the closing and opening times to which they are linked, depend closely on the control and load conditions and thermal cycles induced by the losses and the environment.We performed various simulations by varying the power imposed on the surface. The main purpose of these simulations is to compare the results with other results without a cooling system in order to validate the modeling. Figure 3 shows the evolution of losses in IGBT as a function of temperature without and with the cooling system.

It is clearly observed on these two graphs that adding the cooling system the losses in the semiconductor decreases. Our modeling is therefore valid. We will reuse it in the next part with a chopper.

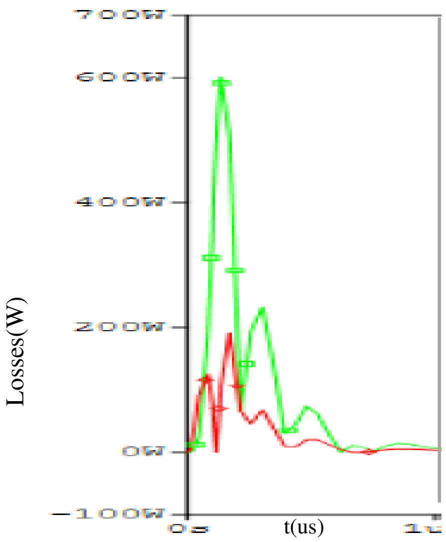

Fig.2. Losses in components without and with the cooling system

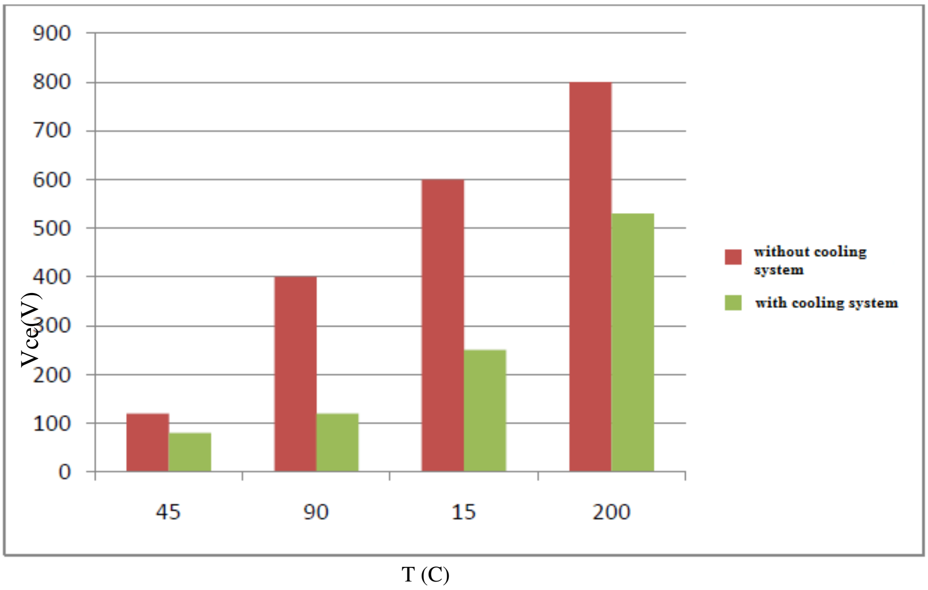

Fig.3. Losses as a function of temperature without and with the cooling system

4. DESCRIPTION OF THE BOOST CONVERTER

The BOOST converter (Fig.4) produces an output voltage greater than the input voltage. During phase 1, the PWM signal is in the high state from 0 to αT, (α: duty cycle), the power switch T closes, which leads to a linear increase of the current in the inductance L. During this phase, the energy is stored in the inductor and the voltage across the latter is equal to the input voltage Ve. During phase 2, the PWM signal is in the low state from αT to T, the power switch is open and the energy stored in the inductance is transferred to the load and the output capacitor Cs by conduction spontaneous mode of the diode D. In continuous conduction mode (the current never canceling in the inductance), it can be shown that the ratio between the output voltage and the voltage depends only on the duty cycle:

$$\frac{Vs}{Ve} = \frac{1}{1-\alpha} \tag{4}$$

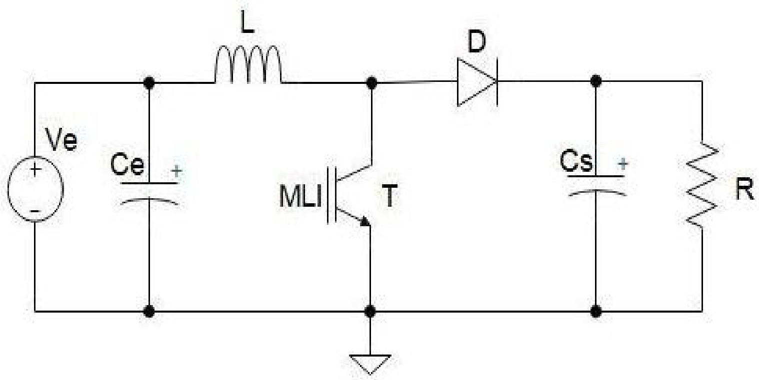

Fig.4. Diagram of the BOOST converter

The losses obviously affect the efficiency, they are at the origin of the heating of the semiconductor components and thus the static converters. The determination of the operating limit from the power point of view (allowable losses compared to the transited powers) is a major concern of the designers of static converters. The objective of this work is to establish a cooling system to minimize losses in static converters.

This model must be valid for all operating points. The results of the latter will be compared to those of another model without a cooling system.

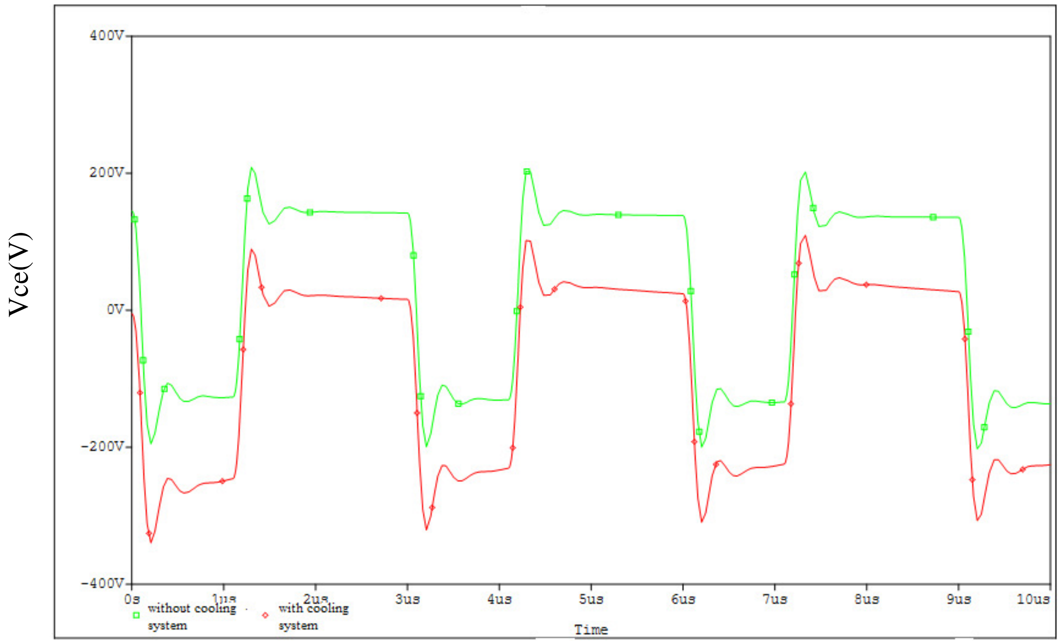

Fig. 5. IGBT voltage without and with the cooling system

- **Performance calculation**

The efficiency calculation is very important in power electronics because the losses are easily high when carrying large amounts of energy. We distinguish conduction losses and switching losses.

The conduction losses come from the fact that transistors and diodes dissipate a certain power when a current passes through them.

$$P_{cond} = (V_{on} \times \alpha + U_j(1-\alpha))I_{moy} \tag{5}$$

The switching losses are related to the change of state of the switches. In general, the manufacturer's data specifies the energy dissipated during forced switching under certain current and voltage conditions. They can be adapted to a specific use by simple proportionality rules: if the gate resistance (slower switching) doubles, or if the average current doubles, or if the voltage doubles, the losses double. The losses are finally calculated taking into account the number of commutations per second.

$$P_{com} = (E_{on} + E_{off}) f_c \tag{6}$$

Due to losses in the circuit, the power available at the output of the converter Pout is lower than the power drawn at the input source Pin. The output η of a converter is then given by:

$$\eta = \frac{P_{out}}{P_{in}} = \frac{P_{in} - (P_{cond} + P_{com})}{P_{in}} \tag{7}$$

To validate our cooling system we calculated the efficiency of the chopper described in Fig. 6 with and without a cooling system.

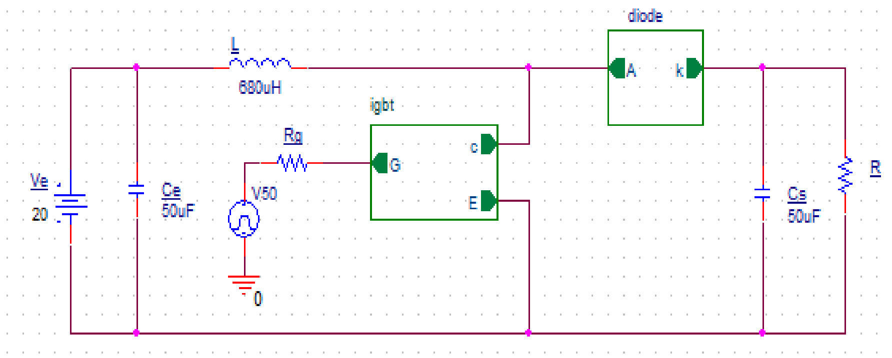

Fig.6. Simulated circuit using Pspice software

Modeling based on physical characteristics of the electrical and thermal behavior of the component [5,6] enables us to faithfully reproduce the instantaneous evolution of the electrical characteristics of the components. We will proceed to the calculation of the losses by simulation under Pspice environment taking into account the losses caused by the commutation in the diode and the IGBT.

From the curves of the currents and voltages of the IGBT and the diode that we evaluate, we have calculated the efficiency. The result shows the advantage of adding a cooling system.

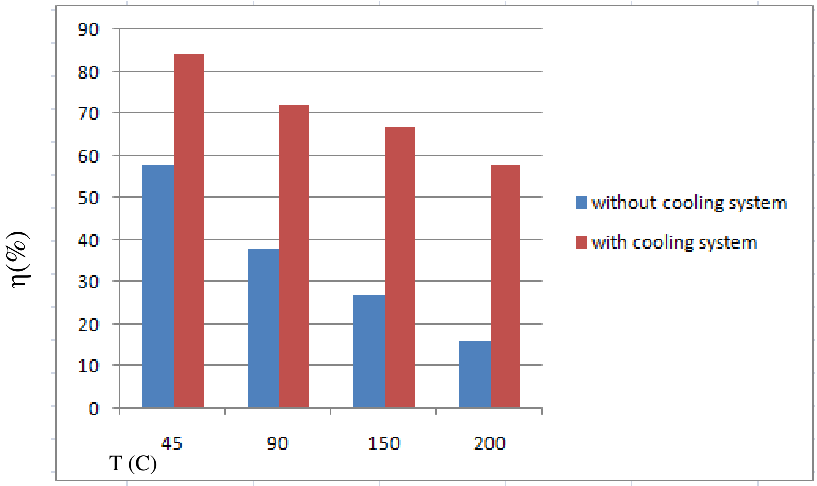

Fig.7. Efficiency of a static converter as a function of temperature without and with the cooling system

5. CONCLUSION

In this article, we wanted to present the study of a power electronic component system. For this, we have presented at the beginning a description of the cooling system. Then, we presented our cooling loop and the results that were compared to simulations without a cooling system performed with the Pspice software. In the last part, we presented the study of a chopper cooling and we could demonstrate the interest in the use of a cooling system to improve the performance of the chopper.

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