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LOSSES COMPARISON FOR INVERTERS WITH Si AND SiC DEVICES FROM PUMPED STORAGE SYSTEMS

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Abstract: *The pumped storage is a well-established technology, capable of enhancing the integration of renewable energy sources. The power electronics block is a key component of the pumped storage systems (PSS). It enables the control, and interfaces the PSS with the energy source. The technological progress in manufacturing power devices has led to the development of new devices based on wide band gap materials, such as silicon carbide (SiC). A comparison of the losses on the inverter that controls the PSS is realized in this paper, considering the new SiC and the classic silicon (Si) technology for the power devices in the inverter's structure. The Simulation platform for Power Electronics Systems (Plecs) is used.*

Key words: *pumped storage, power losses, SiC power devices.*

1. Introduction

Pumped storage is one of the most widespread energy storage technologies. The Electric Power Research Institute (EPRI) reports that 127 GW of the bulk energy storage is accomplished by pumped storage [8].

Not only that pumped storage presents important advantages over other storage methods, such as high capacity, high efficiency, fast time response, but it also facilitates the integration of renewable energy sources [3], [6].

The photovoltaic sector experienced a strong growth of the installed power in the last years. In 2014, at least 40 GWp of PV systems were installed globally [11], while for the wind energy, the Global Wind Energy Council (GWEC) market statistics released in 2013 states that the wind energy has reached a cumulative global capacity of 318 GW, with an increase of nearly 200 GW in the last five years [9].

2. Objective of the Paper

An important aspect of the PSS for renewable energy sources is related to the efficiency, due to the losses that appear because of a long energetic chain.

The key component of the system is the power electronics block because it interfaces the PSS with the energy source (renewables or not).

An important technological progress in manufacturing power devices based on wide band gap materials, such as silicon carbide (SiC), took place in the latest years. This has led to significant improvement of the operating-voltage range for unipolar devices and of the switching speed and/or

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specific on resistance compared with silicon power devices. These devices can provide significant improvement of power density and efficiency in power converters [4], [5].

In this paper a comparison of the losses of the inverter which controls the motor pump group is realized considering different power devices, namely the Si and SiC transistors. The Simulation platform for Power Electronics Systems (Plecs) is used.

3. Description of the System

The PSS is consisted of one or more motor-pump groups. The control is implemented by means of the VSI (Voltage Source Inverter), which is part of the VSC (Voltage Source Converter) together with a rectifier. This facilitates also the variable speed operation of the system, which leads to improved performance. The block scheme of the system is presented in Figure 1, in which the VSC, the induction motor (IM) which drives the pump, and the pump can be seen.

The inverter efficiency is analysed considering two different types of power devices (Si and SiC) for a system of 15 kW.

The main parameters of the analysed devices are presented in Table 1 [7], [10]. The same modulation technique was used in both cases, namely SVM (Space Vector Modulation).

The motor that drives the pump has a big impact on the system's efficiency. The motor's efficiency is influenced by the loading torque, which for pumped storage applications is dependent on the square of the speed. This means that the torque is lighter for lower speeds operation compared to the nominal case. The pump's power is dependent on the third power of the speed [12]. This leads to the fact that the motor at lower speeds absorbs lower currents. The authors analysed this issue in [2]. The losses of the inverter are dependent on the instantaneous current absorbed by the motor.

The loading torque of the motor that drives the pump is presented in Figure 2. This was implemented according to the centrifugal pump's torque [12].

The parameters of the motor fed by the voltage source converter (VSI) are given in Table 2.

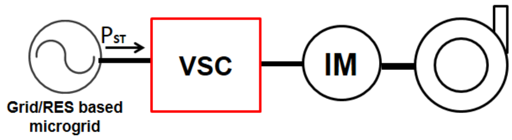

Fig. 1. *Pumped storage system*

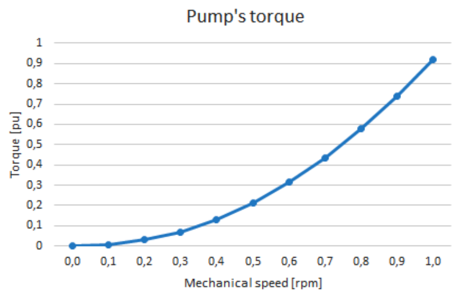

Fig. 2. *The induction motor's load torque in pumped storage systems*

Table 1

Semiconductor devices parameters

Parameter	Si	SiC
V_{CEN}/I_C	1200V/75 A	1200V/120 A
$V_{threshold}$	5.2 V	2.6 V
E_{on}	9.5 mJ	1.7 mJ
E_{off}	6.5 mJ	0.4 mJ

Induction motor parameters Table 2

Parameter	Value
Nominal power	15 kW
Nominal voltage	400 V
Nominal current	28 A
Mechanical speed	1460 rpm
Frequency	50 Hz
Power factor	0.8
No of pole pairs	2

The mathematical model of the losses on the VSI is presented in the next section of the paper.

4. Losses Mathematical Model of the VSI Inverter

The main losses of the inverter are the conduction losses and switching losses:

$$P_t = P_{cond,inv} + P_{sw,inv}, \qquad (1)$$

where:
P_t - total losses,
$P_{cond,inv}$ - conduction losses,
$P_{sw,inv}$ - switching losses.

4.1. Conduction Losses

Conduction losses of each active device (transistor or diode) depend on the on-state voltage $v_{ON}(t)$ and on the instantaneous current $i(t)$ passing through it. The device on-state voltage can be modeled using a first-order linear approximation comprised of a threshold voltage and a series resistance r_T as follows:

$$v_{ON}(t) = v_{T0} + r_T \cdot i(t). \qquad (2)$$

The conduction losses in a transistor or diode can be expressed as:

$$P_{cond} = \frac{1}{T}\int_0^T v_{ON}(t) i(t)\,\mathrm{d}t, \qquad (3)$$

where T is the fundamental period of the inverter.

4.2. Switching Losses

Power semiconductor switching losses are determined by the total commutation time the device is turned on or off, and by the voltage $v(t)$ and current $i(t)$ across the device during this process. The energy dissipated during commutation is E_{on} and E_{off} for turn-on and turn-off, respectively. The device manufacturers on their datasheet provide these.

The average switching power losses P_{sw} over a complete fundamental period T may be determined by summing all the commutations of the device during the respective interval of time. If f_s is the switching frequency of the device, there will be $m_f = f_s/f$ commutations during one fundamental period, it results:

$$P_{sw} = \frac{1}{T} \cdot \sum_{k=1}^{m_f} [E_{on}(k) + E_{off}(k)], \qquad (4)$$

where $E_{on/off}(k)$ is the energy lost during commutation at instant k.

It is well known [1] that the total inverter losses can be expressed as six times the total losses of a transistor and respectively its freewheeling diode, computed for one-half wave:

$$\begin{aligned} P_{t,2inv} &= 6(P_{cond,T} + P_{cond,D} + P_{sw,T} + P_{sw,D}) \\ &= 6(P_{cond,T} + P_{cond,D} + P_{sw,T+D}), \end{aligned} \qquad (5)$$

where:
$P_{cond,T}, P_{cond,D}$ - conduction losses of one transistor, respectively diode during one fundamental frequency;
$P_{sw,T}, P_{sw,D}$ - switching losses of one transistor, respectively diode during one fundamental frequency.

5. System Simulation and Results

The block scheme of the system realized in the Simulation platform for Power Electronics Systems (Plecs) is presented in Figure 3. The inverter together with the motor for driving the pump can be seen.

The thermal library of the Plecs was used to analyse the losses of one transistor and a diode.

The results are presented in accordance with the reference frequency of the inverter. The frequency range of 30-50 Hz has been considered because this is the most efficient operation zone of induction motors for pump's driving [2].

In Figure 4 the switching losses for Si and SiC devices are presented. It can be seen that for the new technology (SiC), the losses are situated between 0.02 W and 1.7 W, while in the case of the Si devices, the losses are situated between 2.8 W to 13 W.

The conduction losses are represented in Figure 5. For the SiC devices, the conduction losses are around 3 W, while using Si devices for the inverters structure, the losses are from 11 W to 11.7 W for the considered frequency range.

By summing the losses, for the SiC technology the total losses are around 3 W for the whole frequency range, while for a Si device, the losses are situated between 14.9 W in the case of 30 Hz, and 28 W, for the 50 Hz operation (Figure 6).

The inverter total losses are calculated according to Equation (5). The losses on the diodes are also taken into account. The inverter's total losses for the considered range of the frequency are represented in Figure 7. It can be seen that in the case of nominal operation of the system (50 Hz of the reference frequency), the losses are equal to 230 W for Si device, and to 90 W for SiC device. In the case of the system operation at 30 Hz, the losses for Si device are 140 W, while for the SiC device, 65 W. As it was expected, the losses that occur at lower frequencies, respectively lower speeds, are lower than the ones at nominal frequency operation. This happens because of the fact that the currents absorbed by the motor at lower speeds are lower than the ones absorbed at nominal operation.

The inverter's efficiency is equal to 98.2% for the operation 30 Hz reference frequency, and 97.68% for nominal operation (50 Hz) if Si devices are considered for the inverter's structure. In the case of the new technology, SiC, the efficiency is situated between 98.74% and 98.62%. The losses on the filter have been taken into account for determining the inverter's total efficiency (Figure 8).

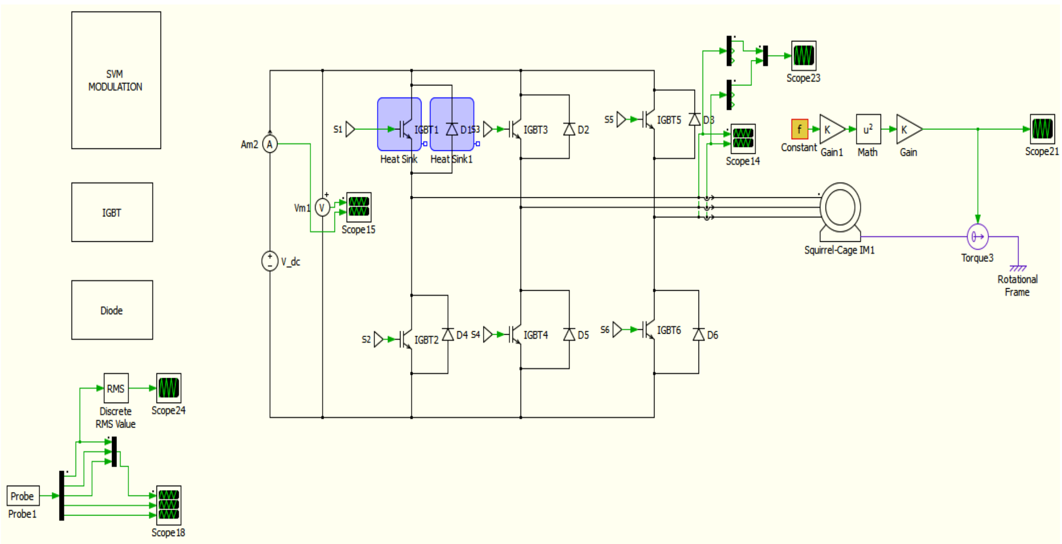

Fig. 3. *The block scheme of the system realized in the Simulation platform for Power Electronics Systems* (*Plecs*)

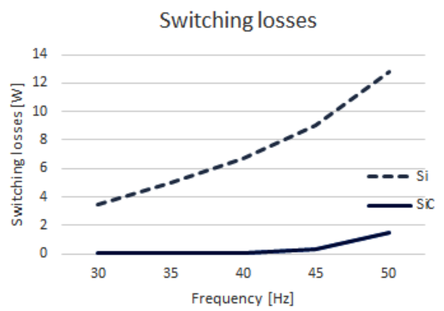

Fig. 4. *The switching losses on Si and SiC devices*

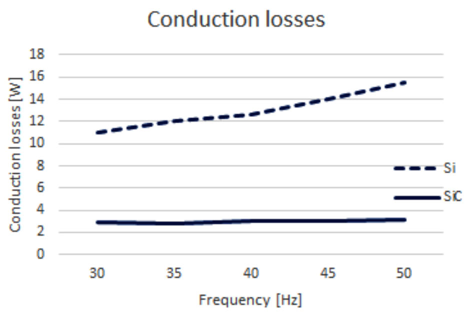

Fig. 5. *The conduction losses on the Si and SiC devices*

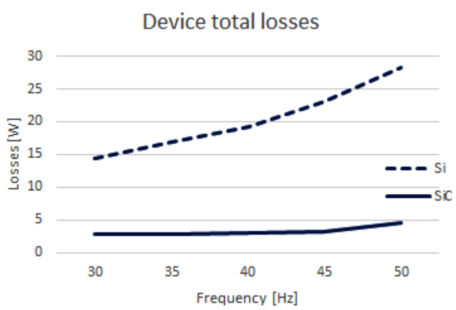

Fig. 6. *The total losses on Si and SiC devices*

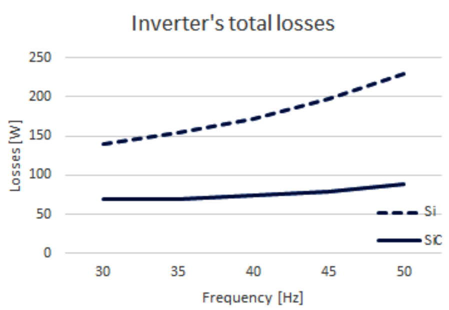

Fig. 7. *The inverter's total losses*

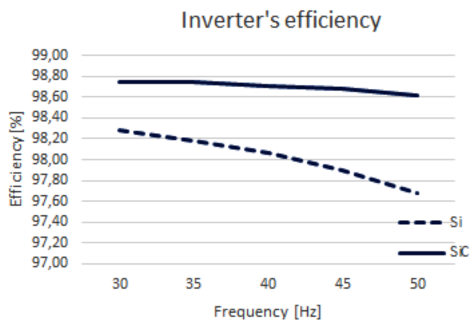

Fig. 8. *The inverter's efficiency*

6. Conclusions

The technological progress from the latest years in the power electronics field has led to the development of new devices based on wide band gap materials, such as silicon carbide.

These devices can be part of the structure of the inverters, which have an important role in PSS because they assure the system's control and the interface with the energy source.

This paper presents a comparison of the losses on the inverters from the structure of the PSS. If the new technology (SiC) is implemented, the inverters total losses are lower (90 W), compared to the case in which Si devices are part of the inverters structure (230 W). This is the case of nominal speed operation.

Moreover, the losses at lower operation speeds are lower compared to the nominal speed operation. The reason for this is the fact that the currents absorbed by the motor are lower at lower speeds, due to the pump's torque characteristic.

Acknowledgements

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