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Pre-sizing methodology of embedded static converters using a virtual prototyping tool based on an optimisation under constraints method: comparison of two power-sharing topologies

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Abstract: This study deals with pre-sizing methodology of embedded static converters using optimisation for which high performances of weight, volume and efficiency are required. Moreover, in the automotive and aircraft domains, power-sharing architectures should be an other investigation path to reach such performances. The idea of power sharing is suitable and judicious if the actuators are in the same power range. In this study, the authors consider three electrical machines sequentially driven. The first solution is to use three independent inverters without power sharing, the second one is an inverter with a power-sharing system. A non-conventional DC–AC matrix converter is proposed to replace classical inverters. So as to overcome a priori power designers habits, a general modelling and optimisation is performed to provide a virtual prototyping tool to avoid physical prototyping because of their exhaustive cost. The objective function is the overall volume (mainly the heatsink's volume). The optimisation results are presented and discussed. These preliminary results, under a three-AC drive assumption, show clearly that {inverter + power sharing system} and even the DC–AC matrix converter have an overall volume lower than the three-inverter solution.

1 Introduction

A major problem in the embedded applications is the mass as a key issue because of the impact on the energy consumption. Moreover in internal combustion engine (ICE) drive, the emission of pollutants is a major drawback. Even in electric vehicle (EV), the energy management system aim is to optimise the energy contained in the batteries or fuel cells to enhance their lifetime and to increase the autonomy therefore reducing the charging time from the utility grid where the energy is produced from nuclear or thermal power plants.

Electrical energy management is becoming important in many systems: aircraft, automotive or household appliances have seen their numbers of electromechanical converter increase. The multiplication of embedded electrical systems [1] increases the number of needed power converters. For electrical systems that are sequentially used, power converters could be mutualised. The reduction of power converters number would reduce weight, volume and dimensions of the whole system. The efficiency of the overall system is therefore increased. This structure supplied several machines simultaneously (SMM) and non-sequential manner [2]. The originality of the present paper is the use of an optimisation approach to compare two converter's topologies in order to select the most suitable architecture

allowing to respect specifications [3–8] and reaches an actual objective that is to provide virtual prototyping tools especially for power converters [9–12] to avoid physical prototypes as much as possible.

In fact, the authors propose a description of the embedded drives in transportation and the requirements concerning the reduction of mass and volume to reduce energy consumption, pollutant emissions and overall cost. The idea of power sharing is suitable and judicious if the actuators are in the same power range. In this paper, we consider three electrical machines sequentially driven. The first solution is to use three inverters: Fig. 1. The second one is to use an inverter and a power-sharing architecture as described in Fig. 2a. Besides the immediate reduction of mass, care should be taken to ensure the availability and reliability of all the operating points [13]. Therefore a DC–AC matrix converter has been proposed as a third solution (Fig. 2b).

The final objective would be a general optimisation tool that gives an optimal solution considering general requirements for power-sharing applications. It would be divided into two steps: Fig. 3. The first one, general and industrial specifications are presented and lead to the best structure: {inverter + current-sharing system}, DC–AC matrix converter or others. The second one, the output of the first step is optimised considering three-dimensional

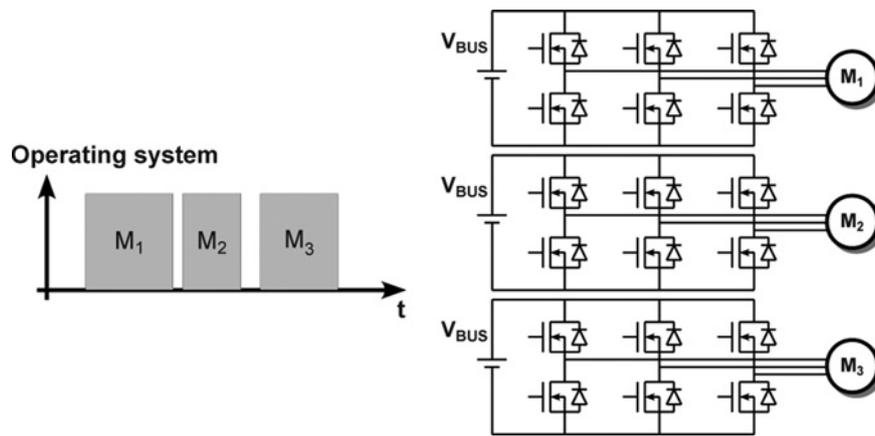


Fig. 1 Conventional converter architecture in the case of three sequential AC drives

a Inverter and power-sharing system
b DC–AC matrix converter

(3D) constraints. The semiconductor routings and heatsink dimensions are optimised [14] coupling finite elements simulations (thermal and electromagnetism) to a circuit-type simulator. Then, leakage inductances and thermal phenomenon are modelled.

In this paper, authors focus on the first step to give a pre-sizing approach based on a virtual prototyping tool and classical modelling based on manufacturers' datasheets. To do that a three identical motors of 3 kW maximal power each are considered. A DC link provides an electrical energy of voltage V_{bus} .

This paper is organised as follows. In Section 2, matrix and inverter converters are presented to perform power sharing AC drive systems. In Section 3, modellings of the DC–AC matrix converter, the inverter and the power-sharing system are proposed to carry out the optimisation approach. In this context, operating and semiconductor, electrothermal modellings are performed. A power switch modelling is introduced so as to provide a generic approach to optimise the considered converters. Then, the optimisation method is presented in Section 4. Finally, the main optimisation results allowing us to compare the inverter and the DC–AC matrix converters are given and discussed.

2 Power-sharing converter architectures

The converter topology provides a sequentially operating with the objective of having, at least, an overall volume or weight less than three independent power converters.

The authors have chosen to focus the study on three solutions:

- Non-mutualised inverters;
- Mutualised inverter with a sharing current system with semiconductor devices;
- DC–AC matrix converter.

2.1 Three inverters without power sharing

Fig. 1 shows a three-inverter without current-sharing system. It is obviously the first topology that can be proposed. Even if a non-sequential functioning is possible, this solution is considered as a reference to be compared with the following solutions: {inverter + power-sharing system} and DC–AC matrix converter.

2.2 Inverter with a power-sharing system

Fig. 2*a* proposes a single inverter and a sharing current system solution. It directly ensues from the first solution. The power-sharing system is based on semiconductor devices. It could be an electromechanical but this issue is not considered by the authors.

2.3 Matrix converters

The proposed DC–AC matrix converter solution for a three-motor application is presented in Fig. 2*b*. Matrix converters are mostly known for AC–AC converters [15–19] and recent advances and new topologies have been proposed [20].

In our case, a DC–AC matrix has been analysed in a reliability point of view [13] in the case of AC drive faults. The conclusion has shown that this architecture is the most convenient because currents faults are less important than those of inverter and power-sharing system. In the present paper, a comparison between these architectures will be done from the point of view of volume optimisation under the electrothermal constraints.

2.4 Comparison between topologies

The advantage of the classical three inverters without power sharing is that the power converters can be installed close to the electrical machines. However, the power-sharing system could provide a volume decrease as it will be shown in this paper for a three-motors application (3 kW). In a general point of view, a conclusion cannot be provided because it depends on many assumptions: bus voltage, electrical machine power, ambient temperature, etc. According to the matrix converters, the mutualisation is not provided but it is shown in this paper that the overall volume is better than the three-inverter solution. Then, even if switching mechanisms are complex and even if specific gate drivers are necessary, this 'new' topology is considered here.

3 Converters modelling

In this section, the modelling of the proposed converters is described. The following assumptions must be considered first. Losses calculations are computed with steady-state equations of the electrical machines. The modelling are

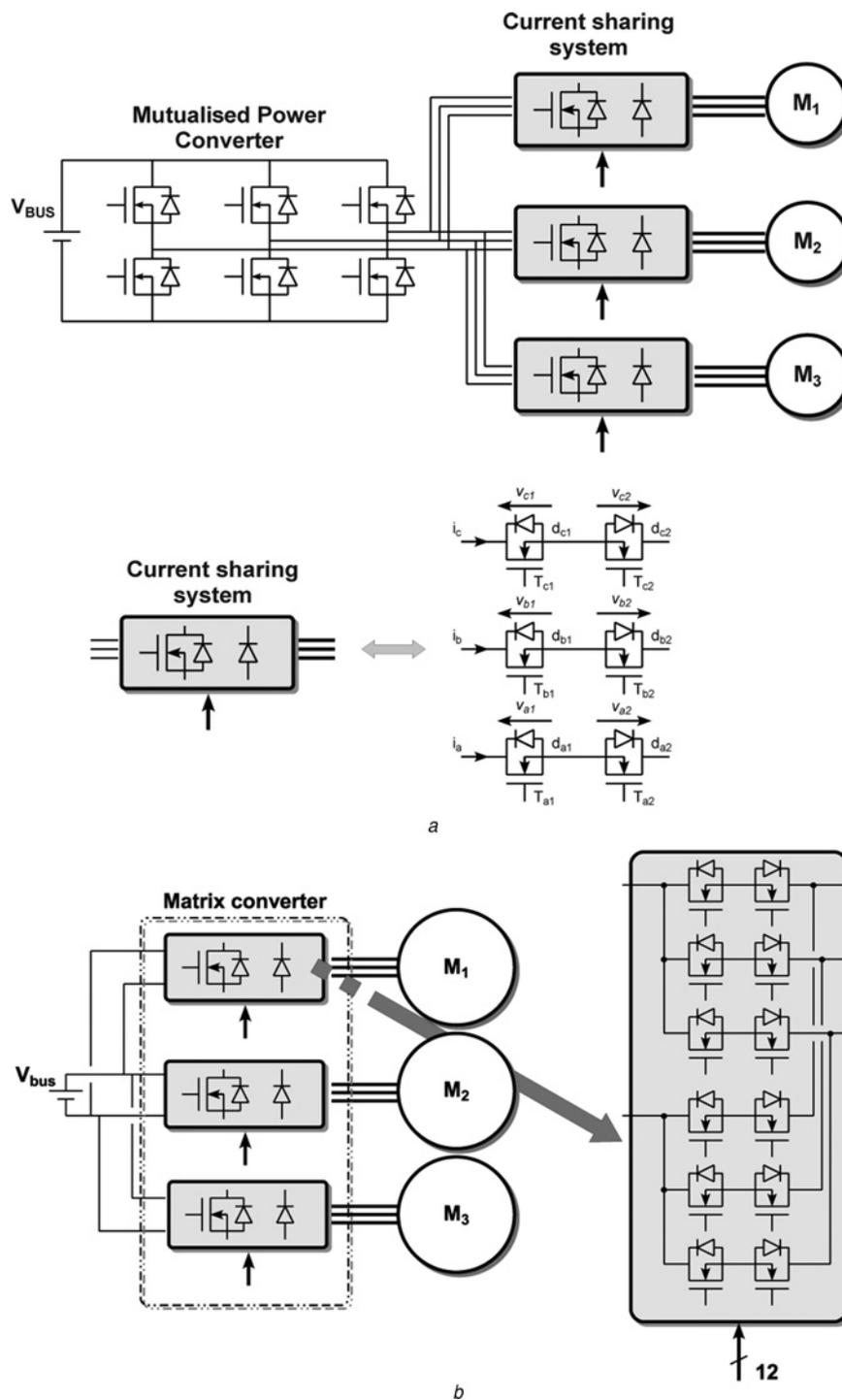


Fig. 2 Inverter and DC-AC matrix converters for power-sharing applications case of three sequential AC drivers
 a Inverter and power-sharing system
 b DC-AC matrix converter

based on classical equations and manufacturers' datasheets. Then, the maximal electrical power, the phase between current and voltage of motor lines are considered and supposed to be constant.

3.1 Inverter modelling

The inverter topology is given in Fig. 2a. Consider six power switches and their corresponding currents and voltages: $\{i_k\}_{1 \leq k \leq 6}$ and $\{v_k\}_{1 \leq k \leq 6}$. The motor currents are supposed to be sine waves, which define a balanced

three-phase load

$$i_a(t) = I_0 \sin(\omega t - \varphi) \quad (1)$$

$$i_b(t) = I_0 \sin(\omega t - \varphi - 2\pi/3) \quad (2)$$

$$i_c(t) = I_0 \sin(\omega t - \varphi + 2\pi/3) \quad (3)$$

φ is the angle between current i_a and the fundamental of v_{aN} . I_0 is the maximal value of $\{i_a, i_b, i_c\}$. V_{bus} is the DC-link voltage. Considering the assumptions, losses calculations

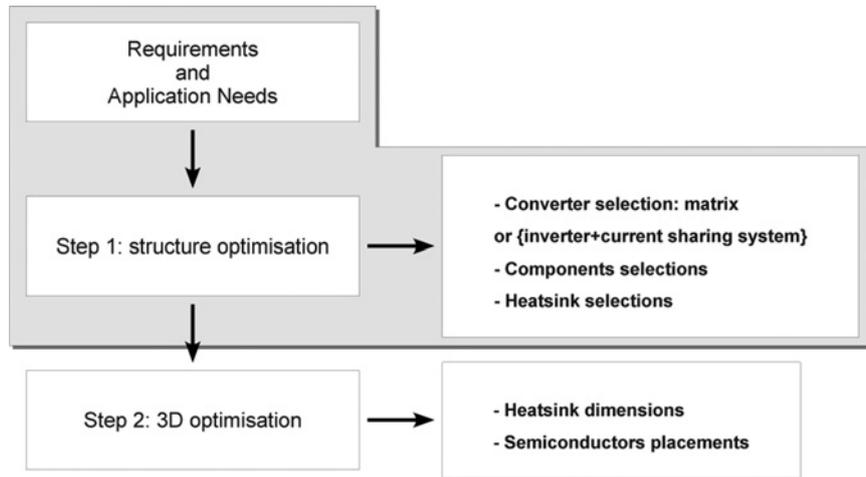


Fig. 3 Definition of a two-step optimisation process of the virtual prototyping tool

are given by [21, 22] as follows

$$P_{\text{cond}} = \frac{1}{2} \left(V_0 \frac{I_0}{\pi} + \frac{r}{4} I_0^2 \right) + m \cos \varphi \left(V_0 \frac{I_0}{8} + \frac{r}{3\pi} I_0^2 \right) \quad (4)$$

$$P_{\text{sw}} = \frac{f_{\text{sw}}}{\pi} (E_{\text{on}}(I_{\text{nom}}, V_{\text{nom}}) + E_{\text{off}}(I_{\text{nom}}, V_{\text{nom}})) \frac{I_0}{I_{\text{nom}}} \frac{V_{\text{bus}}}{V_{\text{nom}}} \quad (5)$$

$$P_{\text{T}} = P_{\text{cond}} + P_{\text{sw}} \quad (6)$$

P_{cond} is the forward conduction losses, P_{sw} the switching losses and P_{T} the total losses for one power switch. r and V_0 are the forward resistance and the forward voltage of the switch (if a MOSFET is considered, $V_0=0$). Therefore MOSFETs and IGBTs are modelled with the same equation that provides a generic approach. m is the PWM modulation index. f_{sw} is the switching frequency, E_{on} and E_{off} are the turn-on and turn-off energies of the switch, I_{nom} and V_{nom} are the nominal current and voltage of the power switch.

The power switch is associated to a power diode (additional for IGBT, intrinsic for MOSFET). According to [21, 22]

$$P_{\text{cond,d}} = \frac{1}{2} \left(V_{\text{d0}} \frac{I_0}{\pi} + \frac{r_{\text{d}}}{4} I_0^2 \right) - m \cos \varphi \left(V_{\text{d0}} \frac{I_0}{8} + \frac{r_{\text{d}}}{3\pi} I_0^2 \right) \quad (7)$$

$$P_{\text{sw,d}} = \frac{f_{\text{sw}}}{\pi} E_{\text{rec}}(I_{\text{dnom}}) \left(\frac{0.45 I_0}{I_{\text{dnom}}} + 0.55 \right) \frac{V_{\text{bus}}}{V_{\text{dnom}}} \quad (8)$$

$$P_{\text{T,d}} = P_{\text{cond,d}} + P_{\text{sw,d}} \quad (9)$$

$P_{\text{cond,d}}$ is the forward conduction losses of the diode, $P_{\text{sw,d}}$ the switching losses and $P_{\text{T,d}}$ the total power losses for one diode. Here, E_{rec} is the turn-off energy of the diode that is a function of I_{dnom} . I_{dnom} and V_{dnom} are the nominal current and voltage of the power diode, r_{d} and V_{d0} are the forward resistance and the forward voltage of the diode.

3.2 Current-sharing system modelling

The power-sharing system is given in Fig. 2a. An equivalent power switch is made of two power MOSFETs (or two IGBT modules with freewheeling diodes). There are conduction

losses and no switching losses. The motor currents are supposed to be sine waves and to define a balanced three-phase load as described in (1)–(3).

According to the previous assumptions, the conduction losses are expressed by

$$P_{\text{cond,IGBT,MOSFET}} = \frac{V_0 I_0}{\pi} + \frac{r I_0^2}{4} \quad (10)$$

$$\text{with, } V_0 = 0 \text{ for MOSFET} \quad (11)$$

$$P_{\text{cond,diode}} = \frac{V_{\text{d0}} I_0}{\pi} + \frac{r_{\text{d}} I_0^2}{4} \quad (12)$$

where V_0 is the voltage drop of IGBTs and diodes, r_{d} is the equivalent resistor value of IGBTs, MOSFETs and diodes.

3.3 DC-AC matrix modelling

The DC-AC matrix converter solution with a three motors application is given in Fig. 2b. In Fig. 4, the switching algorithm is presented so as to compute power losses [13]. In [23], more details are given about the switching conditions of power switches.

The first assumption is that V_{bus} is positive and i_{a} can be either positive or negative. Four signals are defined to drive the four power switches (MOSFETs in Fig. 4): C_{11} , C_{12} , C_{21} and C_{22} . M_{11} , M_{12} , M_{21} , M_{22} are the MOSFET or the IGBT power switches. d_{11} , d_{12} , d_{21} and d_{22} are the power diodes. Regarding conduction losses, MOSFET or IGBT and diodes losses depend on φ , I_0 and m . According to the switching conditions and using the previous algorithm, the losses $P_{\text{cond},M_{11},M_{22}}$ and $P_{\text{cond},d_{12},d_{21}}$ are calculated from (4). The losses $P_{\text{cond},M_{21},M_{12}}$ and $P_{\text{cond},d_{11},d_{22}}$ are calculated using (7).

Considering switching losses, M_{11} and M_{22} , d_{11} and d_{22} are under hard switching conditions. Then, the switching power losses are given by (5) for $P_{\text{sw},M_{11},M_{22}}$ and by (8) for $P_{\text{sw},d_{11},d_{22}}$.

3.4 Semiconductor electrothermal modelling

The semiconductors electrothermal modelling is taken into account in the pre-sizing approach. MOSFET, IGBT and diodes electrical parameters are function of junctions temperatures [24].

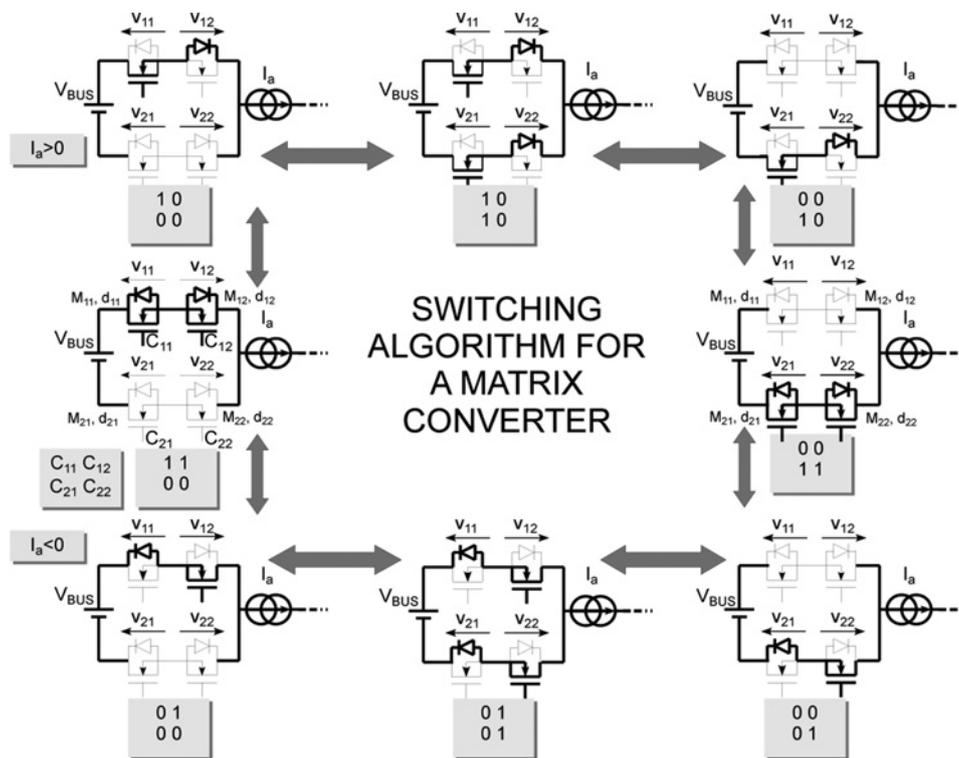


Fig. 4 Matrix converter modelling and power semiconductor switchings

In this case, the worst cases are considered for electrical parameters: V_0 , r , V_{d0} and r_d . For the MOSFET series resistance r , the maximal value is reached for the maximal functioning temperature (125°C in our case). For the diode and IGBT voltage drop (V_{d0} and V_0), the maximal values are reached for the minimum functioning temperature (20°C in our case).

3.5 Heatsink thermal modelling

An equivalent thermal resistance is considered for the heatsink modelling. According to manufacturers datasheets, the thermal resistance is a function of the length [3]. The proposed modelling is the following

$$R_{th,hs}(L_{hs}) = a_{hs} + b_{hs} e^{-c_{hs}L_{hs}} \quad (13)$$

a_{hs} , b_{hs} and c_{hs} are parameters that depend on the considered heatsink. L_{hs} is its length.

In Table 1, manufacturers values are proposed for the heatsink 335AB black anodised. Equation (13) and manufacturer values are compared in Fig. 5.

3.6 Generalised modelling of power switches

In the inverter, the power-sharing system and the matrix converter, power switches can be either IGBT with freewheeling diode, IGBT without freewheeling diode, MOSFET, MOSFET with freewheeling diode, etc. Then, so as to optimise the choice of the best power switch, a generalised approach is proposed.

The generalised power switch includes a switch (a) and three diodes (b), (c) and (d) as shown in Fig. 6. A database

Table 1 Typical performances of 335AB black anodised heatsink

Length L_{hs} mm	$R_{th,hs}$ °C/W
50	2.00
75	1.60
100	1.40
150	1.20
200	1.15

is performed for the optimisation process. Each components (a), (b), (c) and (d) are automatically chosen in this database.

4 Optimisation

The system optimisation is performed in this section. The objective function, optimisation variables and constraints are listed (Fig. 7). A Monte Carlo (MC) algorithm is performed here for the proposed virtual prototyping tool.

4.1 Objective function

The overall volume Vol_{hs} of the heatsink is considered as the objective function F_{obj} . So that

$$F_{obj} = Vol_{hs} = l_{hs} L_{hs} e_{hs} \quad (14)$$

where L_{hs} is the length, l_{hs} the width and e_{hs} the heatsink thickness. In the manufacturer process, the shape and the heatsink width are constant and the length can be adjusted. Consequently, L_i is considered as an optimisation variable. In our application, four heatsinks technologies are considered in a specific database.

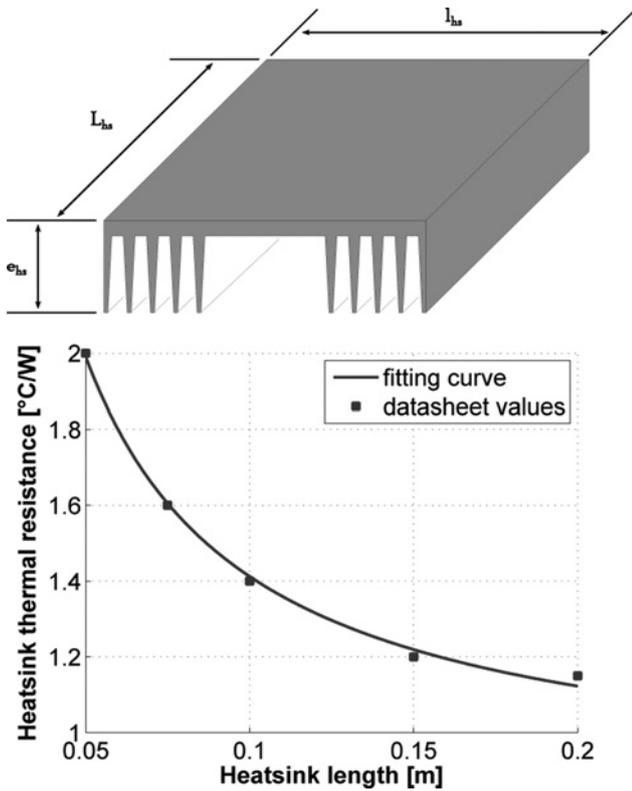


Fig. 5 Shape of the heatsink 335AB black anodised and heatsink thermal resistance as a function of heatsink's length comparison between analytical equation and datasheet's values

For each component technology, some key parameters must be given in the database. Currently, IGBT's parameters are voltage drop V_{cesat} and switching energies E_{on} E_{off} .

For MOSFET's series resistance R_{dson} and switching energies.

For diodes's voltage drop v_{on} and recovery charge Q_{rr} .

4.2 Optimisation variables

4.2.1 Inverter and power-sharing system: The inverter and the power-sharing system are presented in Fig. 2a. The power semiconductor components of the inverter are modelled with (a_1) , (b_1) , (c_1) and (d_1) (Fig. 6). The six power switches are supposed to be identical because of the three-phase motors are considered without operating faults. For the same reason, the power-sharing system is built with power semiconductor components that are modelled by (a_2) , (b_2) , (c_2) and (d_2) .

The heatsink modelling leads to the consideration of the heatsink shape modelled by a heatsink number (or reference) in this specific database: N_{hs} and the heatsink length L_{hs} .

The optimisation variables for the inverter and the power-sharing system are given by the vector X_i

$$X_i = [(a_1), (b_1), (c_1), (d_1), (a_2), (b_2), (c_2), (d_2), N_{hs}, L_{hs}] \quad (15)$$

4.2.2 Matrix converter: The matrix converter system is presented in Fig. 2b. According to the matrix algorithm switching mechanism of Fig. 4, the elementary branch is carried out using two power components. Using the generic modelling, this components are modelled with (a_1) , (b_1) , (c_1) , (d_1) , (a_2) , (b_2) , (c_2) and (d_2) .

As the inverter and the power-sharing system, the matrix converter heatsink is also characterised by a reference N_{hs} and length L_{hs} .

The optimisation variables for the matrix converter are given by the vector X_m

$$X_m = [(a_1), (b_1), (c_1), (d_1), (a_2), (b_2), (c_2), (d_2), N_{hs}, L_{hs}] \quad (16)$$

4.3 Optimisation constraints

The optimisation problem includes constraints that must be verified.

The first one is to chose suitable components for (a_1) , (b_1) , (c_1) , (d_1) , (a_2) , (b_2) , (c_2) and (d_2) :

- (a_1) , (a_2) : MOSFET or IGBT without freewheeling diode or IGBT with freewheeling diode;
- (b_1) , (b_2) : diode or short-circuit;
- (c_1) , (c_2) : diode or open-circuit;
- (d_1) , (d_2) : diode or open-circuit;
- If (b_1) is a diode, (c_1) must be a diode;
- If (a_1) is an IGBT without freewheeling diode and (b_1) is a short-circuit, (c_1) must be a diode;
- If (b_2) is a diode, (c_2) must be a diode;
- If (a_2) is an IGBT without freewheeling diode and (b_2) is a short-circuit, (c_2) must be a diode.

The number N_{hs} must not be upper than the total number of heatsinks present in the database: here $N_{hs} \leq 4$.

The length L_{hs} of the heatsink number N_{hs} must be higher than $L_{hs}(N_{hs})_{min}$ and less than $L_{hs}(N_{hs})_{max}$

$$L_{hs}(N_{hs})_{min} \leq L_{hs}(N_{hs}) \leq L_{hs}(N_{hs})_{max} \quad (17)$$

The overall surface of the semiconductor components must be less than the half-surface of the heatsink

$$\sum_{\text{Semiconductors}} \text{Surfaces} \leq \frac{1}{2} L_{hs} L_{hs} \quad (18)$$

The maximal value of the junction temperature must be less than $T_{jMAX} = 125^\circ\text{C}$

$$\text{Max}((T_j)_{\text{Semiconductors}}) \leq T_{jMAX} \quad (19)$$

The objective function to be minimised is the heatsink's volume.

5 Optimisation results and comparison

Optimisation results from the virtual prototyping tool are presented in this section. The optimisations are performed with Matlab™. According to the results, the DC-AC matrix converter and the power-sharing system have a lower overall volume than the classical three-inverter topology.

The system's requirements are:

- Three identical electrical machines
- Power: 3 kW
- Voltage bus: 270 V
- Switching frequency: 2.1 kHz

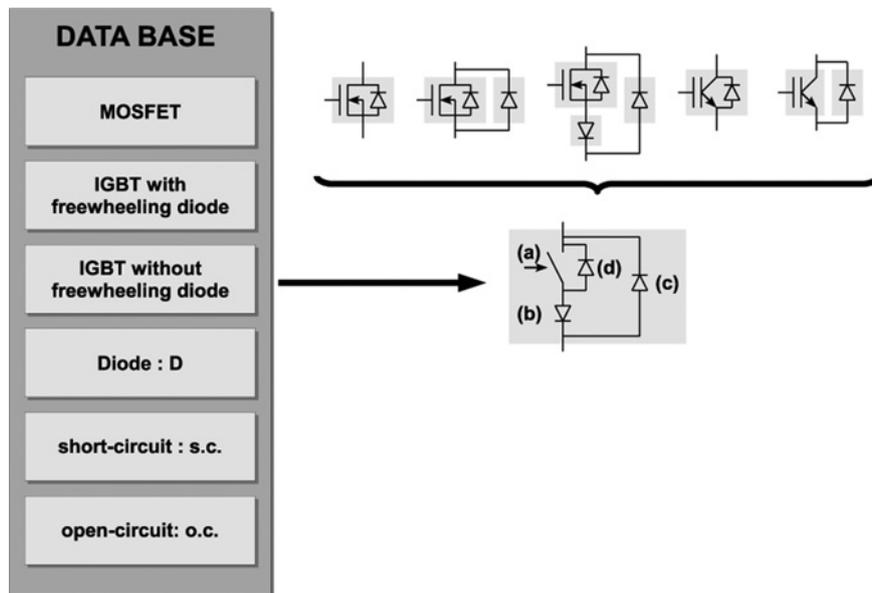


Fig. 6 Generalised modelling of power switches and components database

5.1 Inverter and power-sharing system

For the inverter and the power-sharing system, the main results are given in Table 2. The optimised power semiconductor is the IGBT N°3 without freewheeling diode and the diode D N°1 for the inverter. For the power-sharing system the most suitable switch is the MOSFET N°9. The obtained heatsink is the N°4 for both the inverter and power-sharing system. The optimised volume is 0.0988 litres. Note that the obtained maximal junction temperature is 124.5°C.

$$F_{obj} = 0.0988 \text{ litres}$$

$$\text{Efficiency} = 96.5\%$$

5.2 Three-inverter converter

For the three-inverter topology, the result is the same than the previous one in the case of the inverter and the power-sharing

system. The inverter is duplicated three times. The optimisation result is presented in Table 3. Note that the optimised volume in this case is 0.1245 litres.

$$F_{obj} = 0.1245 \text{ litres}$$

$$\text{Efficiency} = 98.5\%$$

5.3 DC-AC matrix converter

For the matrix converter, the optimisation results are presented in Table 4. We note that the minimal volume is 0.0992 litres. The optimised solution is to use an IGBT without freewheeling diode (M_{11} and M_{22}) and to add an external diode (d_{11} and d_{22}) whereas a MOSFET is chosen for M_{12} M_{21} : COOLMOS™ IXKC20N60C

$$F_{obj} = 0.0992 \text{ litres}$$

$$\text{Efficiency} = 97.7\%$$

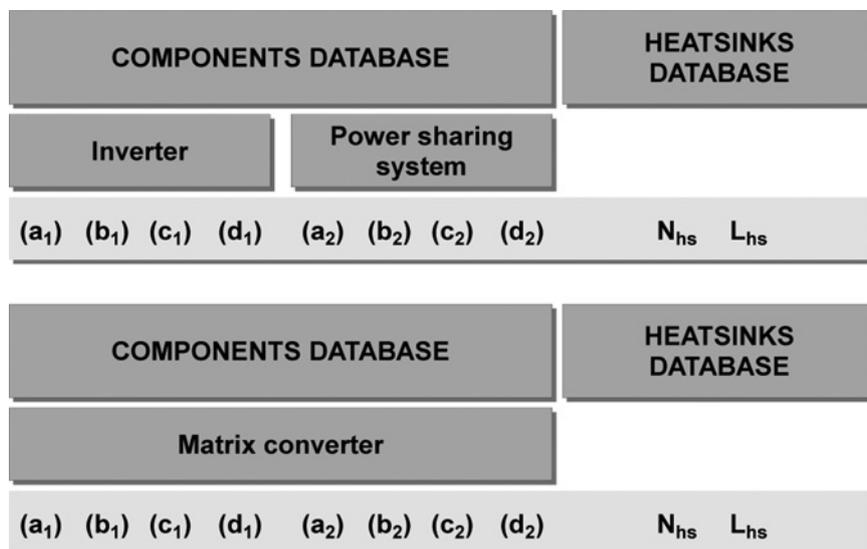


Fig. 7 Optimisation variables definitions for the {inverter + power-sharing system} and for the matrix converter

Table 2 Optimisation results for the inverter and the power-sharing system

Inverter					
(a_1)	(b_1)	(c_1)	(d_1)	L_{hs} m	N_{hs}
IGBT N°3 power sharing	s.c.	D N°1	o.c.	0.0723	4
(a_2)	(b_2)	(c_2)	(d_2)	L_{hs} m	N_{hs}
MOSFET N°9	s.c.	o.c.	o.c.	0.0996	4

Table 3 Optimisation results for the three-inverter converter

Inverter					
(a_1)	(b_1)	(c_1)	(d_1)	L_{hs} m	N_{hs}
IGBT N°3	s.c.	D N°1	o.c.	0.0723	4

5.4 Comparison between structures

The optimisation results lead authors to consider both the {inverter + power-sharing system} and the matrix converter as the best solutions from a volume point of view. In fact, the minimal volume of the matrix converter solution is very close to the volume of the inverter associated to the power-sharing system (0.0992 litres instead of 0.0988 litres). In Fig. 8 are given the optimisation results for the converters: the main objective is the overall volume and the efficiency is plotted to add an other point of view of the pre-sizing approach.

Nevertheless, the current work is about a three motors application. Under this strong assumption, a general conclusion cannot be given. Then, according to this preliminary results, other aspects should be prospected. Therefore a generalised approach should be proposed considering the number of machine as an optimisation parameter. Maybe, for five motors, the matrix converter solution would have a lower volume and the difference between {inverter + power-sharing system} and matrix converter volumes would be more significant.

However, considering fault analysis given in [13], the matrix converter is more suitable in the case of open-circuit fault of a MOSFET or an IGBT. It has been proved that for the matrix converter there is no overcurrent in the motor, whereas an overcurrent of about ten times the nominal current is present in the inverter case.

5.5 Comparison of computation times

The computation times needed to run these optimisations are compared in Table 5 (Intel Core i5 CPU, 2.67 GHz, 4 Go RAM). As result, the DC-AC matrix converter MC optimisation requires 500 000 evaluations compared with 10 000 for the other converters. That is the reason why the computation times differences are so huge. Nevertheless,

Table 4 Optimisation results for the matrix converter

(a_1)	(b_1)	(c_1)	(d_1)	(a_2)	(b_2)	(c_2)	(d_2)	L_{hs}	N_{hs}
IGBTN°4	s.c.	DN°1	o.c.	MOSFETN°9	s.c.	o.c.	o.c.	0.0762	1

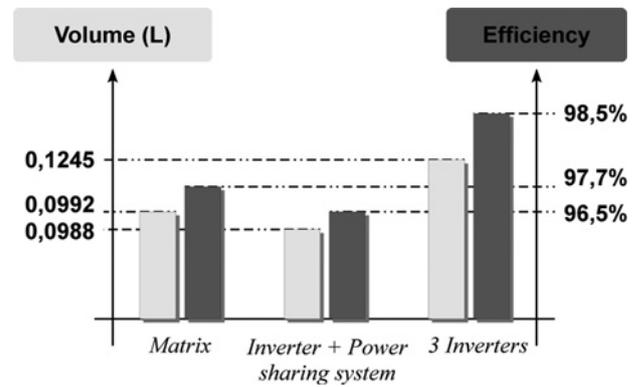


Fig. 8 Comparison of the optimisation results: volume and efficiency

Table 5 Parameters of the MC algorithm and computation time

	N_{MC}	Time	F_{obj} litres	Efficient, %
matrix	500 000	41 h	0.0992	97.7
inverter and power-sharing system	10 000	110 s	0.0988	96.5
three-inverter converter	10 000	105 s	0.1245	98.5

computation times could be reduced with the use of other optimisation algorithms such as global optimisation.

6 Conclusions

A pre-sizing approach using optimisation under constraints of DC-AC converters for a power-sharing application is presented in this paper. The considered converter load is a three AC-machine. According to the state of the art of such system topologies, a classical three-inverter and an {inverter + power sharing} converter are presented and optimised. Authors have also proposed a new DC-AC matrix converter operating as an inverter. The proposed approach allows us to select an optimal architecture considering volume, electrothermal and components technology choice aspects.

Considering the exhaustive cost of physical prototypes, a virtual prototyping tool has been developed to answer the industrial needs. This method is based on classical modellings and manufacturers' datasheets. This leads to a first step where physical prototypes are not necessary and provide to industrial engineers first approximations of the converters' performances.

In this way, generic models are used to compute losses that lead to thermal and volume aspects: the overall volume of the heatsink is considered as the objective function and junction temperatures as constraints. MOSFETs, IGBTs and diodes power semiconductors databases are provided to feed the generic methodology for the components choice. The heatsink choice is based too on a specific database.

Three converters architectures are modeled and optimised. The results are compared considering the final volume of the heatsink. Above the assumptions, the {inverter + power-sharing system} volume is the lowest. However, the small difference between inverter and DC-AC matrix results cannot lead to a definitive conclusion. Consequently, capacitors volume and switching frequency will be added in future works to perform a more accurate analysis. Moreover, the number of the AC machines is an important parameter too. Optimisations are being processed to give a general overview of the problem considering the number of machine as an important optimisation parameter. To further improve the system optimisation, the electrical machine will be modelled and optimised with the converter and the bus capacitors.

7 References

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