



HAL
open science

Improved current Control of Floating Interleaved Boost Converter Dedicated to Vehicular Applications

Nassira Barhoumi, Hajer Marzougui, Faouzi Bacha

► **To cite this version:**

Nassira Barhoumi, Hajer Marzougui, Faouzi Bacha. Improved current Control of Floating Interleaved Boost Converter Dedicated to Vehicular Applications. 2021 IEEE 2nd International Conference on Signal, Control and Communication (SCC), 2021 IEEE 2nd International Conference on Signal, Control and Communication (SCC), Dec 2021, Tunis, Tunisia. pp.107-112, 10.1109/SCC53769.2021.9768391 . hal-04057741

HAL Id: hal-04057741

<https://hal.science/hal-04057741v1>

Submitted on 13 Apr 2023

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Improved current Control of Floating Interleaved Boost Converter Dedicated to Vehicular Applications

1st Nassira Barhoumi

Electrical Engineering Department,
University of Carthage , INSAT ,
B.P. 676 ,1080, Cedex Tunis, Tunisia
nassira.barhoumi@gmail.com

2nd Hajer Marzougui

Electrical Engineering Department,
University of Carthage , INSAT ,
B.P. 676 ,1080, Cedex Tunis, Tunisia
marzougui.ensit@gmail.com

3rd Faouzi BACHA

Electrical Engineering Department,
University of Tunis , ENSIT , TAHA
HUSSEIN STREET, 1008,
Tunisia
Faouzi.Bacha@esstt.rnu.tn

Abstract— This paper investigates the performance of four-phase Floating Interleaved Boost Converter (FIBC) for vehicular applications. For such applications, current control is indispensable in order to ensure the vehicle power (eventually the current) requirement satisfaction. For this reason, two methods are applied in this work to control the current of the source associated to the studied converter which is a fuel cell in our case. This first method is based on using one current control loop which allows to maintain the total current in the output of the source equal to its reference. The second method consists on improving the first one by applying a current control loop for each converter leg (i.e using four control loops). This converter offers improved efficiency and voltage gain, while ensuring lower input current ripple than other DC-DC boost converter topologies.

In this paper, the proposed controls are evaluated for the same road conditions by applying the New European driving cycle (NEDC). Simulation results are presented to validate the effectiveness of the two adopted controls and prove the improvements presented by the technology using four control loops.

Keywords—DC/DC Converter, floating interleaved boost converter, fuel cell, electrical vehicle.

I. INTRODUCTION

A fuel cell is a device that converts chemical energy directly into electrical energy without any thermal or mechanical process. The stack at fuel is one of the most promising for power generation on-board applications, due to high energy density, high efficiency and low temperature of operation, allowing it to start faster compared to other types. However, some constraints are still pending, in particular its slow dynamics and its low voltage produced at the output. For these reasons, a DC / DC converter is not only necessary to raise this voltage up to the voltage level of the DC bus, but also for conditioning the output voltage of the fuel cell which varies greatly with load[1].

Several topologies based on the basic architecture of the classic DC / DC boost converter has been proposed [1], [2], [3] in order to improve compactness, voltage gain and also energy efficiency. Basic changes to the DC / DC boost classical allow to build fault tolerant interleaved architectures to improve the gain of elevation and minimize the ripple current input [4].

The combination of two or more interleaved boost floating architecture improves, so, the voltage gain compared to the conventional boost topology because the voltages across the capacitors add up. In addition, with the presence of static redundancy [5], the converter is able to operate in degraded mode. For all these reasons, floating boost interleaved architectures are ideally suited to the expectations of Fuel cell electric vehicle applications [2], [6]. This is due to several advantages that presented the mentioned topology. Indeed, its size and volume of passive components are reduced compared to other topologies. Thus, input current ripple and DC bus ripple are reduced depending on the number of legs used in the floating converter. Besides, this converter is modular. It improves the reliability of the system owing to the presence of degrees of freedom and increases the power of this converter thanks to the parallel connection of legs.

The interleaved floating DC / DC boost converter is of particular interest due to the presence of a non-floating and floating bus, it is fault tolerant due to the presence of static redundancy [7]. This redundancy is opposed to dynamic redundancy, which is often used to make a topology tolerant to faults.

In this context, the objective of our work is to improve the current control of a four phase-floating interleaved boost DC / DC converter used to interface a PEMFC dedicated to vehicular application. Two control strategies are developed; a single-loop control for the total current of the four inductances. In the second strategy, four current loops are applied, one for each leg, in order to guarantee a balanced current in the four phases of the converter [4.8]. Simulation results are presented in order to validate the chosen topology and prove the effectiveness of the developed control strategies.

II. FLOATING INTERLEAVED BOOST CONVERTER TOPOLOGY

The concept of interleaving, on which the proposed topology is based, is ensured by the parallel connection of a non-floating and a floating version of the DC / DC boost converter at the input. Thus, a delay between control signals for switches S1, S2, S3 and S4 should be performed. Interleaving two or more converter legs allows to reduce the input current ripple [9]. In addition, this topology makes it possible to reduce the electrical constraints (i.e. voltage and current) on power semiconductors.

The number of phases of a DC / DC floating interleaved boost converter must be always even in order to keep a balance between the non-floating part (i.e. top part) and the floating part (i.e. bottom part). Moreover, in terms of reliability, this architecture is more robust compared to that with two phases[10].

Fig. 1 presents a 4-phase floating interleaved DC/DC boost converter and is built from the non-floating version of the boost converter (i.e. and the floating one (i.e. lower part)) [5]. This adapted topology consists of connecting n conventional boost converters in parallel sharing a common DC bus and the offset of the control signals of the power switches (similar to floating interleaved topologies) [6]. The offset hang on the number of the converter legs and is equal to T / n where T is the commutation period of the converter.

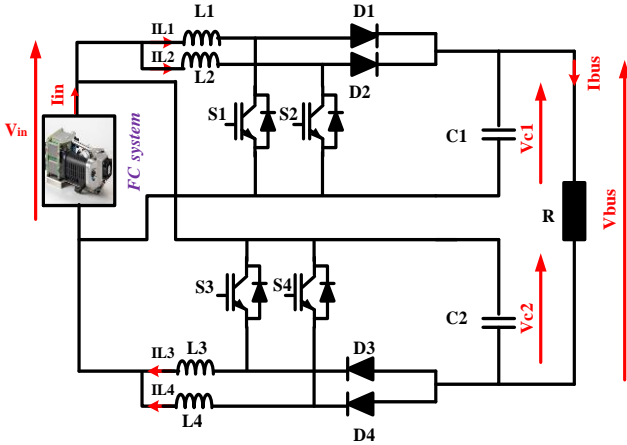


Fig. 1. Four-phase Floating Interleaved Boost Converter topology

It is to note, also, that the loss of a phase of a part (i.e. floating or non-floating part) for a 4-phases converter could be compensated by the other phase located on the defective part. However, by keeping the balance of the converter, this leads to the excess of one phase, thus creating additional electrical stresses, in particular on the magnetic components.

All the passive components are ideal elements without the parasitic parameters and they are also equal.

$$C_1 = C_2 = C$$

$$L_1 = L_2 = L_3 = L_4 = L$$

Regarding the duty cycle, we will build two models and according to these models we will make two controls, one control for each model:

For the first one:

$$d_1 = d_2 = d_3 = d_4 = d \quad (1)$$

For the second one:

$$d_1 \neq d_2 \neq d_3 \neq d_4 \quad (2)$$

III. FLOATING INTERLEAVED BOOST CONVERTER

A. MODELING WITH A SINGLE CONTROL LOOP

1. Equations

In order to ensure the adequate control of the converter, the performance goals needed for the appropriate dynamic models of used topology are needed. In the first stage of the converter, equations Fig.2 given two operating sequences. For the sequence of operation ($0 < t < DT$) and ($DT < t < 2DT$), the equations are given as follows:

$$\begin{aligned} \frac{dI_{L1}}{dt} &= \frac{(r_d(1-d)-dr_t)}{L} I_{L1} + \frac{d-1}{L} V_{C1} + \frac{1}{L} I_{Bus} \\ \frac{dI_{L2}}{dt} &= \frac{(r_d(1-d)-dr_t)}{L} I_{L2} + \frac{d-1}{L} V_{C1} + \frac{1}{L} V_{Bus} \\ \frac{dI_{L3}}{dt} &= \frac{(r_d(1-d)-dr_t)}{L} I_{L3} + \frac{d-1}{L} V_{C2} + \frac{1}{L} V_{in} \\ \frac{dI_{L4}}{dt} &= \frac{(r_d(1-d)-dr_t)}{L} I_{L4} + \frac{d-1}{L} V_{C2} + \frac{1}{L} V_{in} \\ \frac{dV_{C1}}{dt} &= \frac{1-d}{L} I_{L1} + \frac{1-d}{L} I_{L2} - \frac{1}{RC} V_{C1} - \frac{1}{RC} V_{C2} + \frac{1}{RC} V_{in} \\ \frac{dV_{C2}}{dt} &= \frac{1-d}{L} I_{L3} + \frac{1-d}{L} I_{L4} - \frac{1}{RC} V_{C1} - \frac{1}{RC} V_{C2} + \frac{1}{RC} V_{in} \end{aligned} \quad (3)$$

where I_{Lx} ($x=1,2,3,4$) is the inductor current, V_{Cy} ($y=1,2$) is the capacitor voltage, I_{in} and V_{in} are respectively the input current and the input voltage while I_{Bus} and V_{Bus} are the output current and the output voltage, respectively. The input current and the DC-bus voltage dynamic are given by equation system (4).

$$\begin{aligned} \frac{dI_{in}}{dt} &= \sum_{i=1}^4 \frac{dI_{Li}}{dt} - \frac{dI_{bus}}{dt} \\ \frac{dV_{bus}}{dt} &= \sum_{i=1}^2 \frac{dV_{ci}}{dt} - \frac{dV_{in}}{dt} \end{aligned} \quad (4)$$

2. Average model

The average model was applied, known as average circuits on equations (3) and (4). The average model of the investigated converter is given, so by equation system (5). Where X is the state vector, while U presents the control vector.

$$\begin{cases} \dot{X} = AX + BU \\ Y = CX \end{cases} \quad (5)$$

Where:

$$\dot{X} = \begin{pmatrix} \frac{dI_{L1}}{dt} & \frac{dI_{L2}}{dt} & \frac{dI_{L3}}{dt} & \frac{dI_{L4}}{dt} & \frac{dV_{C1}}{dt} & \frac{dV_{C2}}{dt} \end{pmatrix}^t$$

$$X = (I_{L1} \ I_{L2} \ I_{L3} \ I_{L4} \ V_{C1} \ V_{C2})^t \quad (6)$$

$$U = V_{FC}$$

A =

$$A = \begin{pmatrix} \frac{(r_d(1-d)-dr_t)}{L} & 0 & 0 & 0 & \frac{d-1}{L} & 0 \\ 0 & \frac{(r_d(1-d)-dr_t)}{L} & 0 & 0 & \frac{d-1}{L} & 0 \\ 0 & 0 & \frac{(r_d(1-d)-dr_t)}{L} & 0 & 0 & \frac{d-1}{L} \\ 0 & 0 & 0 & \frac{(r_d(1-d)-dr_t)}{L} & 0 & \frac{d-1}{L} \\ \frac{1-d}{L} & \frac{1-d}{L} & 0 & 0 & -\frac{1}{RC} & -\frac{1}{RC} \\ 0 & 0 & \frac{1-d}{L} & \frac{1-d}{L} & -\frac{1}{RC} & -\frac{1}{RC} \end{pmatrix} \quad (7)$$

$$B = \begin{pmatrix} \frac{1}{L} & \frac{1}{L} & \frac{1}{L} & \frac{1}{L} & \frac{1}{RC} & \frac{1}{RC} \end{pmatrix}^t \quad (8)$$

$$C = (1 \ 1 \ 1 \ 1 \ 0 \ 0)$$

3. Conventional current control

To correctly select and design correctors, it is essential to establish control purposes that can be formulated as follows:

The fuel cell flow should be divided equally between the different phases of the conversions to avoid overloading one of the phases, especially for high load values. In addition, the phase currents should be advisable to compensate each other to reduce the input current ripple, which is undesirable in FC applications.

Stability and dynamic performance should always be guaranteed when the system works in a closed loop.

In the first proposal, the used PI controller will make possible to obtain the reference of the current in the phases from the difference between the reference of the current in the inductors and the current of the measured inductors. In the second, it will make it possible to obtain the reference of the current in each phase from the difference between the current reference in each inductor and the current measured in each inductor.

To ensure the validity of the current output control loop, the controller parameters (KP and Ki) can be determined by Ziegler Nichols method.

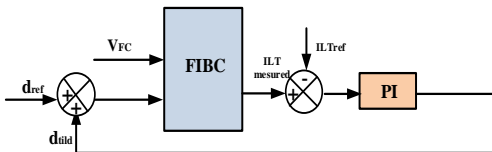


Fig. 2. Current control loop

The adopted structure includes:

- A controller of the inductor Current which is based on the duty cycle d.

- An average model of the FIBC converter.
- A model of the fuel cell.

The output current of the converter is limited and compared with the desired reference current. The PI regulator output signal makes it possible to make available the work cycle d which guarantees that the total current of the four inductances in the desired reference value.

TABLE I. 4-PHASE FIBC SPECIFICATIONS

Parameter	Value
Rated input voltage	24V
Output voltage	100V
Switching frequency	20KHz
Inductance	120μH
Capacitor	470μF

a. Simulation results for a variable load

To test the behavior of our converter when it is associated to fuel cell in order to satisfy the power requirement in vehicular application, we applied the speed profile (NEDC: New European Driving Cycle) which is presented in Fig.3 For this speed profile, the power required by the vehicle is shown in Fig.4.

A proportional integral controller was used, as mentioned above, to control the current in the input of the proposed converter. The corresponding responses in relation to the various electrical variables are presented in this part.

Figure.5 shows the load current. Its waveform shows the same evolution of the power required by the load which is presented by a traction motor in an electric vehicle.

By exploiting evolution of the total current of the four inductances and its reference shown in Fig.7, we can confirm that their evolutions satisfy that is imposed by the control loop applied in this work.

For Fig.8, it shows the current of a single phase of the converter. This current presents the quarter of the total current of the four inductances.

The duty cycle obtained from the current control loop is illustrated by Fig.10. This variable is used to control the IGBTs used in the adopted converter.

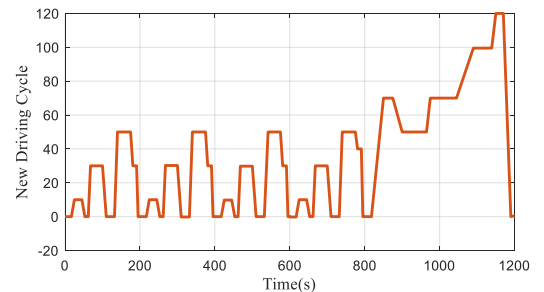


Fig. 3. New European Driving Cycle (NEDC)

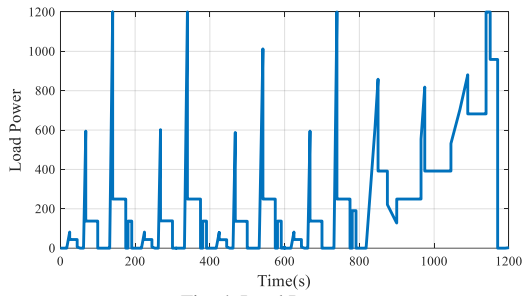


Fig. 4. Load Power

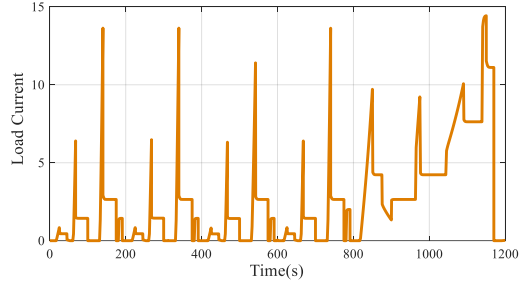


Fig. 5. Load Current

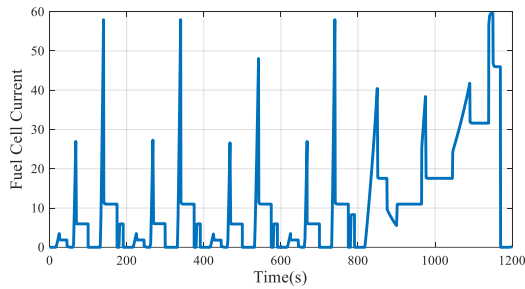


Fig. 6. Fuel Cell Current

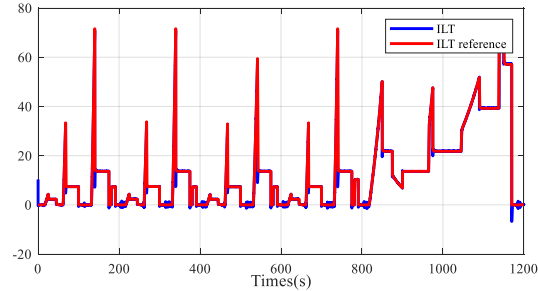


Fig. 7. ILT measured and ILT reference

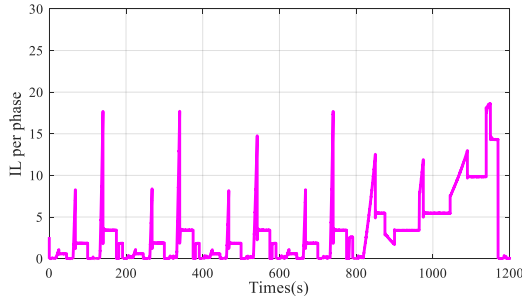


Fig. 8. IL per phase

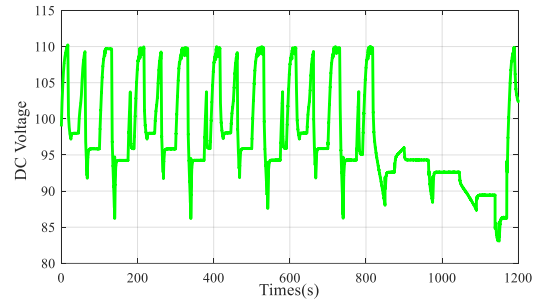


Fig. 9. DC bus voltage

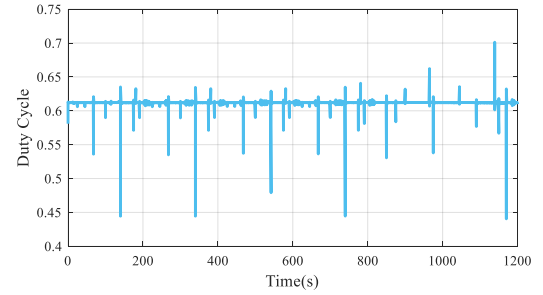


Fig. 10. Duty Cycle

By exploiting results shown in this section, it should be mentioned that the duty cycle used to control the converter operating presents important peaks which can influence on the converter performances. Thus, using a single control loop can present a lot of problems in the event of a fault occurring. The control adopted should be so improved by controlling each phase independently of other phases.

B. MODELING WITH A CONTROL LOOP FOR EACH LEG

1. Equations

$$\begin{aligned}
 \frac{dI_{L1}}{dt} &= \frac{(r_d(d_1-1)-d_1r_l)}{L} I_{L1} + \frac{d_1-1}{L} V_{C1} + \frac{1}{L} V_{FC} \\
 \frac{dI_{L2}}{dt} &= \frac{(r_d(d_2-1)-d_2r_l)}{L} I_{L2} + \frac{d_2-1}{L} V_{C1} + \frac{1}{L} V_{FC} \\
 \frac{dI_{L3}}{dt} &= \frac{(r_d(d_3-1)-d_3r_l)}{L} I_{L3} + \frac{d_3-1}{L} V_{C2} + \frac{1}{L} V_{FC} \\
 \frac{dI_{L4}}{dt} &= \frac{(r_d(d_4-1)-d_4r_l)}{L} I_{L4} + \frac{d_4-1}{L} V_{C2} + \frac{1}{L} V_{FC} \\
 \frac{dV_{C1}}{dt} &= \frac{1-d_1}{C} I_{L1} + \frac{1-d_2}{C} I_{L2} - \frac{I_{ch}}{C} \\
 \frac{dV_{C2}}{dt} &= \frac{1-d_3}{C} I_{L3} + \frac{1-d_4}{C} I_{L4} - \frac{I_{ch}}{C}
 \end{aligned} \tag{9}$$

2. Average model

The representation of the state space system is shown by the equation system (9).

$$\begin{cases} \dot{x} = Ax + Bu \\ y = Cx + Du \end{cases} \tag{10}$$

Where:

U is the control or input vector, Y is the output, and X is the vector of state variables.

$$\begin{cases} x = [I_{L1}, I_{L2}, I_{L3}, I_{L4}, V_{c1}, V_{c2}]^T \\ y = [V_{FC}, I_{ch}]^T \\ u = V_{Bus}(t) \end{cases} \quad (11)$$

With:

$$\dot{X} = \begin{pmatrix} \frac{dI_{L1}}{dt} & \frac{dI_{L2}}{dt} & \frac{dI_{L3}}{dt} & \frac{dI_{L4}}{dt} & \frac{dV_{C1}}{dt} & \frac{dV_{C2}}{dt} \end{pmatrix} = \begin{pmatrix} \frac{(r_L(1-d_1)-d_1r_f)}{L} & 0 & 0 & 0 & \frac{d_1-1}{L} & 0 \\ 0 & \frac{(r_L(1-d_2)-d_2r_f)}{L} & 0 & 0 & \frac{d_2-1}{L} & 0 \\ 0 & 0 & \frac{(r_L(1-d_3)-d_3r_f)}{L} & 0 & \frac{d_3-1}{L} & 0 \\ 0 & 0 & 0 & \frac{(r_L(1-d_4)-d_4r_f)}{L} & \frac{d_4-1}{L} & 0 \\ \frac{1-d_1}{C} & \frac{1-d_2}{C} & 0 & 0 & 0 & 0 \\ 0 & 0 & \frac{1-d_3}{C} & \frac{1-d_4}{C} & 0 & 0 \end{pmatrix} \begin{pmatrix} I_{L1} \\ I_{L2} \\ I_{L3} \\ I_{L4} \\ V_{C1} \\ V_{C2} \end{pmatrix} + \begin{pmatrix} \frac{1}{L} & 0 \\ \frac{1}{L} & 0 \\ \frac{1}{L} & 0 \\ \frac{1}{L} & 0 \\ 0 & -\frac{1}{C} \\ 0 & -\frac{1}{C} \end{pmatrix} \begin{pmatrix} V_{FC} \\ I_{ch} \end{pmatrix} \quad (12)$$

In the rest of our work we will neglect the two resistances r_d and r_t :

$$\begin{pmatrix} \frac{dI_{L1}}{dt} \\ \frac{dI_{L2}}{dt} \\ \frac{dI_{L3}}{dt} \\ \frac{dI_{L4}}{dt} \\ \frac{dV_{C1}}{dt} \\ \frac{dV_{C2}}{dt} \end{pmatrix} = \begin{pmatrix} 0 & 0 & 0 & 0 & \frac{d_1-1}{L} & 0 \\ 0 & 0 & 0 & 0 & \frac{d_2-1}{L} & 0 \\ 0 & 0 & 0 & 0 & \frac{d_3-1}{L} & 0 \\ 0 & 0 & 0 & 0 & \frac{d_4-1}{L} & 0 \\ \frac{1-d_1}{C} & \frac{1-d_2}{C} & 0 & 0 & 0 & 0 \\ 0 & 0 & \frac{1-d_3}{C} & \frac{1-d_4}{C} & 0 & 0 \end{pmatrix} \begin{pmatrix} I_{L1} \\ I_{L2} \\ I_{L3} \\ I_{L4} \\ V_{C1} \\ V_{C2} \end{pmatrix} + \begin{pmatrix} \frac{1}{L} & 0 \\ \frac{1}{L} & 0 \\ \frac{1}{L} & 0 \\ \frac{1}{L} & 0 \\ 0 & -\frac{1}{C} \\ 0 & -\frac{1}{C} \end{pmatrix} \begin{pmatrix} V_{FC} \\ I_{ch} \end{pmatrix} \quad (13)$$

$$B = \begin{bmatrix} 1/L & 0 \\ 1/L & 0 \\ 1/L & 0 \\ 1/L & 0 \\ 0 & -1/C \\ 0 & -1/C \end{bmatrix} \quad (14)$$

$$C = [1 \ 1 \ 1 \ 1 \ 0 \ 0] \quad (15)$$

3. CURRENT CONTROL PER PHASE

This type of controller is used for interleaved boost topologies (12), (13), (15), (16), and it makes it possible to actually distribute the instantaneous currents between different phases.

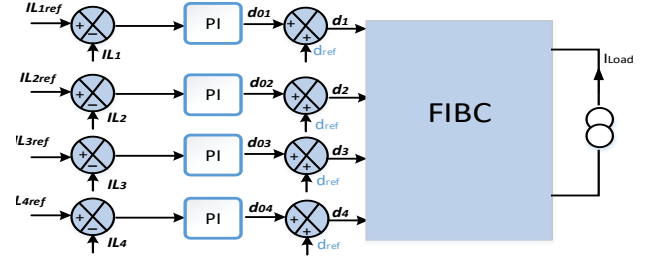


Fig. 11. Control model

The control loops shown in Fig.11 are applied, in this part, to the proposed 4-phase FIBC. In order to test the behavior of our system in this case, the same conditions (NEDC), used to test the performances of a single control loop, are now applied to prove the effectiveness of using a control loop for each phase.

For the driving cycle (NEDC) presented in Fig. 3, we present the obtained results in Fig.12-16.

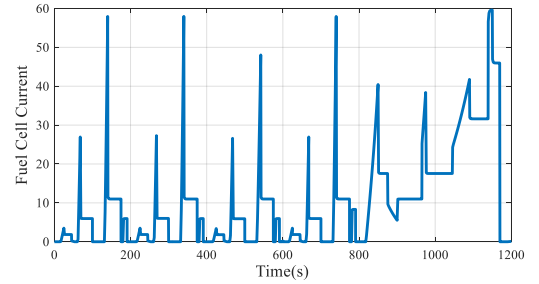


Fig. 12. Fuel Cell Current

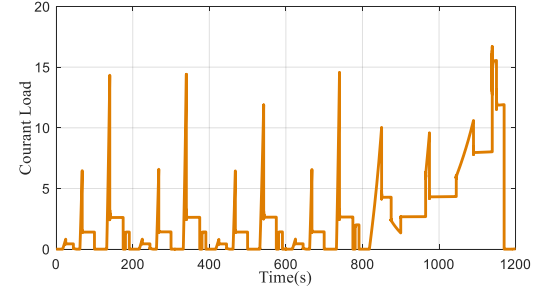


Fig. 13. Load Current

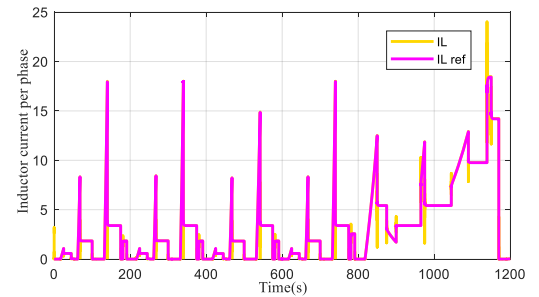


Fig. 14. iL measured and iL reference (per phase)

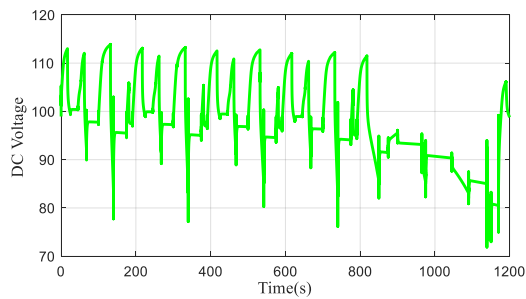


Fig. 15.DC Voltage

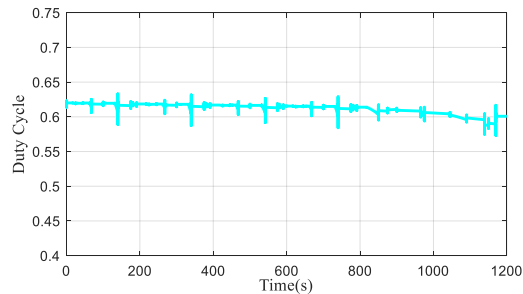


Fig. 16.Duty Cycle

We can observe from the results presented in this section, that the studied system operates obeying to that is imposed by the proposed control loops.

We can see that the duty cycle does not present the peaks seen when only a single current control loop is applied. The improvement of results can be proved also by exploiting the results presented in Fig.14 which shows the waveform of the current of one phase and its reference. This figure proves good performances guaranteed by the proposed control.

I. Conclusion

The purpose of this paper was to modeling and to propose a control loop for a floating DC/DC boost converter.

The proposed control is based on the regulation of the output current by a PI regulator. Indeed, the floating DC/DC converters composed of four legs are shifted relatively to each other by a 90° angle which causes a difference on the phase currents and the output voltage in the event of a failure one of these legs. Some tests were made using Matlab-Simulink to show the robustness of our system and simulation results validated the chosen control. Thus, the obtained results demonstrated the performance of the system when one of the two parameters is varied: Load and DC bus voltage in order to improve the reliability of the converter.

REFERENCES

- [1] S. Kascak, M. Prazenica, M. Jarabicova, R. Konarik, "FOUR PHASE INTERLEAVED BOOST CONVERTER - ANALYSIS AND VERIFICATION," *AEI*, vol. 18, no. 1, pp. 35–40, Mar. 2018,
- [2] H. Marzougui, A. Kadri, J-P. Martin, M. Amari, S. Pierfederi & F. Bacha, "Implementation of energy management strategy of hybrid power source for electrical vehicle", *Energy Conversion and Management*, 195 (2019), pp 830–843,
- [3] H. Marzougui, M. Amari, A. Kadri, F. Bacha & J Ghouili, "Energy management of fuel cell/ battery/ ultracapacitor in electrical hybrid vehicle", *International Journal of Hydrogen Energy*, 42 (2017), pp 8857-8869,
- [4] Y. Huangfu, S. Zhuo, F. Chen, S. Pang, D. Zhao, and F. Gao, "Robust Voltage Control of Floating Interleaved Boost Converter for Fuel Cell Systems," *IEEE Trans. on Ind. Applicat.*, vol. 54, no. 1, pp. 665–674, Jan. 2018.
- [5] S. Zhuo, A. Gaillard, D. Paire, E. Breaz, and F. Gao, "Design and Control of a Floating Interleaved Boost DC-DC Converter for Fuel Cell Applications," in *IECON 2018 - 44th Annual Conference of the IEEE Industrial Electronics Society*, Washington, DC, Oct. 2018, pp. 2026–2031,
- [6] D. Guilbert, A. Gaillard, A. N'Diaye, and A. Djerdir, "Power switch failures tolerance and remedial strategies of a 4-leg floating interleaved DC/DC boost converter for photovoltaic/fuel cell applications," *Renewable Energy*, vol. 90, pp. 14–27, May 2016,
- [7] Q. Li, Y. Huangfu, J. Zhao, S. Zhuo, and F. Chen, "Controller design and fault tolerance analysis of 4-phase floating interleaved boost converter for fuel cell electric vehicles," in *IECON 2017 - 43rd Annual Conference of the IEEE Industrial Electronics Society*, Beijing, Oct. 2017, pp. 7753–7758.
- [8] C. D. Lute, M. G. Simões, D. I. Brandão, A. A. Durra, and S. M. Muyeen, "Development of a four phase floating interleaved boost converter for photovoltaic systems," in *2014 IEEE Energy Conversion Congress and Exposition (ECCE)*, Sep. 2014, pp. 1895–1902.
- [9] S. Pang, B. Nahid-Mobarakeh, S. Pierfederici, Y. Huangfu, G. Luo, and F. Gao, "Fault-tolerant consideration and active stabilization for floating interleaved boost converter system," in *IECON 2017 - 43rd Annual Conference of the IEEE Industrial Electronics Society*, Beijing, Oct. 2017, pp. 7947–7952.
- [10] N. Barhouni, H. Marzougui, F. Slah, and F. Bacha, "Modelling and Control of Floating Interleaved Boost Converter for Electric Vehicle," in *2019 International Conference on Signal, Control and Communication (SCC)*, Hammamet, Tunisia, Dec. 2019, pp. 314–319,