Test-prototype design of an isolated bidirectionnal DC-DC converter for UPS application

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Abstract -- **This publication proposes the hardware design for a test-prototype of a bi-directional isolated dc-dc converter based on a dual full bridge with active clamp converter model in order to create a UPS function for a micro-cogeneration boiler.**

Control and measurement circuitry choices are proposed to optimally operate so that it can connect a 48V battery pack to a 380V bus and perform a two-way power transfer.

I. INTRODUCTION

To perform a bidirectional dc-dc conversion, several topologies are proposed in [1] and an ideal way to proceed is to design a single conversion stage. For our application shown in fig. 1, [2] lists a few advantages that the full bridge with active clamp topology allows us to benefit from : reduced input-ripple current, optimization of the isolation transformer, inherent protection against flux-walking in the isolation transformer and the soft switching operated for the different pair of mosfets. On top of that, the possibility to have a battery voltage variation over a wide range.

Texas Instrument published in 2016 a design reference of this type of converter. This does not exceed the stage of proof-of-concept. We rely on the operating modes they describe. However, the proposed circuits are not pragmatic and many circuits are not essential.

This is why some relevant references will be proposed here. They will be selected for an operating frequency of 100kHz.

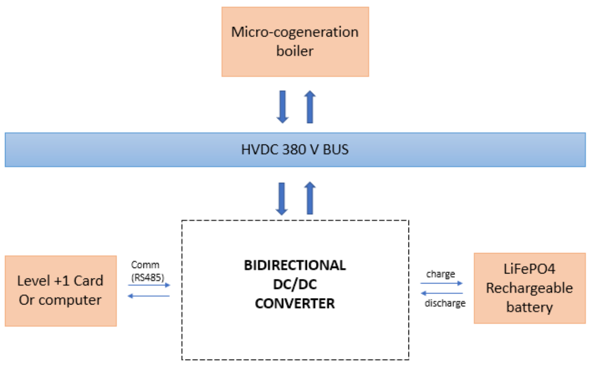

Fig. 1. Bi-directional dc / dc converter for ups application

II. CIRCUIT DESCRIPTION

The considered converter on fig. 2 has full bridges on each side of one isolation transformer to allow a large power transfer. The use of switches allows the bridges to be in a role of inverter or synchronous rectifier.

Depending on the operating direction, the converter will work in current-fed full bridge (boost mode) or voltage-fed full bridge (buck mode).

The topology of the dual full bridge converter is equipped with a clamp branch to contain the numerous transients and to recover the leakage energy. Furthermore, as described in [3], it is used to perform soft-switching, reducing the energy losses in high frequency operation.

In addition, in boost mode, the clamp branch allows to maintain the voltage overshoot problem which appears at the closing of the bus-side mosfets and to achieve a zero-voltage switching condition for the current-fed side switches. [4] details the PWM control scheme of the mosfets to be in these conditions.

In buck mode, it is a phase-shifted PWM signal type that allows to achieve a zero-voltage zero-current condition for the bus-side switches and to reduce the losses.

The converter also has a flyback circuit connected to the main inductor to provide a "cold-start" mode, when the HV DC bus is completely discharged at start-up, and this to avoid voltage spike caused by the current difference between the current fed inductor and leakage inductance of the isolation transformer. It can also reduce the current flowing through the active switches.It works in this mode until the HV bus reaches 270-V DC and then the system switches over, to work as a current-fed converter.

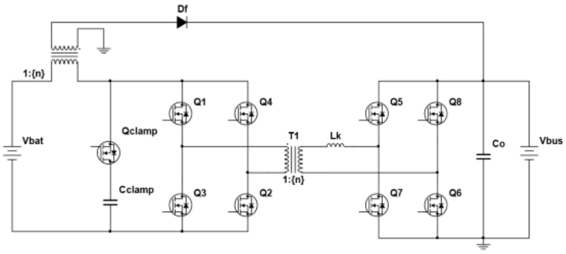

Fig. 2. Bi-directional fulll-bridge dc / dc converter with a unified soft-switching and soft-start capability

III. BATTERY

The battery type proposed for this set-up is LiFePo4. Compared to other types of lithium accumulators [5], they have lower capacitance and lower power density. However, as mentionned in [6], this type has safety overriding criterion for use as a UPS system and in the co-generation boiler working environment. Indeed, this battery has non-toxic material and is not overheated or catches fire in case of overcharging or overload. This type also has features such as lower cost, and longer cycle life.

IV. SWITCHING MOSFETS

For the battery side, the results obtained in [2] announce a peak voltage at turnoff on the low-voltage mosfet of 75V. The channel-n mosfet that will be used for the bridge and the clamp branch is a *SUP700E* from Vishay, which supports a breakdown voltage of 100V. It has a low R_{DSON}. This parameter is important to have ZVS condition when turning off. It also has a low Q_G and Q_{GD} (142 nC and 18,5 nC) wich will condition the switching speed. The maximum needed current can be calculated (eq. 1) when charging the parasitic capacitor. For a target rise time of 13 ns :

$$ICHG = \frac{Qgd}{trise\_target} = 1{,}38\ A \qquad (1)$$

For the bus side, the model must be able to withstand a rapid high voltage change. The chosen channel-n mosfet is the *IPA60R385CP* from Infineon. Its breakdown voltage goes up to 650V and it supports dv/dt values of 15V/ns.

V. CONTROL AND DRIVING

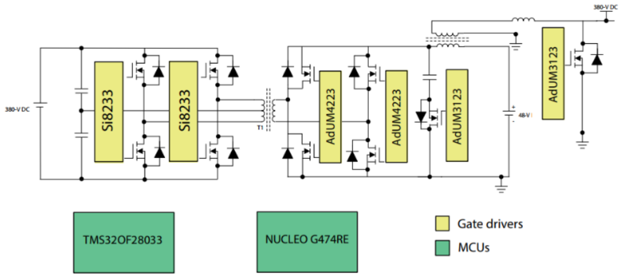

Fig. 3. Control and driving circuits

Control

Fig. 3 shows the different control circuits. For testing purposes, two different MCUs are deployed. The first is the *DSP TMS320F2803* proposed by Texas Instrument. At first, the use of this one is envisaged, because its operation has already been demonstrated.

But in order to have a more known microcontroller, which has a preferable development environment (*STM32 Cube IDE*) and reduced cost, the use of a STM32G4 microcontroller is proposed. The table 1 shows that the *STM32* model has slightly better characteristics than the one from Texas Instrument.

The two microcontrollers are provided on the board and the choice is made by soldering zero ohm resistors to activate the different control signals.

	TMS320F2803	STM32G4
frequency	60 Mhz	170Mhz
programmable GPIO	45	107
Operations	16x16 or 32x32 MAC 120 MIPS	16x16 MAC 216 DMIPS
Flash Memory	512 Kb flash	512Kb flash
ADC	1x 12 bits, up to 16 channels 4,6 MSPS	5x 12 bits, up to 42 channels 4 MSPS
Timers	16 timers	17 timers

TABLE. I. Characteristic of proposed MCU's

Gate drivers

For the low voltage side gate drivers, two isolated half bridge gate drivers (*Adum4223*) from Analog Device are selected. Insulation is not mandatory but it ensures a good EMC. They can deliver a source current of 4A (enough for the *SUP70030E*). They work up to a frequency of 8 Mhz and have a disable function. The power supply of the upper MOSFET driver is done by a bootstrap circuit which has the advantage of an external bootstrap diode which does not directly heat the driver.

For the high voltage side gate drivers, two half bridge gate drivers (*Si8233*) from Skyworks are now proposed. They allow an isolated control required for the 380V side. They also have a deadtime function to define a delay between the switching of the two mosfets of the branch to avoid a short circuit which would be extremely damaging.

The drivers of the clamping and flyback circuits are *AduM3123* 1-channel from Analog Device. They allow an isolated control and have a disable function.
All deactivation signals will be linked into one and it will be activated when a security state is active.

VI. MEASUREMENTS

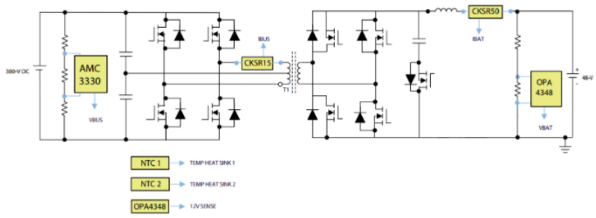

Fig. 4. Measurement circuits

The measurement of different currents, voltages and temperatures is necessary for regulation, intelligent monitoring, safety and load balancing. Fig. 4 shows where these measurement elements are positioned.

Current measurement

Two current measurements are necessary. One at the upper level of the bridge on the battery side and one at the transformer secondary side. CKSR Current transducers from LEM are proposed. They allow the isolated and bidirectional measurement of the converter currents. They also allow the measurement of pulsed current (I_{BUS}). The transducer provides a differential measurement that we scale and convert into an single-ended signal to connect directly to the microcontroller.

For the low side, where the current will be the highest, the peak current can reach 47 A (for a 2280W battery). The CKSR-50 is recommended while for the high side, the CKSR-15 is sufficient (5A peak at 380VDC).

Voltage measurement

Three measurements are proposed: The voltage on the battery side, the voltage on the bus side and the auxiliary 12V voltage from which the other voltage levels are also generated.

For the bus voltage, a measurement of the voltage divider by an isolated amplifier of high precision is used. It is the AMC3330 from Texas Instrument. It has the advantage of having an integrated isolated DC-DC converter to supply the isolated part.

For the voltage on the battery side and auxiliary 12V, an OPA48 is sufficient

Temperature measurement

For the temperature measurement, we could provide NTCs to be screwed on each radiators. This allows a precise measurement as close as possible to the radiators. The measurements will also be sent to the OPA48.

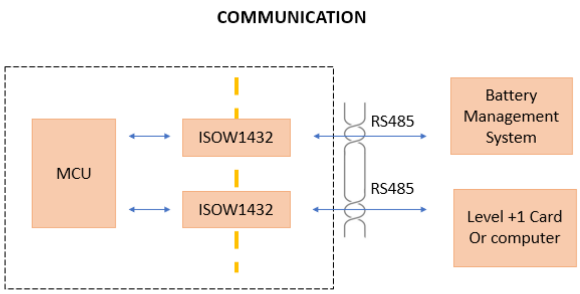

Fig. 5. Communication diagramm

VII. COMMUNICATION

Two communications are provided: one to the battery management system and one to a higher control board. These are done with the RS485 communication protocol. It is a protocol that counts some criteria necessary to operate in a harsh environment. Espacially, a differential communication that provides good noise immunity, and also faster communication, low level interface.

An additional insulation can be thought between the mcu and the outside of the system as illustrated in fig.5. For this purpose, two ISOW1485 modules are used. They allow an isolated communication.

VIII. POWER STAGE

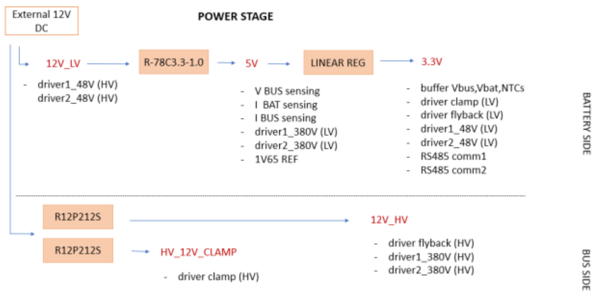

Fig. 6. Proposed supplies

Fig.1 shows the power stage organization. The clamp and flyback drivers control side are referenced on the LV side.

For the bus side gate driver, an isolated 12V supply is set up to avoid external noises . The R12P12S dc/dc module from RECOM provides 6.4 kVDC isolation and up to 2W power.

IX. PCB DESIGN

(temporary illustration)

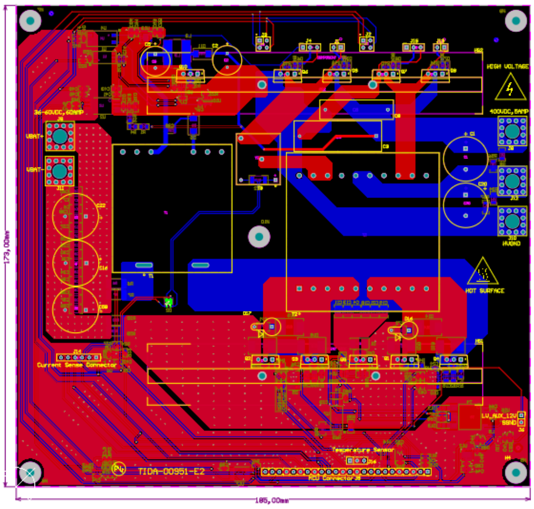

Fig. 7. Routing view of test prototype

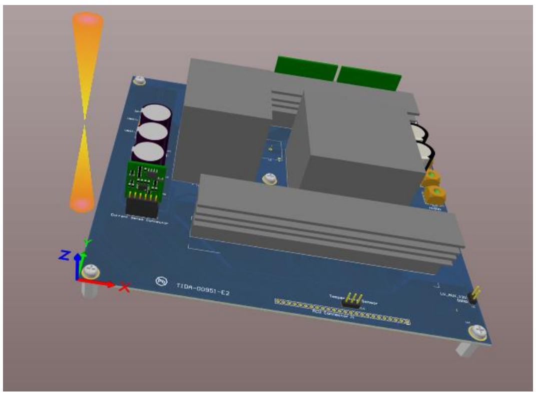

Fig. 8. 3D view of converter

Fig. 7 shows the top view of the pdb and fig. 8 shows the 3D representation in Altium designer. In terms of layout, the low level and high level parts are separated by good isolation distances. To save space, the circuitry of the texas mcu is positioned under the nucleo board, between its terminal blocks. The design is made in two layers.

X. CONCLUSION

In this paper, a brief description of the circuit is done and new references are proposed for the main modules needed to operate the converter, while paying attention to the important parameters. A next step is to proceed to new tests with the proposed circuits and thus obtain values to characterize output ripple, transition time, startup, switching stress and so on. This publication can help potential circuit designers to deploy this type of converter for the studied value range.

XI. REFERENCES

[1] A Geetha, N.P. Subramanian, R. Gnanadass, “Operation if current-fed Dual Active Bridge DC-DC Converters for Microgrid,” in *International Journal of Recent Technology and Engineering (IJRTE)*, 2019, pp. 3167-3175.

[2] Sivakumar R, “Designing a high-efficiency, isolated bidirectionnal power converter for a UPS,” in *Analog application Journal*, 2017.

[3] Jung G.Cho, Geun H. Rim, « *Zero Voltage and Zero Current Switching Full Bridge PWM Converter Using Secondary Active Clamp,* » 1996, in IEEE, pp 657-663.

[4] Kunrong Wang, V., F. C. Lee, and Jason Lai, “ *operation principles of bi-directional full-bridge dcdc converter with unified soft-switching scheme and softstarting capability* ” , 2000, pp. 111-118.

[5] G. Albright, J Edie and S aL-Hallaj, « *A Comparison of Lead Acid to Lithium-ion in Stationary Storage Applications* », AllCell Technologies LLC, 2012.

[6] BA Anandh, A Shankar Ganesh, R Sakthivel, D Mahesh Kumar, E Prem Kumar, «*Smart Battery Management System Using LiFePO4 Battery for Offline UPS* » , in al 2021 J. Phys.: Conf. Ser.

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