Double input DC-DC converter for highly flexible and reliable Battery Storage Systems

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Abstract. Battery storage systems are fundamental in UPS applications. UPSs are exploited when high reliability is required. A DC-DC converter is typically used to interface the battery to the inverter to match the different voltage levels. In normal operation, the battery of the UPS is not used and it intervenes only during grid blackout. However, the battery is subjected to deterioration and UPS intervention could fail. In medium and high power UPS, more battery modules are connected in series. If one battery is damaged, all the series is affected. To prevent this issue, a new double-input DC-DC converter is presented in this paper. The two DC sources can be controlled separately, resulting in a system reliability improvement. In addition, the damaged battery is not bypassed; hence the overall system performance can be maximized, since the deteriorated battery can provide energy at a limited rate. Additionally, the proposed converter allows batteries based on different technologies to be mixed together, achieving the best performances from each technology.

1 Introduction

The global frequency of outages and blackouts has been increasing due to the rise in power demand and control of energy supply. To address these issues, Uninterruptible Power Supply (UPS) systems are often utilized. UPSs are also widely employed to supply loads that are crucial or sensitive to disturbances in the electrical grid such as data centers, medical systems, life support equipment, communication and network systems [1].

Various methods can be used to provide longer run time; however, diesel generators and batteries remain the most popular choice at the present time. In UPS systems, a DC-DC converter that often interfaces a bank of batteries is commonly employed [2,3]. The battery bank needs to be recharged at some point after supplying electricity during a grid voltage disruption or power outage; therefore, bidirectional power flow must be managed. If unidirectional DC-DC architectures are used, two different converters are required in order to charge and discharge batteries respectively. For this reason, bidirectional DC-DC converters play a key role in UPS systems. In addition, low voltage batteries are preferred

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due to reliability and availability requirements and cost factors [4-5]; thus, researchers are currently studying bidirectional boost converter topologies with high voltage gains [6-9]. In literature, various solutions have been presented both with and without galvanic insulation [10-14]. A new double-input bidirectional boost architecture has been proposed in [15], where only three switching devices are utilized, whereas the more conventional solution made of two half-bridge converters connected in parallel uses four switching devices. The efficiency of the proposed DC-DC converter has been analyzed in [16] and a new modulation strategy has been developed and introduced in [17], exploiting the operation in Discontinuous Conduction Mode (DCM) at low-loads. In this study, this innovative DC-DC boost converter is considered, and after presenting its architecture and control principles, some simulation tests will be shown.

2 Converter Structure and control

The architecture of the proposed converter is depicted in Fig. 1.
As mentioned in the introduction, it is a boost topology and it is bidirectional. V1 and V2 are the two input voltages and their sum must be lower than Vout, which is the DC-link voltage. I1 and I2 are the two currents, which can be separately controlled. As stated in the introduction, in this particular architecture only three switching devices are employed, compared to the conventional solution where two half-bridge DC-DC converters are connected in parallel, in which four switches are used.

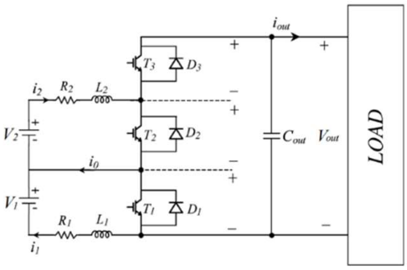

Fig. 1. DC-DC proposed converter structure.

The converter can work in the same working conditions of the two half-bridge converters; hence the two DC sources can be charged and discharged, since the two currents I1 and I2 can be both positives and negatives,
In the first modulation strategy presented in [15] only one switching device is OFF at the same time, while the other two are ON, as depicted in Fig. 2

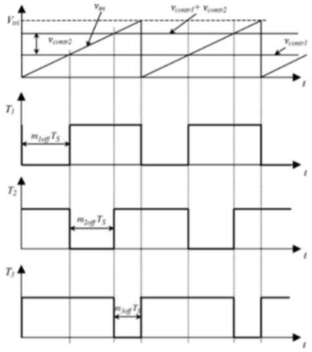

Fig. 2. First modulation strategy for the converter.

In order to exploit the operation of the converter in DCM at low loads, a new modulation technique has been designed and presented in [17], resulting in a overall increase of the system efficiency. In this particular control, an IGBT is kept always off during the entire switching period. Consequently, the current remains null when reaching zero, and DCM is exploited. The scheme of the control is reported in Fig. 3.

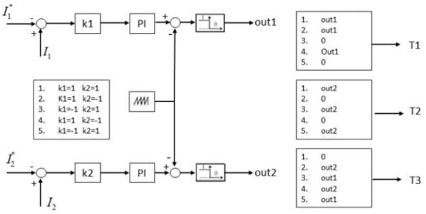

Fig. 3. Second modulation technique exploiting DCM.

For this converter architecture, two degrees of freedom exist, therefore two quantities among I1, I2, and Vout are possible to be controlled.
One solution is the current control, in which two reference currents are imposed, and the outputs of the PI controllers are used to generate the firing pulses. Fig. 4 shows the block diagram of the control.

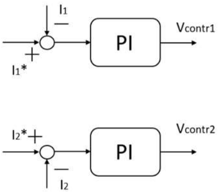

Fig. 4. Current control scheme.

A second solution is the control scheme reported in Fig. 5, where an outer loop regulates the DC-link voltage. In this condition, I1 current reference is represented by the output of the voltage PI, while the reference for I2 is external.

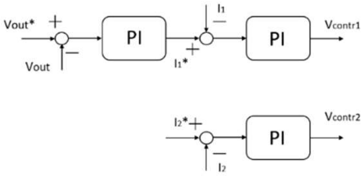

Fig. 5. DC-link voltage regulation control scheme.

Another option is to synthesize both the two currents reference signals from the output of the voltage PI controller, as depicted in Fig. 6. In this control scheme the DC-link regulation is made by both the two DC sources, while in the previous control only one DC source contributes to the regulation.

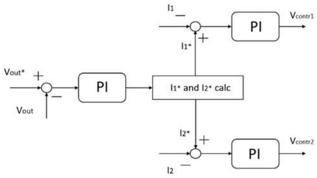

Fig. 6. Second DC-link voltage control.

3 Simulation results

A model of the system has been implemented in Matlab/Simulink/Plecs environment with the parameters reported in Table I. To show the behaviour of the proposed DC-DC converter in normal conditions and during faults, simulation tests have been carried out and some results are reported in this section.

For these simulations, an application where a battery storage system and a supercapacitor are involved is considered; therefore, V1 is the battery storage system and V2 is the supercapacitor bank.

Table 1. Converter parameters.

Parameter	Value	Parameter	Value
IGBT type	SKM400GA124D	V_2	40 V
V_1	100 V	V_{out}	400 V
L_1	910 μH	R_1	0.01 Ω
L_2	950 μH	R_2	0.01 Ω

For the first simulation the current control of Fig.4 has been considered, and the results are depicted in Fig. 7. The two references have been set to 25 A for the battery and 15 A for the supercapacitor and their instantaneous values are reported together with the average values in Fig. 7. Additionally, Fig. 7 also shows the three gate signals m1, m2 and m3, where it can be noticed that m3 is always zero.

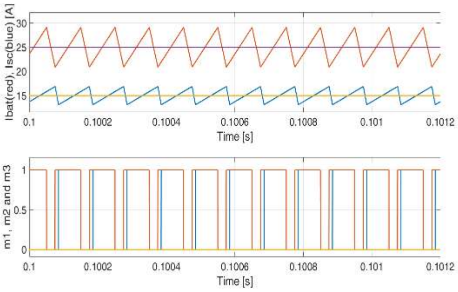

Fig. 7 I1 (red) and I2 (blue) (up), the three firing signals m1, m2 and m3 (down).

The second simulation test reports the results DC-link voltage regulation depicted in Fig. 5. The current reference for the supercapacitor has been set to 30 A, whereas 400 V is the reference for the DC-link voltage. In this case, the battery reference I1 is 7.95 A. In Fig. 8 the two instantaneous currents are shown analogously to what reported in the first simulation test.

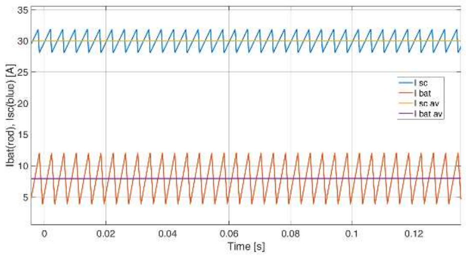

Fig. 8. I1 (red) and I2 (blue) with the DC- link control.

The DC-link voltage is depicted in Fig. 9 for the entire simulation (0.2 s).

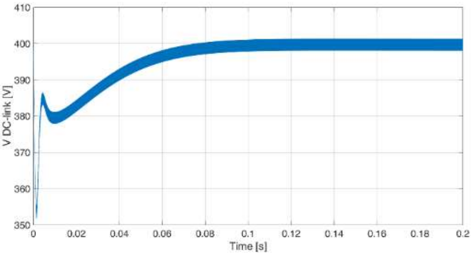

Fig. 9. DC-link voltage.

For the last simulation test the behaviour of the presented converter during a fault has been investigated. A short circuit of one of the two DC sources has been simulated. Fig. 10 shows the two instantaneous currents and the DC-link voltage is reported in Fig. 11.

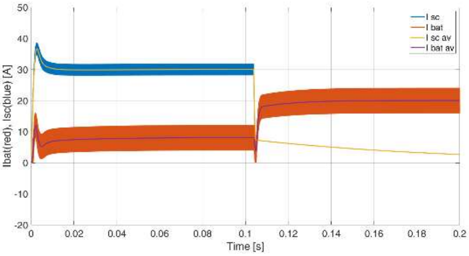

Fig. 10. I1 (red) and I2 (blue) during short-circuit fault.

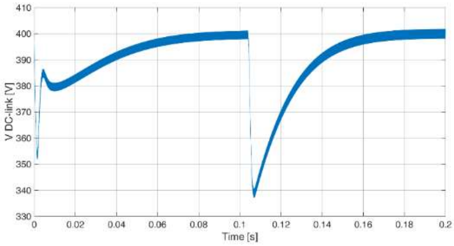

Fig. 11. DC-link voltage during short-circuit fault.

As in the previous test, the I2 current reference has been set to 30 A and 400 V has been imposed as a reference for the DC-link. At 0.105 s the short circuit occurs; as a result, I1 current reference increases from 7.95 A to 20 A. After the fault, the DC-link voltage, which was dropped due to the short circuit, correctly returns to 400 V, as highlighted in Fig. 11.

4 Conclusion

In this study a bidirectional DC-DC boost converter has been presented, where only three switches are used to interface two DC sources with a DC-link. The structure of the DC-DC converter and its main control principles have been analyzed in Section II.

A system where a battery and a supercapacitor bank are involved has been considered in this paper and some simulation results have been shown in Section III.

5 References

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