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Five level cross connected cell for cascaded converters

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Abstract

Proposed here is an alternate Five-level four-quadrant cascaded multilevel converter cell configuration that compared to the other cell configurations, for dc fault current limitation, will be more compact and avoid the external dc breaker. Loss comparison on cells with dc fault blocking capability for the cascaded converter is also presented.

Introduction

Multilevel converters have been an effective solution to reduce the harmonic distortion at the converter output and to reduce the converter losses for transmission applications. In particular, a multilevel converter consisting of a number of two quadrant half-bridge cells connected in a cascaded fashion is shown in Fig.1 [1,2,3]. From the system point of view, the drawback of this converter using half-bridge cells is that they can provide only unipolar voltage. Providing an opposite polarity voltage in converter limb is in particular advantageous to limit the surge currents in case of a dc fault. For this requirement, an external breaker with fault current limitation can be used. On the other hand, four quadrant converter cells may also be used instead of half-bridge cells. The possible cell configurations available in literature are shown in Fig. 2 [3,4]. Different cells types shown in Fig.2 can be controlled to produce a dc voltage as well as an ac voltage.

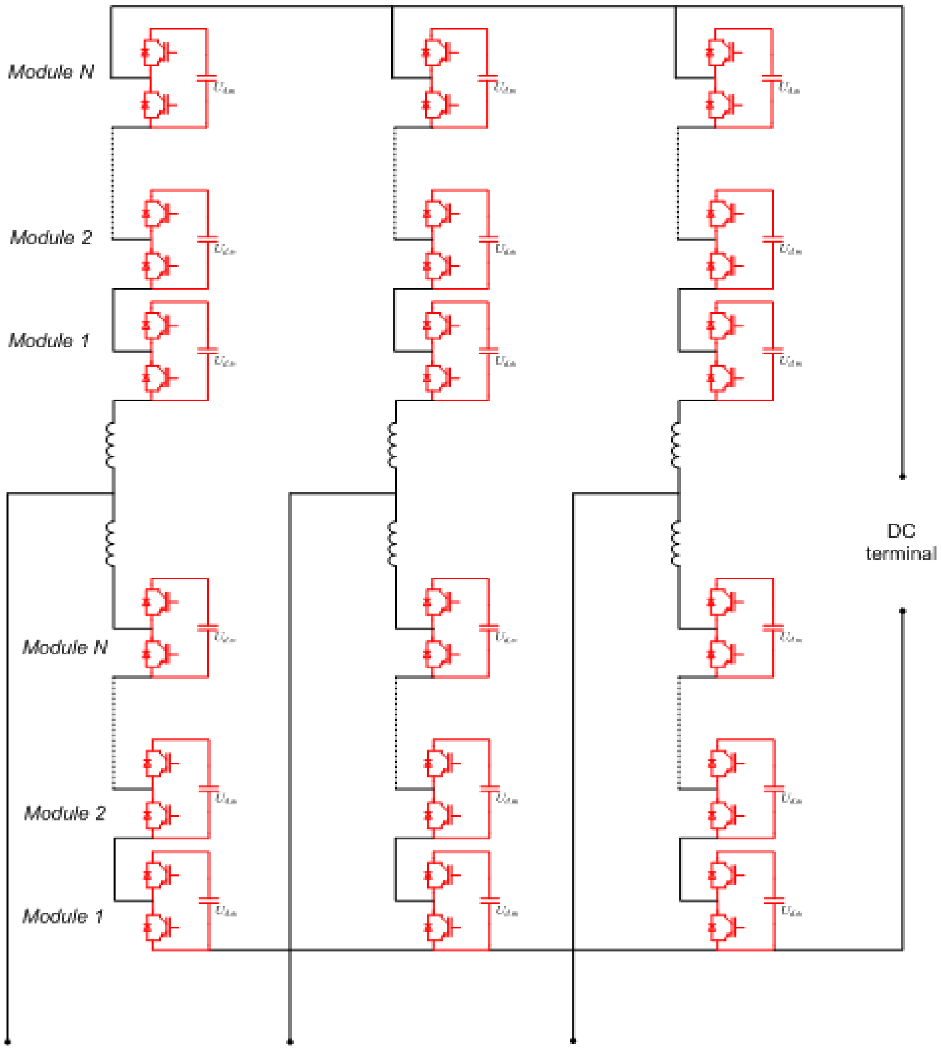
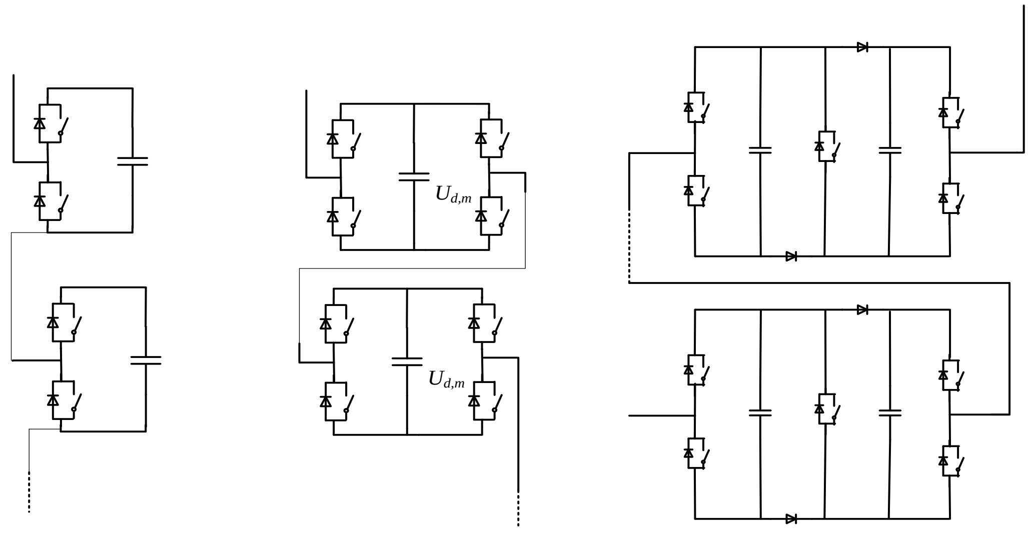


Fig.1 : Cascaded two level converter

The simplest structure of the cascaded converter can be formed by a series connection of half-bridge cell as shown in Fig.2 (a)**.** However, this configuration does not have fault limiting capability due to only the unidirectional voltage. Thereby there is a need for an external fault current limiter, which may be included in the dc breaker.

Series connection of full-bridge is presented in Fig.2 (b). It offers dc fault current blocking capability by imposing the reverse voltage as it can provide four quadrant operation follows with two extra switches. This structure is also advantageous as it provides better capacitor balancing which contributes in cell capacitor voltage ripple reduction. Normal and fault operation of this structure is shown in Fig.4.

Another cell structure called clamped-double-cell shown in Fig.2 (c) has been recently proposed to address the fault current limitation of the series connected half-bridges [4]. This converter operates as a series connection of half-bridge cells with extra switch in conduction path while during the fault it operates as series of full-bridge cells by blocking the switch.



(a) (b) (c)

Figure 2 : State of the art ac/dc modular multilevel converter cells.

By a proper switching technique of different aforementioned cells in the cascaded structure shown in Fig.1, the ac voltages of the two cascaded branches in a phase leg are in controlled in differential mode whereas the dc voltages are in common mode. Thereby a pure dc voltage will appear at the dc terminals and a pure desired ac voltage will synthesized at the ac terminal.

Taking into account that cell structure is a building block of the cascaded topologies, optimization is necessary to increase the functionality and efficiency according to different converter topology structure with more integration. To reduce the cost and loss in a cell-based multilevel converter, it is important to conceive a cell configuration which produces more number of voltage levels with the least number of device requirements. Proposed here is an alternate Five-level four quadrant cell configuration for cascaded converters. Compared to the full-bridge cell configuration, this proposed structure will be compact. Positive and negative voltage insertion in either current direction with more switch integration leads to fault current limitation inside the converter, and fault current clearance capability which avoid the extra dc breaker. Furthermore, more switching states redundancy offers freedom to distribute a possible director switch function inside the cells.

Proposed cell structure

The proposed cell structure is presented in Fig.3. As shown, this cell consists of two half-bridge cells connected back to back in a crossed fashion. This structure is able to generate a symmetrical 5 level output voltage of $2U_{d,m}$, $U_{d,m}$, 0, $-U_{d,m}$, and $-2U_{d,m}$ according to different switching states shown in Table.1. The last switching states are extra switching states, which are advantages in the configuration of [3] director switch functionality.

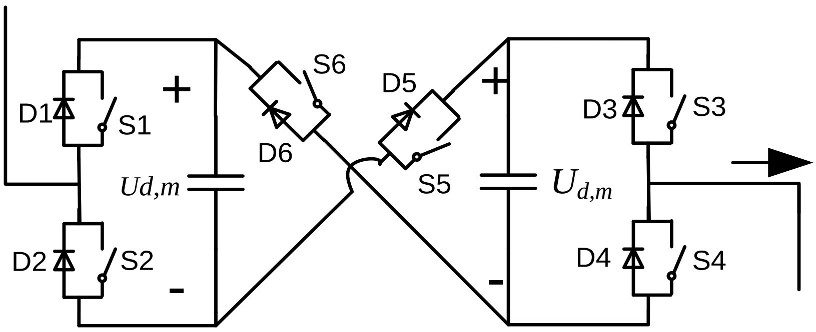


Fig. 3 Proposed ac/dc cross connected half-bridge cell (Five-level four-quadrant).

Positive and negative voltage insertion in either current direction with more switch integration leads to fault current limitation and fault current clearance capability inside the converter which avoid the extra dc breaker. Furthermore, more switching states redundancy offers freedom to distribute a possible director switch function inside the cells. As shown any voltage level can also be achieved in either current direction which can offer more flexibility in capacitor voltage control of the proposed cell structure. There is also a switching state which contributes to block the converter arm by opening the conduction path using cross switches S_5 and S_6. Converter arm can be also energized using the proposed cell structure from both the dc and ac side through the diodes: D_1, D_5, D_4 when $I_{arm}>0$ and the diodes: D_2, D_6, D_3 when $I_{arm}<0$.

Table 1: Output voltage associated with different Switching states

S_1	S_2	S_3	S_4	S_5	S_6	V_{out}	I_{arm}
1	0	1	0	1	0	$-U_{d,m}$	$I_{arm}>0$ or $I_{arm}<0$
1	0	1	0	0	1	U_{dm}	
1	0	0	1	1	0	$-2U_{d,m}$	
1	0	0	1	0	1	0	
0	1	1	0	1	0	0	
0	1	1	0	0	1	$2U_{d,m}$	
0	1	0	1	1	0	$-U_{d,m}$	
0	1	0	1	0	1	$U_{d,m}$	
*	*	*	*	0	0	Blocking	

Fault current limitation capability

There are different possibilities to clear the fault current inside modular multilevel converters using the cell structure. This section describes various cell combination solutions for fault clearance inside the converter. To be able to clear the dc fault, converter arm needs to at least provide the pole to ground dc voltage terminal in opposite polarity. Therefore, the rating of the bidirectional cell structure within each converter arm should be selected in such a way to meet this requirement. Therefore, four different combinations can be formed in order to block the dc voltage in the modular multilevel converter using the conventional and proposed two and four quadrant cell structures. If assumed that the blocking voltages of all cells are equal, the available solutions are:

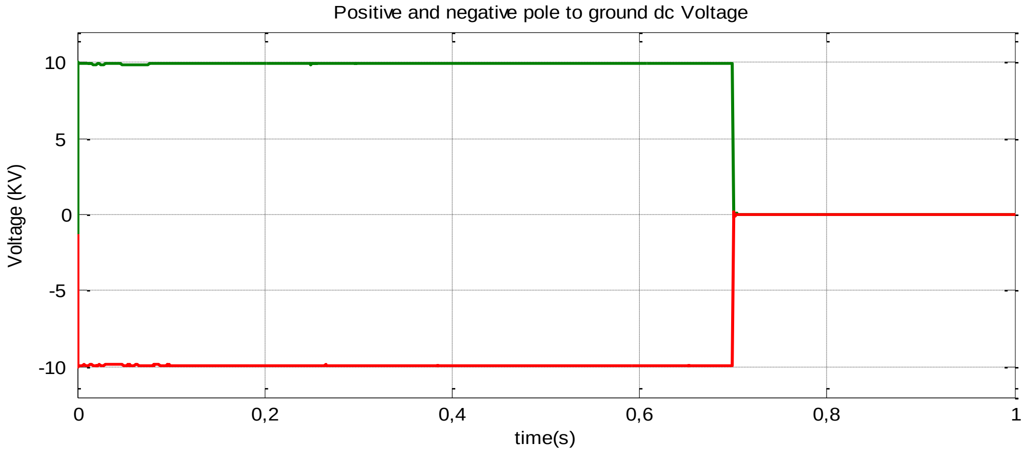
(1) 100% full-bridge cell

(2) 100% Clamped double cell

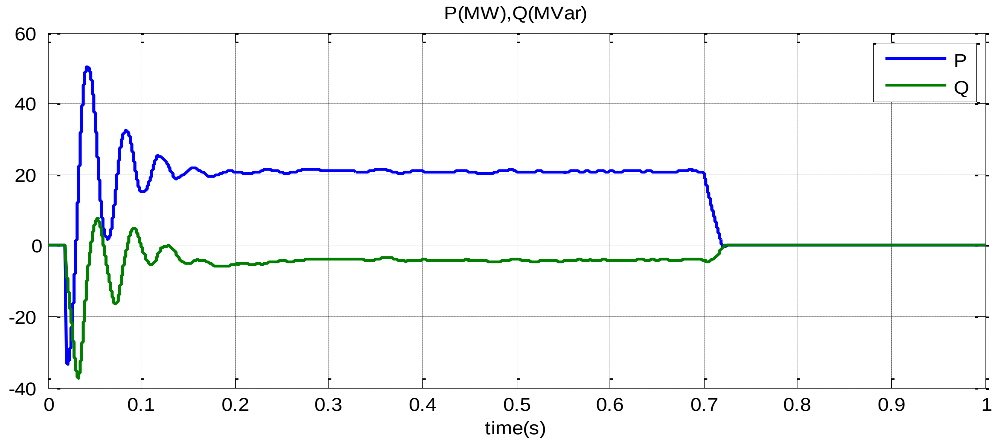
(3) 50% full bridge cell + 50% half bridge cell

(4) 25% cross connected cell + 75% half bridge cell

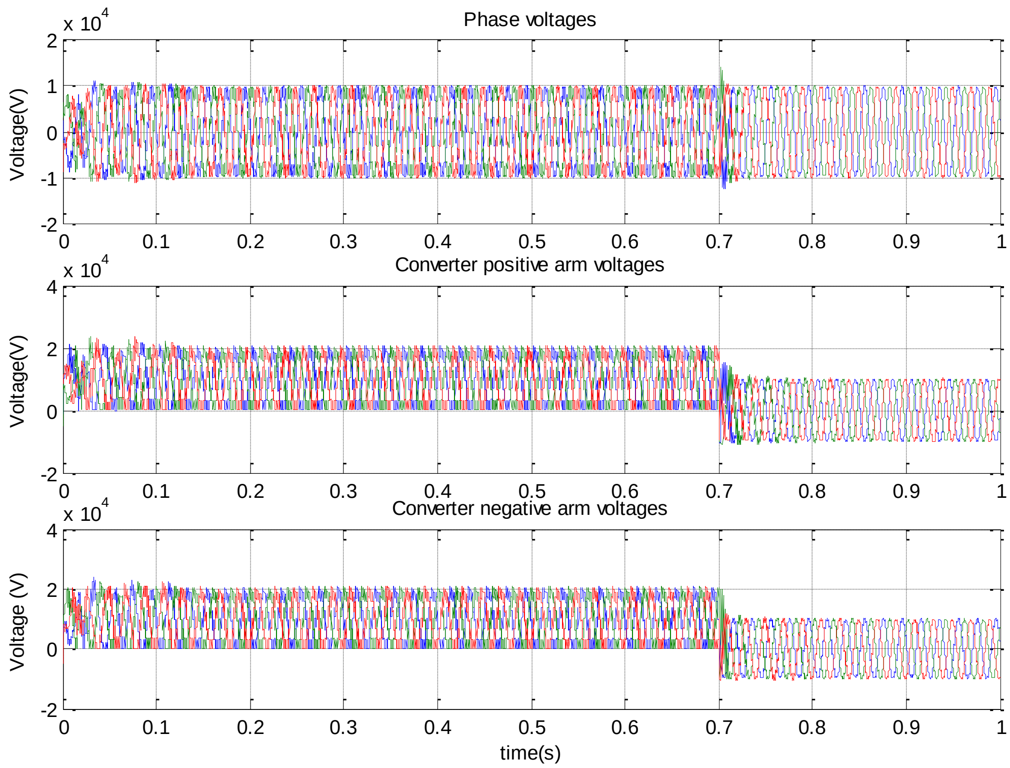
where, they all have the same dc fault blocking capability. Options (1)-(3) are formed by combinations of the conventional cell structured already discussed in Fig.2. However, option (4) is the proposed mixed cell combinations for cascaded converters. As shown, the rating of the four-quadrant cells in the proposed structure is minimized which contributes to a more compact converter structure for dc fault blocking capability. Using four quadrant cells is beneficial as said from a system point of view in case of dc faults. Therefore, Fig.4 shows some typical waveforms that illustrate the effect of having fault current limitation in case of a dc network. It is assumed that a pole to pole dc fault occurs at 0.7s and all IGBTs are blocked in 100µs after the fault.


Positive and negative pole to ground dc Voltage
Voltage (KV)
10
5
0
-5
-10
0
0,2
0,4
0,6
0,8
1
time(s)

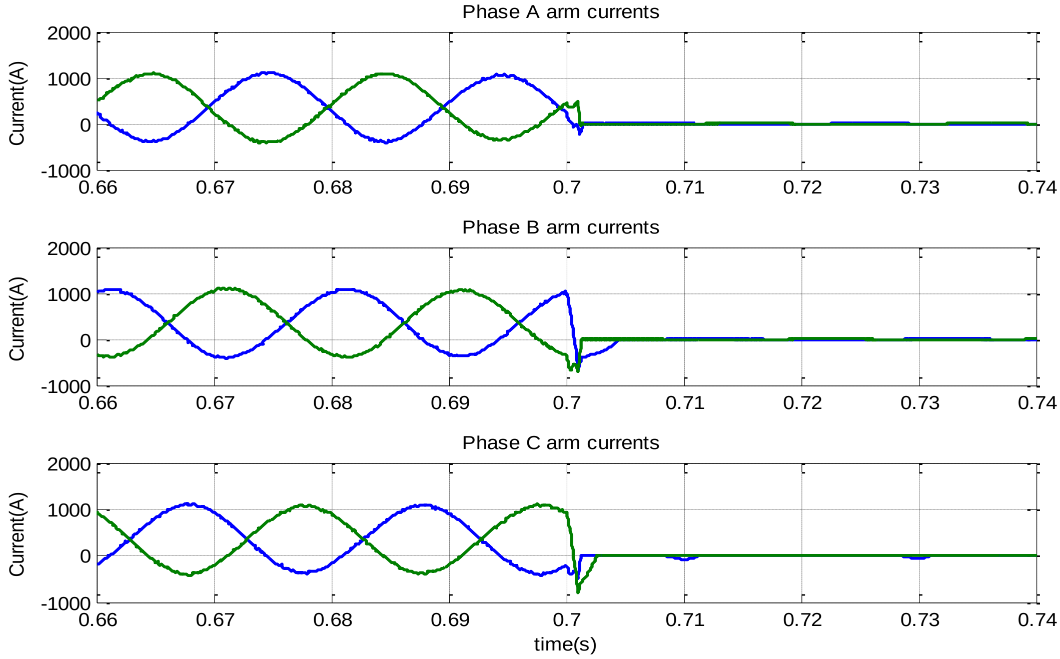
(a)


P(MW),Q(MVar)
P
Q
60
40
20
0
-20
-40
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time(s)

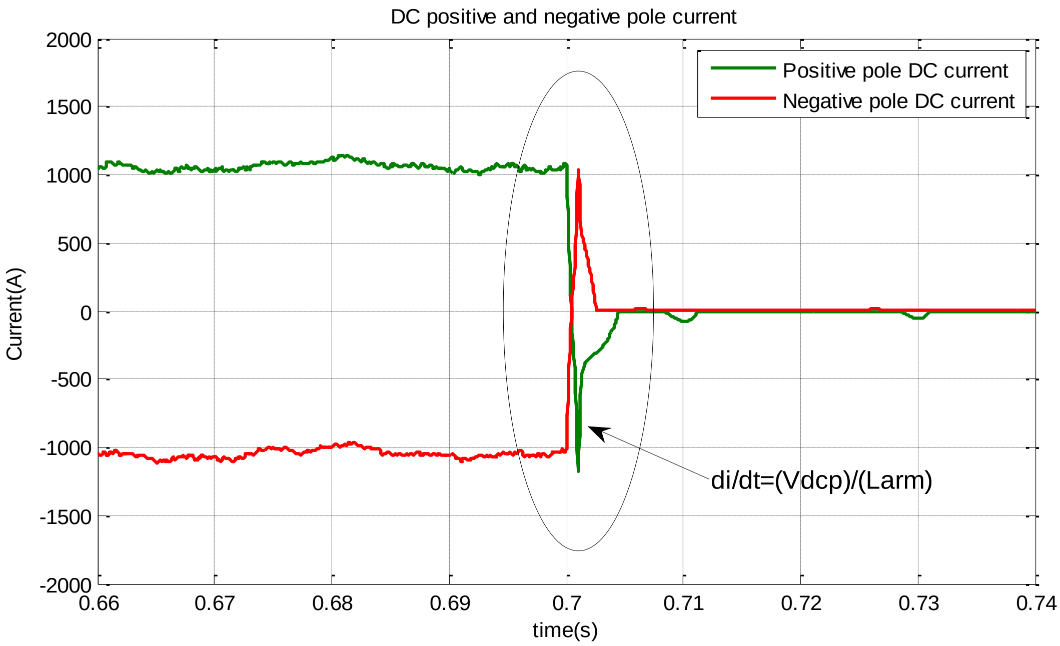
(b)


Phase voltages
x 10^4
Voltage(V)
Converter positive arm voltages
Converter negative arm voltages
Voltage (V)
time(s)

(c)



(d)



(e)

Fig.4: DC fault in dc network.(a) dc voltages (pole to pole) fault ,(b) P-Q, (c): converter output voltage, positive and negative arm voltages in each phase, (d): converter arm currents, (e): dc fault current and limited converter current.

Loss comparison of different cell structures

Cost of the converter is influenced directly by component counts and loss of the cell structure as a converter building block. Therefore, it is critical to have a loss comparison between different cell structures for fault blocking capability inside the converter arm. A case study has been carried out for a modular multilevel converter with the specification given in Table.3. A 3.3kV HiPak IGBT has been used for loss comparison between different cell solutions (See Table.2 for the datasheet).

Table 2 : ABB HiPak 5SNA 1200G330100

VCE	3.3 kV	Iref	1.2 kA
IC	1.2 kA	Vref	1.8kV
VT0	1.75 V	Temp	125 C
rT	1.66 mΩ	Eon	1.73 J
VD0	1.5 V	Eoff	1.9 J
rD	0.75 mΩ	Erec	1.67 J

Table3: Modular multilevel converter specifications

Total power rating	20 MVA
Phase voltage RMS	7 kV
Line frequency	50 Hz
Phase current RMS	1 kA
dc current	1 kA
Pulse number	3
Total dc link voltage	+/-10kV
Cell dc link voltage	1.67kV
Cell number per arm	12

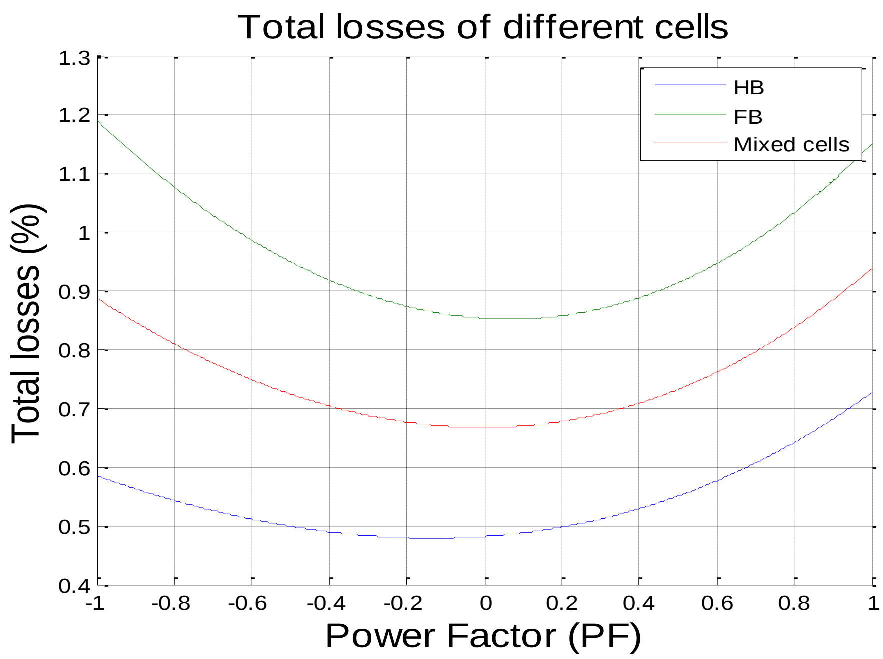


Fig.5: HB: 100% Half-bridge cells

FB: (1)100%Full-bridge cells

Mixed cells:
(2) 100% Clamped double cell
(3) 50% FB cell + 50% HB cell
(4) 25% cross connected cell + 75% HB cell

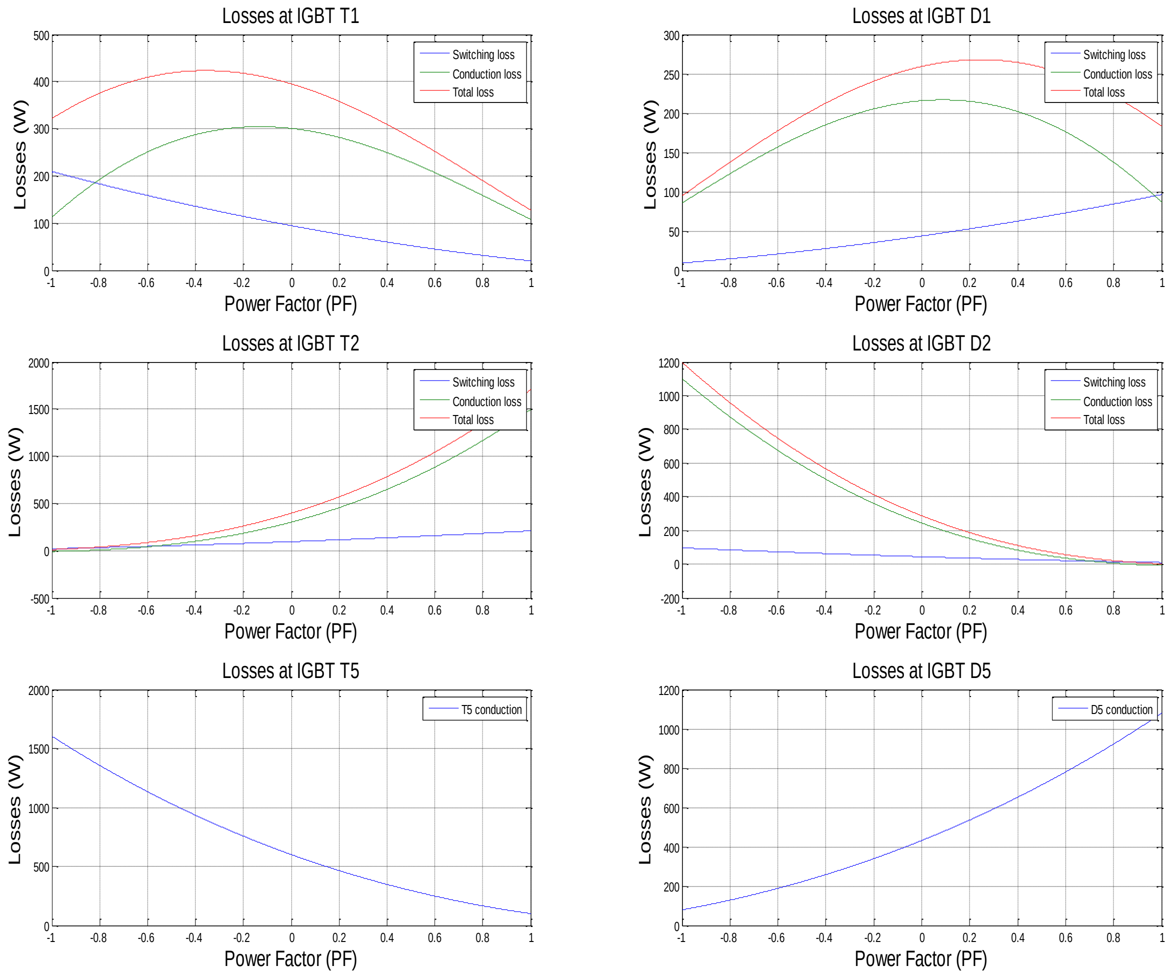


Fig 6. Cell losses at different IGBT positions, (T_5,D_5 is the constant on switching in the clamped double cell or full-bridge cell or crossed connected cell)

According to Fig.5, half bridge cells present a minimum loss compared to other cell combinations without dc fault blocking capability due to minimum number of components. On the other hand, the full-bridge cells present the highest total loss with 100% dc fault blocking capability. However, it is also shown that in all three different cell combinations [(2)-(4)]; with 100% fault dc blocking capability, loss figure is higher than half-bridges cells but less than full-bridge cells owing to an extra switch and diode (S_5 and D_5) in conduction path of all these configurations. The detailed loss calculation of different switching device has been presented in Fig.6. These results show that the mixed cell solution (options (2)-(4)) are the best choice for dc fault blocking capability while they present a minimum total converter loss.

The results also confirms that proposed cross connected cells (1) shows a similar performance regarding fault blocking capability and losses compared to other conventional solutions (2) and (3) while it enjoys a compact structure due to only 25% four-quadrant cells in the converter arm.

Conclusion

A five- level four quadrant cross connected cell has been proposed for cascaded converter topologies which can provide dc fault current limitation in case of dc faults on the dc network while it can carry out ac network support as well. Proposed cell offers a five- level four quadrant cell operation with a more compact structure. It has also verified that a proper combination of cross connected cells with half-bridge cells leads to a more compact converter solution for dc fault blocking capability while converter efficiency is same as other mixed cell solutions.

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