IMPROVED CONTROL SYSTEM FOR HYBRID AC/DC MICROGRIDS CONSIDERING TRANSIENT SHORT CIRCUIT FAULTS

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ABSTRACT

In this paper an improved control method for hybrid AC/DC microgrids, focusing on interlinking converter control is proposed. The modification of interlinking converter control is based on considering transient fault situations in both AC and DC subgrids for grid connected mode. According to the main role of interlinking converter as a gateway to deal with bidirectional power transfer control and both ac and dc side voltage control, the transients of AC or DC side faults can be transferred through the converter and harms the other subgrid and even worsening the fault situation. Thus, the effect of AC and DC side faults on the performance of interlinking converter and the main parameters of both subgrids are investigated. Then, a supplementary control is proposed to be capable of distinguishing the fault situations. Finally, in order to prevent transient fault transfer and improve the capability of interlinking converter, a downstream fault limiting function has been added to its operation. A hybrid ac/dc microgrid is simulated and simulation results for ac and dc faults are presented to validate the effectiveness and advantages of the proposed control method using PSCAD/EMTDC software. The simulation results demonstrate appropriate performance of interlinking converter on fault bypass and fault current limitations especially in DC subgrid faults.

INTRODUCTION

Microgrids are the main part of a smart grid and can be classified as ac and dc types. AC and dc Microgrids have been proposed for different applications, and hybrid solutions have been developed. The high penetration of both ac and dc microgrids in modern power distribution systems are going to increase the trends in hybrid ac/dc microgrids. These ac/dc hybrid MG structure and control strategies are presented to save energy, thereby reducing cost and increasing reliability [1]-[5].

In hybrid grid, transmission and distribution infrastructure will be better able to handle possible bidirectional energy flows, allowing for distributed generation such as wind turbines, photovoltaic (PV) farms and other power resources. However, one critical problem of these integrations is the excessive increase in a fault current due to the presence of distributed generation within a hybrid grid [2]. Consequently, both, ac and dc microgrids are required to be equipped with more compatible and reliable components with advanced control strategies [4]-[6].

Among these components, the interlinking converter (IC) plays an important role as a gateway to make the coexistence and interaction of ac and dc subgrids possible in hybrid microgrids. In literature, focusing on ICs control, various methods have been presented [1]. However, most of the studies are concentrated on voltage and frequency regulation strategies [3]-[4], dynamic analysis and control design [5]-[6] or coordinate hybrid power source (HPS) units under unbalanced and nonlinear load conditions [7].

Considering multiple routes from utility, ac subgrid DGs and dc subgrid DGs to fault locations, the excessive fault current in one subgrid could affect the neighbour subgrid of hybrid ac/dc microgrids and it could be able to cause a domino effect in total network. Therefore, smart power devices which could protect smart grid from the increasing fault current are required for the reliability and the safety of power systems. In literature, most of the publications concentrate on separate Superconducting Fault Current Limiters in microgrids [2]. However some others apply this feature to custom power devices such as DVRs or unidirectional power flow applications such as DGs [8].

In order to reduce the fault current in smart hybrid AC/DC microgrids, interlinking converters as a gateway to make the coexistence and interaction of ac and dc subgrids possible in hybrid microgrids, could be improved to enhance the transient stability of hybrid microgrid. If not controlled properly, the IC might also contribute to the ac or dc power lack in the process of compensating the missing power, thus further worsening the fault situation.

Consequently in this paper the effect of ac and dc side faults on the performance of hybrid microgrid is investigated. Then, considering the location of fault, an improved control system for interlinking converter based on transient faults in both ac and dc subgrid is presented. Furthermore, a supplementary control is proposed to be capable of distinguishing the fault situations. Finally, in order to prevent transient fault transfer and improve the capability of interlinking converter, a downstream fault limiting function is added to the interlinking operation.

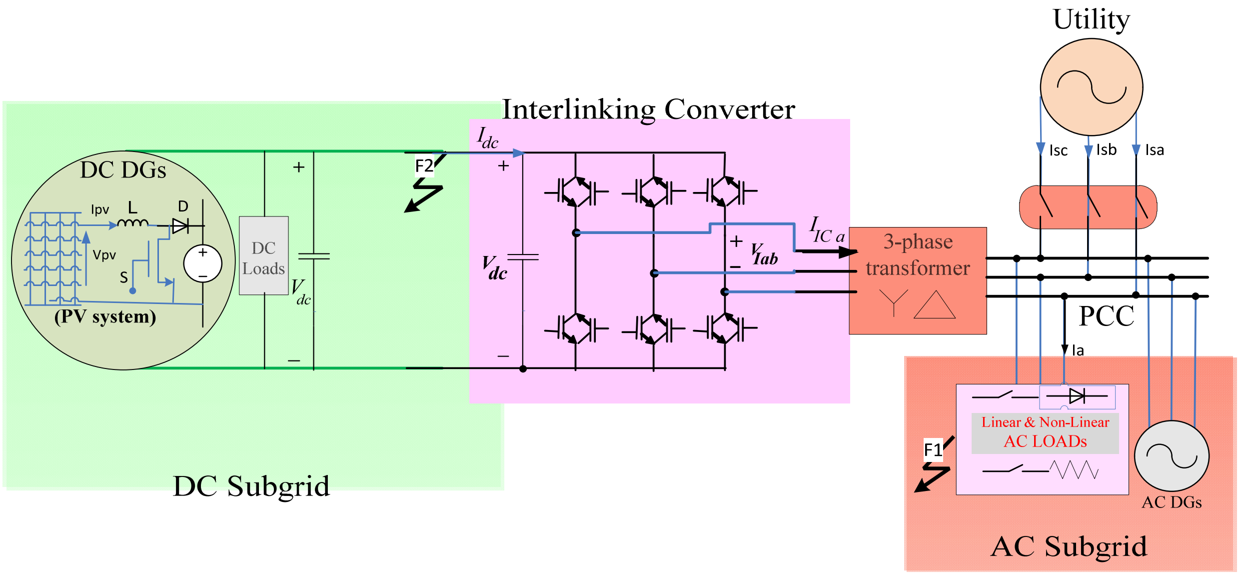

Fig. 1. The main topology of proposed hybrid ac/dc microgrid

PROPOSED HYBRID AC/DC MICROGRID AND ITS IMPROVED CONTROL SYSTEM

The main topology of hybrid ac/dc microgrid with a three phase interlinking converter is shown in Fig. 1. The presented hybrid ac/dc system is composed of a bidirectional energy conversion station using an interlinking converter, an ac distribution line with ac loads (linear and nonlinear) and ac sources (such as static generators), a dc subgrid with dc loads and dc sources (such as PV system). In this figure, a conventional 3phase three-leg power electronic switch (IGBT) based converter implemented the ac/dc conversion, bidirectionally.

The proposed control system of presented hybrid AC/DC Microgrid

In grid-connected mode, the main interlinking converter is to supply required high quality current, voltage and reactive power of ac bus. Furthermore, it should provide stable dc bus voltage for dc subgrid and exchange power between the ac and dc buses, properly.

Focusing on the interlinking converter control, the reference currents of the interlinking converter are produced based on the identification of instantaneous values of active and reactive power, using p-q theory. Power flow equations at dc and ac subgrids are [1]:

$$P_s + P_{ac\,DGs} + P_{conv.} = P_{ac\,loads} \tag{1}$$

$$P_{dc\,DGs} = P_{conv.} + P_{dc\,loads} \tag{2}$$

where, $P_{ac\,DGs}$ and $P_{dc\,DGs}$ are the real power of ac and dc DGs, respectively. $P_{ac\,loads}$ and $P_{dc\,loads}$ are the real power of loads connected to ac and dc subgrids respectively, P_s is the real power injected from utility grid to hybrid ac/dc microgrid, $P_{conv.}$ is the power exchange between ac and dc subgrids through interlinking converter (from dc to ac bus). In order to produce the reference currents of the interlinking converter, first, the instantaneous values of active and reactive power are identified as follows using Clarke's transformation [1]:

$$\begin{bmatrix} P \\ Q \end{bmatrix} = \begin{pmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{pmatrix} \times \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \tag{3}$$

where, v_α, v_β, i_α and i_β are the α-β-components of three phase ac voltages and currents. Using the reverse of mentioned matrix in (3), the reference currents could be extracted. In order to inject the instantaneous power of dc subgrid, an additional dc component ($P_{dc\,DGs}$) must be considered. Identically another additional component ($P_{dc\,cap}$) is subtracted from previous components. This component ($P_{dc\,cap}$) consist of the required power to regulate capacitor voltage, charge the battery and feed the dc loads [13]. Thus the reference currents can be expressed as follows:

$$\begin{bmatrix} i_{\alpha,ref} \\ i_{\beta,ref} \end{bmatrix} = \frac{1}{v_{\alpha\beta}^2} \begin{pmatrix} v_\alpha & -v_\beta \\ v_\beta & v_\alpha \end{pmatrix} \times \begin{bmatrix} P_{ac} + P_{dc\,DGs} - P_{dc\,cap} \\ Q \end{bmatrix} \tag{4}$$

$$P_{dc\,cap} = P_{V\,dclink} + P_{dc,loads} + P_b \tag{5}$$

where, $P_{V\,dclink}$, P_b and $P_{dc,loads}$ are the amount of real powers require to regulate capacitor voltage, charge the battery and feed the dc loads, respectively. Then, the reference currents of interlinking converter in abc form could be achieved, using reverse Clark's transformation. The achieved reference currents must be transformed to reference voltages. Consequently, using Predictive Current Control and Kirchhoff's current law at the common coupling point, the reference voltage can be written as [1]:

$$v^*_{conv.}(n+1) = v_s(n) + L_t\left(\frac{i_s(n) - i_s^*(n)}{T_s}\right) \tag{6}$$

The MPPT algorithm based control scheme for the PV system to track optimal solar panel output voltage is presented based on the fact that the slope of the PV array power curve is zero at the MPP, positive on the left of the MPP, and negative on the right. A simple proportional integral (PI) control can be used to drive dP/dV to zero. Then, the output of PI controller is duty cycle (S_{pv}) for boost converter [1].

Considering transient fault situation a supplementary power management control must be applied in IC's control to reduce the effects of large fault currents and isolate them from neighbour subgrid. Based on the position of IC, two possible types of short circuit faults can be investigated including ac side faults (like F_1) and dc side faults (like F_2) as shown in Fig. 1.

Based on the proposed topology for hybrid ac/dc microgrid, the IC's connection is in parallel with ac subgrid and injects an ac current to the ac bus. If an ac fault occurs in ac subgrid, the IC power injection due to the proposed control of this gateway couldn't be affected. If a dc fault occurs in dc subgrid, because of the series connection of IC with the dc subgrid to feed the loads through main utility a large fault current could pass through the IC. Considering dc subgrid faults, due to the fast discharge of the capacitors, it is difficult to use the amplitude of the converter current to detect a fault. Thus, the current derivative is used to fault detection. This value can be calculated as follows:

$$\frac{di_{dc}}{dt} = -\frac{v_{dc}}{R^2C} e^{-t/RC} \qquad (7)$$

After fault detection, the interlinking converter limits the injected current to the each subgrid that fault is occurred. Fig. 1(b) shows the main block diagram of control system for the interlinking converter and dc DG of hybrid microgrid during normal power transfer.

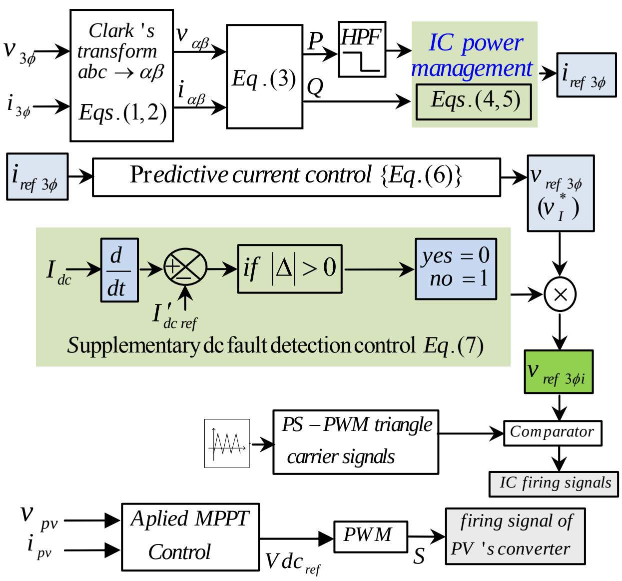

Fig. 2. The block diagram of proposed control system for hybrid ac/dc microgrid during fault situation.

SIMULATION RESULTS

The mentioned hybrid AC/DC microgrid with its proposed control system is implemented using PSCAD/EMTDC software. The simulation results are extracted for 2 fault situations (F1 in AC subgrid and F2 in dc subgrid) to verify its operation. The main parameters of components are given in Table 1.

Table 1.
Main parameters of simulated hybrid ac/dc subgrid

	Parameters	Values
AC subgrid	AC subgrid frequency (f)	60 Hz
	Utility and AC subgrid voltage(V_{ab})	380V
	AC DG rated power($S_{ac,\,DG}$)	25 kVA
	Main ac load ($P_1 + jQ_1$)	$8kW + j\,2.5kVar$
	Linear AC Load(P_2)	$2kW$
	Transformer inductance	4mH
DC subgrid	DC subgrid voltage(V_{dc})	700V
	DC DG rated power($S_{dc,\,DG}$)	10 kVA
	DC Load(P_{dc})	12.5kW
Interlinking Conv.	DC link voltage	700V
	Boost converter frequency($f_{switching}$)	3.5kHz
	Boost converter inductance	30mH
	Transformer inductance	4mH
	Switching frequency ($f_{switching}$)	10kHz
	Output RLC filters	20Ω ; 0.1mH ; 2.7μF
	DC link capacitor(C_S)	1mF

Transient short circuit fault in AC subgrid

In this section, a transient 3-phase to ground short circuit fault is occurred at t=1.25s and its duration is 0.5s. This fault is near the ac loads of ac subgrid and influences the electrical parameters of PCC, where the IC is connected to the utility.

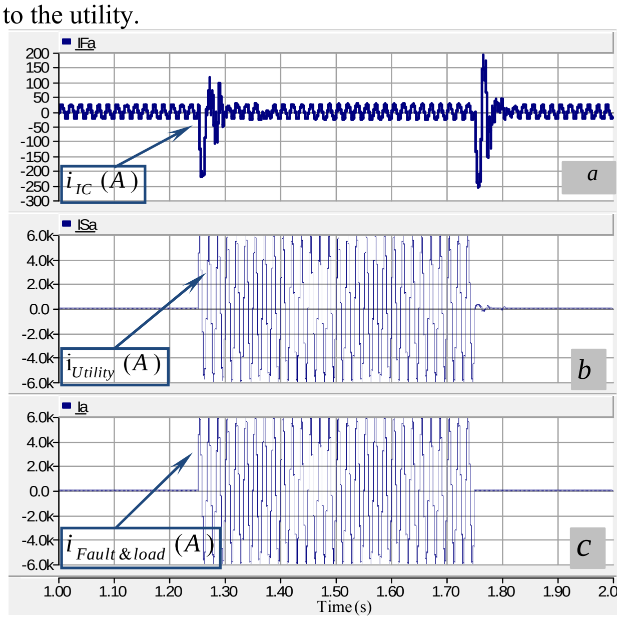

Fig. 3. The injected current of IC (I_{Ica}), source current (I_{sa}) and load side fault current (I_a) for the fault in ac subgrid at F1.

The simulation results of ac side currents (including injected current of IC (I_{Ica}), source current (I_{sa}) and load side fault current (I_a)) for the mentioned 3phase short circuit fault in ac subgrid at F1 are extracted as shown in figure2. Considering ac subgrid faults, as shown in fig. 3(a) the injected current of IC or dc subgrid are not affected by the fault current. Thus, due to the topology of hybrid system and the proposed control system, the interlinking converter and even dc DGs of dc microgrid can ride through the faults. However, a transient inrush current is injected by IC to the ac subgrid in the beginning and end of the fault.

The voltages of ac subgrid at PCC and the dc subgrid line voltage are also illustrated in Fig. 4. A voltage sag is occurred for the ac side voltage as shown in fig. 4(b). However, the IC keeps the dc side voltage stable at nominal dc link voltage value.

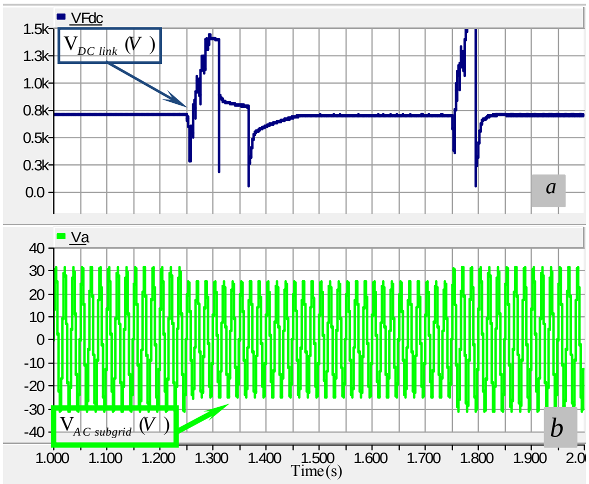

Fig. 4. The dc subgrid voltage (V_{dc}) and ac subgrid voltage at PCC (V_a) for the fault in ac subgrid at F1.

Transient short circuit fault in DC subgrid

For dc subgrid fault, a transient short circuit fault is performed between the IC and DC subgrid (dc loads and a PV system). This fault begins at t=1.25s and continues for 0.5s. Fig. 5 shows the simulation results of injected current of IC (I_{Ica}), source current (I_{sa}), load side (I_a)) and the dc subgrid current (I_{dc}) for the mentioned short circuit fault in dc subgrid (F2) without using the supplementary control. Furthermore, the voltages of ac and dc subgrids for the same situation are shown in fig. 6. Considering the simulations, dc faults directly affect the voltage and currents of IC. Therefore the proposed supplementary control should be applied and limits the injected current of IC to DC subgrid. The ac and dc subgrid currents and voltages for the same dc fault after applying the proposed control with the supplementary control are shown in fig. 7 and fig. 8, respectively.

As shown in Fig. 5(a), the dc side fault (F2) causes a large fault current through the interlinking converter and consequently increasing the ac subgrid or utility current (as shown in Fig. 5(b). furthermore, the large amount of dc current can harm the dc subgrid as illustrated in fig. 5(d). Comparing Fig. 5 with Fig. 6 shows that applying the proposed control can limits the dc fault currents. As shown in Fig. 7(a and d) the ac and dc current of interlinking converter are limited. The ac load current is supplied by the utility as shown in Fig. 7(b). Considering Fig. 6 and Fig. 8, the voltage of ac side doesn't influenced by this type of dc fault in both modes. However, the voltage of dc subgrid is zero during the fault.

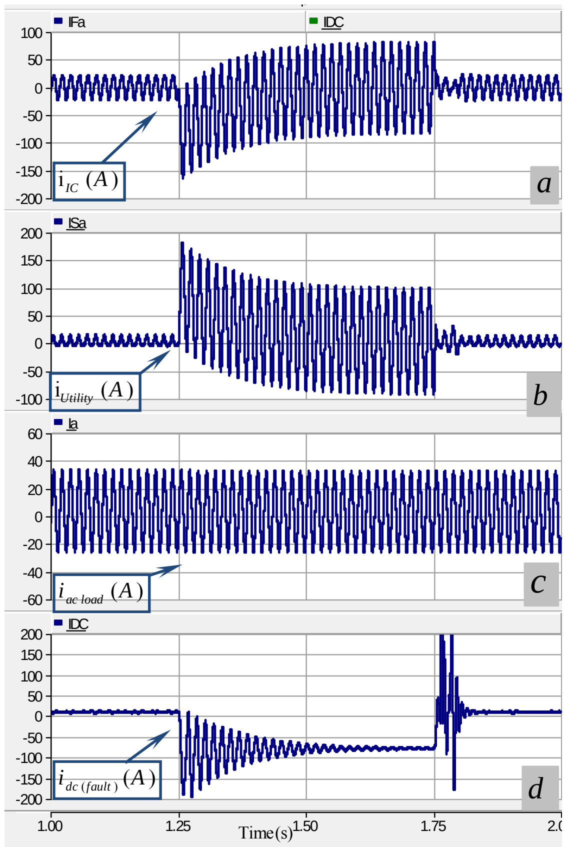

Fig. 5. The injected current of IC (I_{Ica}), source current (I_{sa}), ac load (I_{ac}) and dc fault current ($I_{dc\ fault}$) for the dc subgrid fault at F2 without applying supplementary control.

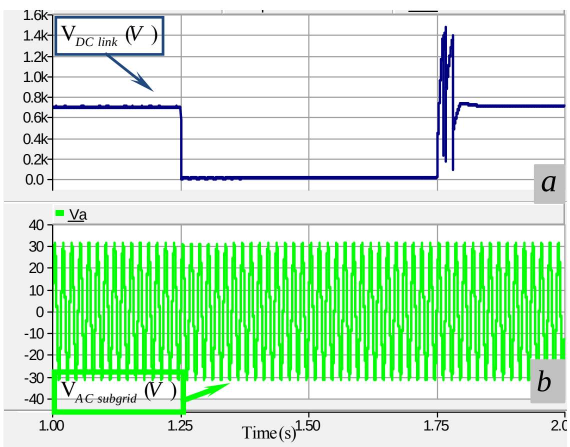

Fig. 6. The dc (V_{dc}) and ac (V_{ac}) subgrid voltage at PCC for the fault in dc subgrid at F2 without supplementary control

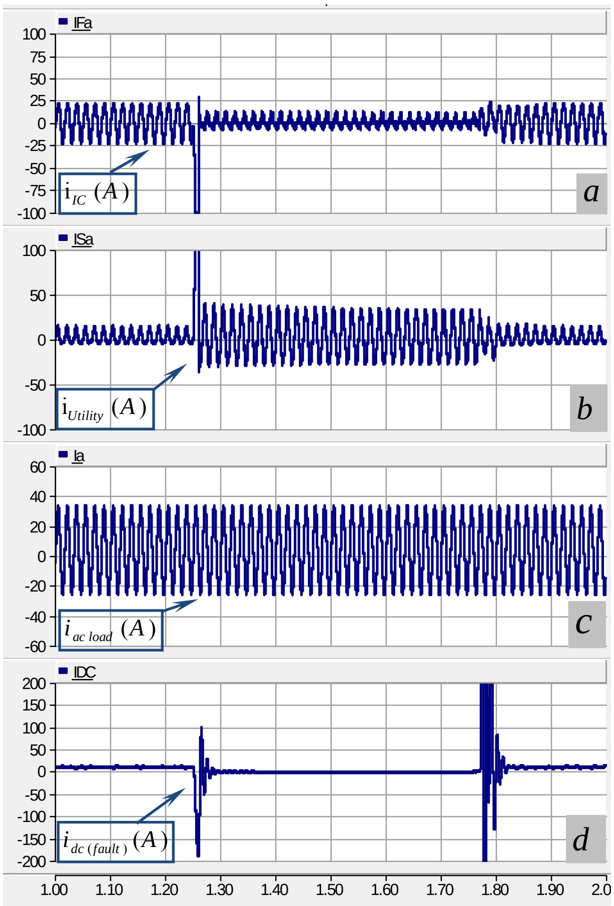

Fig. 7. The injected current of IC (I_{Ica}), source current (I_{sa}), ac load (I_{ac}) and dc fault current ($I_{dc\ fault}$) for the dc subgrid fault at F2 with applying supplementary control.

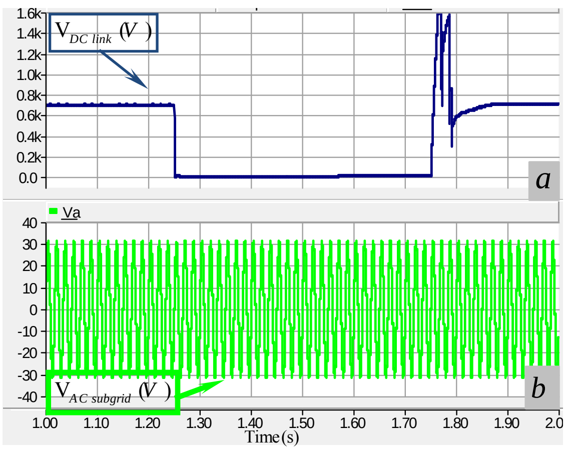

Fig. 8. The dc (V_{dc}) and ac (V_{ac}) subgrid voltage at PCC for the fault in dc subgrid at F2 with supplementary control

CONCLUSIONS

An improved control for interlinking converter considering transient fault situations in both ac and dc subgrids has been presented for hybrid AC/DC microgrids. Considering the effect of AC and DC side faults on the performance of interlinking converter and the main parameters of both subgrids, a supplementary control is proposed to be capable of distinguishing the fault situations and improve the capability of interlinking converter with adding a fault limiting function to its operation. The simulation results shows that due to the topology of hybrid system and the proposed control system, the interlinking converter and even dc DGs of dc microgrid can ride through the ac side faults. However, a transient inrush current is injected through the IC to the ac subgrid at the beginning and end time of the fault.
Furthermore, considering the dc side faults and applying the supplementary, the simulations shows the appropriate performance of interlinking converter on fault bypass and fault current limitations.

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