Hybrid AC/DC Microgrids Implement Global Power Sharing with Multi-Level Bidirectional Inter Allied Converter Communities

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Abstract: When hybrid ac-dc microgrids (HM) are formed, bidirectional inter-allied converters (BIACs) play a significant role as a bridge device for power exchange between ac and dc sub-grids. The BIAC community was created as a means of resolving the stress that a single BIAC multiple converter structure was experiencing. When compared to two-level converters, multi-level converters have benefits that help them maintain their place in present-day and future applications. For distributed power management, the multi-level converter topology improves system efficiency with a lower harmonic content. In order to perform distributed power management, this article describes the implementation of the Multi-Level Bidirectional Inter Allied Converter (MLBIAC) community and the Localised Distributed Proportional Integral Controller (LDPIC) situated at each converter in HM. The PI controller for system stability and that permits information exchange in the localised distribution controller a flexible approach. MATLAB/Simulink software was used to analyse and simulate the principles of balanced power sharing, leading role transition, bidirectional power flow, and system stability to apply MLBIAC in HM and accomplish global power sharing.

Keywords: Global Power Sharing, Hybrid ac-dc microgrid, Localized distributed controller, System stability, Three-level Bidirectional Inter-Allied Converter.

1. Introduction

Power supply to rural areas has always been a major challenge due to distance from power generation plants and it is highly capital intensive to build and maintain long distance transmission lines. Now-a-days generation of power through renewables has gained attention with reduction of fossil fuels. Hence, most of the research moved towards microgrids with medium voltage generation using renewables. With increase in load demand, penetrations of multiple sources for power generation, HM with medium voltage were developed [1]-[3]. In recent years, the requirement of high-power apparatus has begun in large number of industrial applications. Some of the motor drives and utility applications with medium voltage require megawatt power level. In the case of medium voltage microgrids, the majority of the problems arise in connecting only one power semiconductor switch directly. As a result, a Multi-Level Power Converter (MLPC) has been introduced as an alternative in high power and medium voltage applications. The first MLPC with different voltage balance techniques such as diode clamping, flying capacitance and cascaded inverters between different levels including their applications were presented in [4]. Referring to previous work done by researchers, multilevel converters found its applications most in motor drive systems. But coming across the work done in the area of renewables is much less and now it has greater deployment in the present scenario. Literature survey depicts the research work done on multilevel converters in the area of renewables.

The primary job of BIAC is to control the transfer of power between both the grids to meet supply and load demand. Various control and power management have been reported in the literature since last decade and various converter topologies and configurations of inter allied converter are reviewed in [5], [6]. Selection of BIAC depends on control objectives, which are to be fulfilled by it. In [7], a BIAC with pulse width modulation for conventional HM is presented to control ac and dc bus voltages when operated in voltage-controlled mode and to balance power flow when operated in current controlled mode. Further, these converters are paralleled for large power interactions [8]. In [9], a quasi-z-source inverter with bidirectional property is implemented to reduce stress in switches. But it has affected stability problems.

2. Proposed multilevel topology for BIAC

A three-level power converter with neutral clamped topology is considered as TLBIAC as bridging unit for power management in HM and is depicted in fig.1. The TLBIAC is structured with two capacitors C1 and C2 allied in series with a centre tap as neutral. The three-phase power circuit consists of two pairs of switching devices in each phase [10]. With the use of clamping diodes, the centre of each pair of devices is clamped too neutral. Increasing the levels from two to multi the power converter produces a staircase wave approaches to sine wave with minimal harmonic distortion. The operation of all the three phase legs is the same.

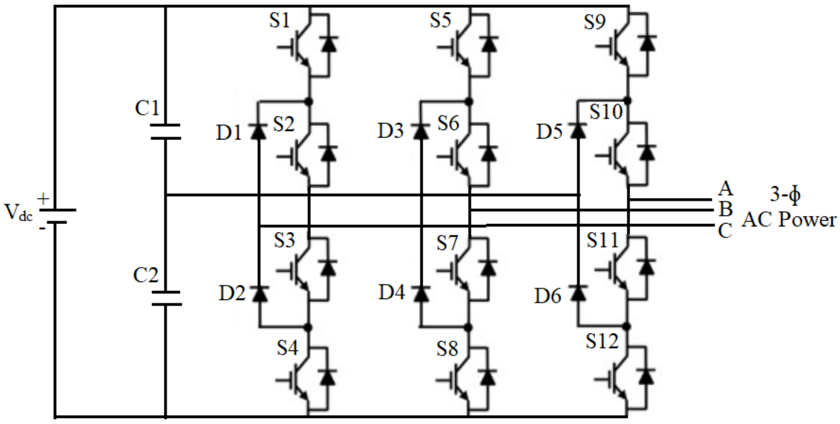


Fig.1. Power circuit of TLBIAC with diode clamped topology

Hence, for the operation of power converter, only one phase leg is considered. The switches S1 and S4 in phase leg ‘A’ work as main switching devices where as S2 and S4 functions as auxiliary devices, which helps to clamp the output voltage to the neutral point using clamping diodes D1 and D2. A carrier based three level pulse width modulation is implemented to drive the TLBIAC with the carrier frequency of 10 KHz in unsynchronized mode of operation. The TLBIAC with configuration is implemented in HM for power management [11] – [13]. As a greater number of renewable generation sources integrated into the HM to meet the load demand, large amount of power flows through the TLBIAC causing stress in it. To overcome the problem of using single TLBIAC, a community with ‘x’ number of TLBIACs were considered. A schematic of HM with TLBIAC community including the renewables, loads, and diesel generators as back up is shown in fig.2.

3. Analysis of power flow using TLBIAC community in HM

Before analyzing the power flow in HM, energy sources except renewables are considered as dispatching units and its operation is under droop control is presented in fig.3.

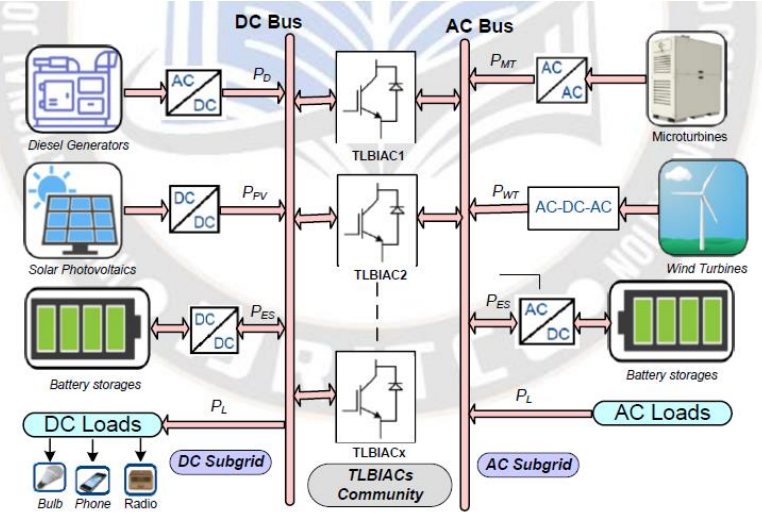


Fig.2. Layout HM with TLBIACs Community

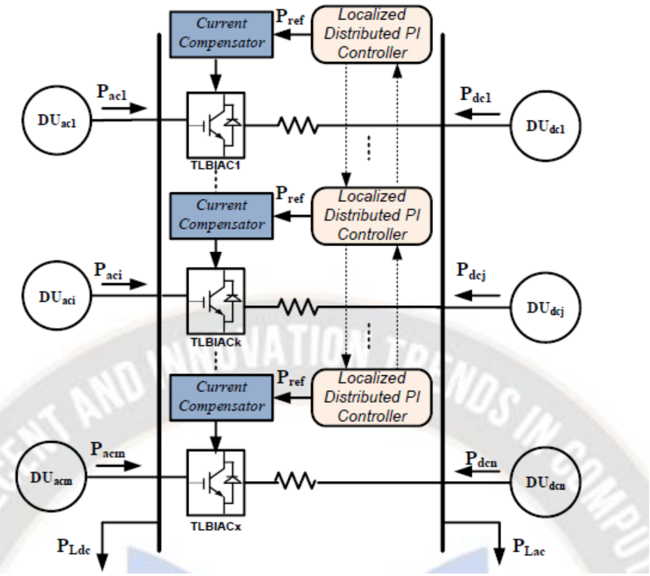


Fig.3 Proposed TLBIACs with control action

Performance of LDPIC

Implementing the proposed multilevel topology to Kth BIAC including current compensator and LDPIC for power management is depicted in fig.3.

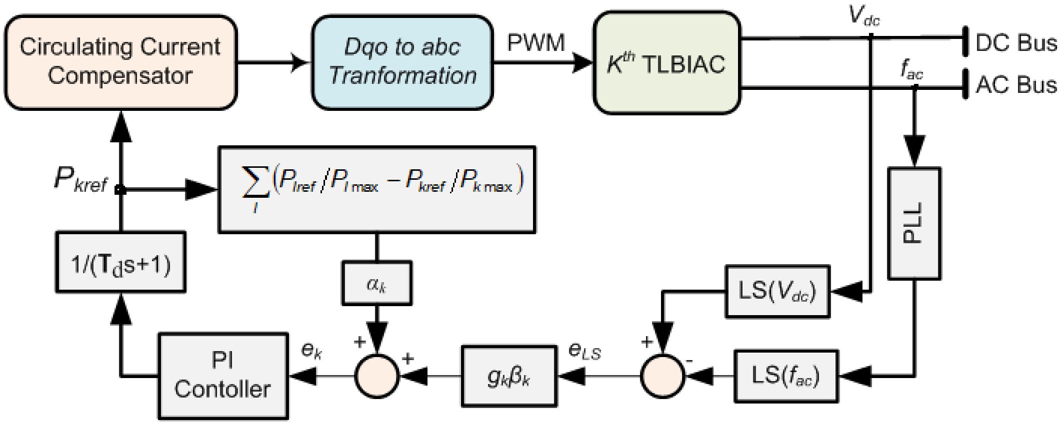


Fig.4. Control strategy for the proposed TLBIACs Community

The power reference generated from the localized distribution control using PI controller is send to the current compensator which drives the TLBIAC. To reduce switching losses, TLBIACs are chosen with large capacity. However, large capacity may have low switching frequency which results a control delay and requires high filter inductance for harmonic suppression of higher order. This affects the power interchanges and rise stability issues with improper design of current compensator [14]. To triumph over these complexities, a suitable current compensator and in order to achieve the aforementioned objectives a LDPIC is designed and placed at each of the TLBIAC in the HM. In fig.2, it is depicted that, the converter community is configured with 'x' no. of TLBIACS [15]. However, for easy analysis quantitatively the community considered to be consisting of three no. of converters and the power rating to be chosen is in the ratio of. Moreover, TLBIAC1 is designed as leader and remaining two are followers. $P_{1max}= P_{2max}=P_{3max}=1:2:3$ Moreover, TLBIAC1 is designed as leader and remaining two are followers.

Table: 1 System parameters

Parameter	**Description**	**Value**
V_{dc}	DC Bus Voltage	710V
f_{ac}	AC Bus Frequency	50Hz
V_{dcmax}	Maximum dc bus voltage	710V
V_{dcmin}	Minimum dc bus voltage	690V
f_{acmax}	Maximum ac frequency	51Hz
f_{acmin}	Minimum ac frequency	49Hz

P_{1max}	Power Rating of BIC1	6KW
P_{2max}	Power Rating of BIC1	4KW
P_{3max}	Power Rating of BIC1	2KW
Kp, Ki	Proportional, Integral gains in LDPIC	2, 800
f1sw, f2sw, f3sw	Switching frequencies of TLBIACs	10KHz, 15KHz, 20KHz

Case1:

First case demonstrates the power sharing among the three TLBIACs during unbalanced loading condition by maintaining and stable shown in fig (1) and fig (2). For analysis purpose it should be considered that, both grids are of equal capacities and AC subgrid feeds the load approximately of about 12.84KW and DC subgrid is of 0.92KW. Hence, it is easy to know that AC subgrid is loaded heavy whereas DC subgrid is loaded lightly.

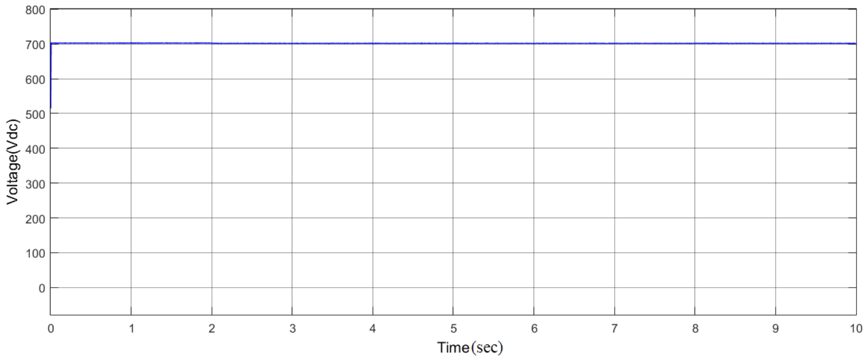


Fig. 5. DC bus voltage

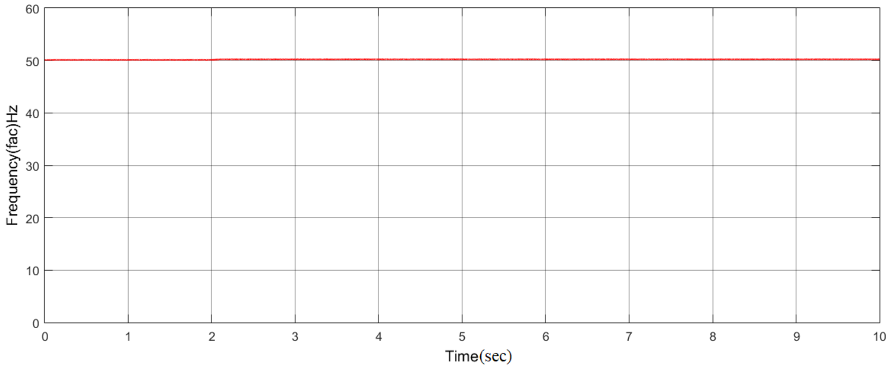


Fig. 6. Stable AC bus frequency

To balance the load between the two subgrids, and to transfer power from DC to AC subgrid the TLBIAC community should be enabled. TLBIAC1 is triggered first, immediately both the subgrids converges the power at the same value i.e, 6.86KW is shown in fig(7) and TLBIAC1 read the power as 5.97KW is depicted in fig(8).

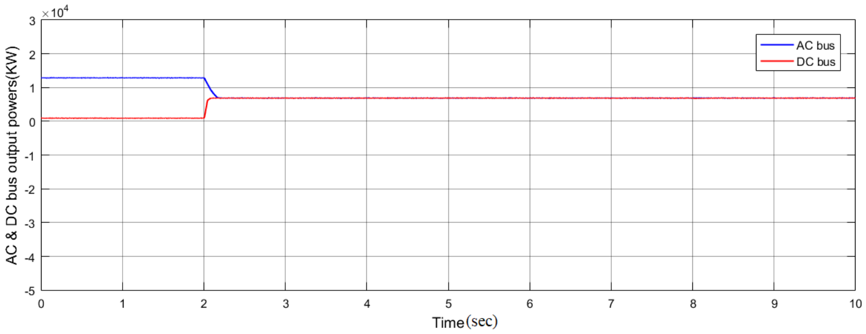


Fig.7. Output power at both the sub-grids AC and DC

Next, TLBIAC2 is triggered ON to avoid overstress faced by TLBIAC1, read as 2.39KW and the power through first converter drops to 3.58KW is shown in fig(8). However, summation of all powers that flow through the converters in the community is equal to 5.97KW. With regard to triggering of TLBIAC3 same results can be obtained and the power distributed among all the three power converters i.e 2.99KW, 1.99KWand 0.99KW is shown in fig(7). Hence, replacing the two level with multi- level converter power can be shared proportionally among sharing.

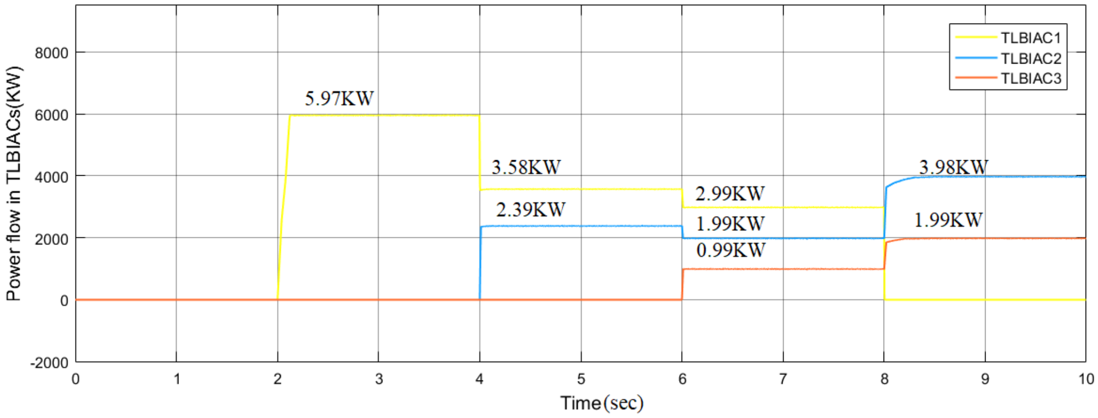


Fig.8. Power sharing among three converters and leading role during fault in first converter

Case 2

Case 2 explains the leading role taken by any other power converter during the failure of first converter in the community. When TLBIAC1 is disabled, due to occurrence of fault, appropriate PWM signals and protective devices were turned off and the power immediately decreases to zero. However, any one of power converter in the community leads the leader role by communicating each other and the total power 5.97KW is distributed among the remaining two converters i.e 3.98KW and 1.99KW respectively is shown in fig(8). Thus, the second objective is achieved approximating the power ratio as 2:1. Hence, from the above discussion it is clear that replacing two level with multi level the system has strong fault tolerant capability.

Case 3

Case 3 explains the bidirectional power flow on TLBIACs community. Considering the state of normal operating conditions of all the power converters, load on both the subgrids were increased. Immediately, inversion of power flow takes place because of increased load in DC subgrid. When load in DC subgrid is high compared to load in AC subgrid, the power changes its direction and flows AC to DC subgrid. The powers can be shown as -3KW, -2KW, and-1KW in fig(10) and output power of both subgrids converge at 19KW shown in fig(9) maintaining and as stable. Whereas, in case of AC load increment compared to DC load regains its original power flow as positive and are shown as 2.9KW, 1.9KW and 0.9KW in fig(10) approximately in the ratio of 3:2:1 maintaining the output power as 30.8KW by both the subgrids shown in fig(9).From the above results it is clear that bidirectional power flow also occurs with replacement of two level with multilevel topology and designing proper LDPI controller.

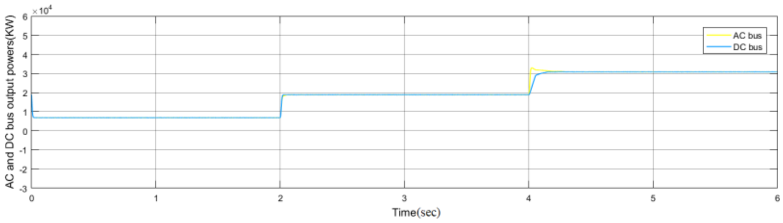


Fig.9. Output powers of AC and DC subgrids

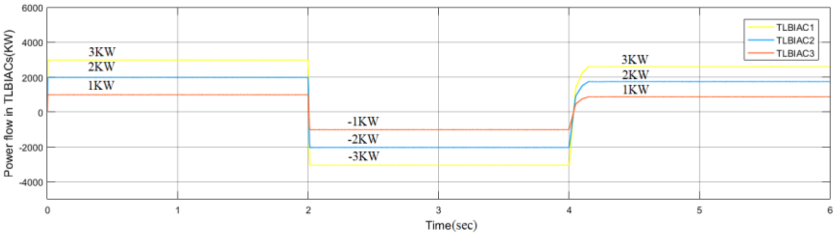
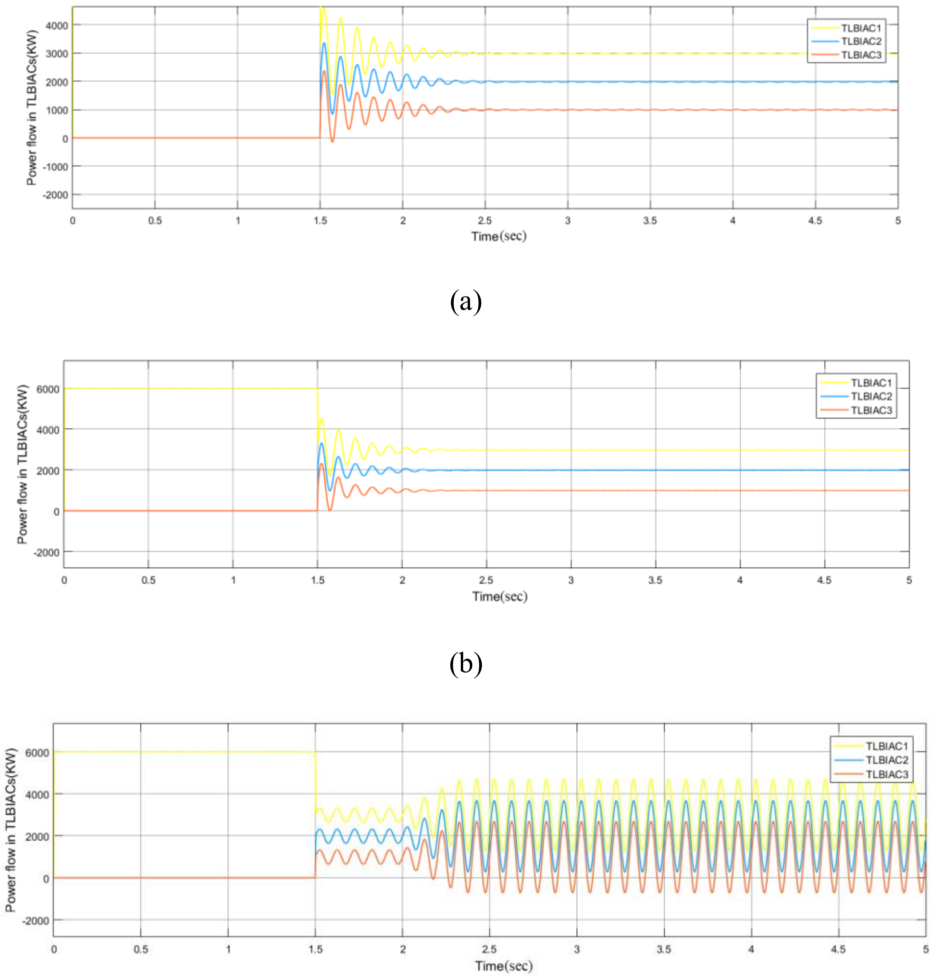


Fig.10. Bidirectional power flow in TLBIACs community

Case 4 Effect of Communication delay on system stability

From the power flow analysis of TLBIACs it can be observed that, a parameter known as communication delay affects the overall system stability. Hence, case 4 discusses about the system performance for various values of communication delays. Referring to case 1, TLBIAC1 is enabled first, and remaining two converters in the community are at stand alone.



(a)

(b)

(c)

4. Conclusions

In order to analyse the principles of power sharing in HM, a TLBIAC community with a neutral clamped configuration is suggested and constructed in this study. Each TLBIAC in the community has an LDPIC attached to it to produce the proper power reference. The community's TLBIACs have effectively demonstrated the ability to take the initiative in role transitions in the event that one or more of the converters fails, sharing the power according to their ratings in a about 3:2:1 ratio while avoiding overstress. Moreover, based on the subgrid's loading circumstances, bidirectional power flow is also made possible. The system's stability is also affected by a communication latency. The power via TLBIAC is monitored for values of 0.5sec, 0.8sec, and 1.0 sec of td, and it is determined that Beyond 0.9 seconds, the system becomes unstable due to the td value. Because of this, the value of td must be less than 0.9 seconds. The suggested approach to achieve worldwide power sharing was validated by MATLAB/Simulink.

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