BIDIRECTIONAL DC-DC CONVERTER WITH HIGH FREQUENCY TRANSFORMER (DHFT) IN AC/DC MICROGRID

Mr. C. Balaji., B.Tech. M.E.,
Assistant Professor, Kings College of Engineering, Pudukkottai

K. Devika
PG Scholar, M.E- Power Electronics and Drives, Kings College of Engineering, Pudukkottai

Abstract
In this paper, DC/DC converter with High Frequency Transformer (DHFT) is proposed to replace the conventional bulky transformer for bus voltage matching and galvanic isolation. Various DHFT topologies have been compared and CLLC-type has been recommended due to its capabilities of bidirectional power flow, seamless transition and low switching loss. DHFT are designed in order to maximize the conversion efficiency and minimize output voltage variations in different loading condition. This paper presents a series-connected high frequency DC/DC converter connected to a DC microgrid system to provide auxiliary power for lighting, control and communication in a DC light. Thus, Metal-Oxide-Semiconductor Field-Effect Transistors (MOSFETs) with a low voltage rating and a turn-on resistance are adopted in the proposed circuit topology in order to decrease power losses on power switches and copper losses on transformer windings. Lab-scale prototypes of the DHFT and hybrid AC/DC microgrid have been developed for experimental verifications.
Keywords*: AC/DC microgrid; DHFT; CLLC; Bidirectional power flow; conversion efficiency*

Introduction

DC Miecrogrid has become popular due to the increasing penetration of DC compatible loads (mainly electronic loads and motors with variable speed drives) and Renewable Energy Sources (RESs)[1,2]. In order to compensate the RESs generation intermittency, localized energy storages, like various electrochemical batteries, ultra capacitor and Lead Acid Battery most of which are DC inherent, are implemented. As a conventional solution, the aforementioned DC sources, storages and loads are connected to the AC network through dedicated DC/AC conversions [3,4].It will induce significant energy loss and reduce system reliability.

Alternatively, DC microgrid, which exhibits better compatibility with DC compatible sources, storages and loads, can be the solution. However, the direct DC compatible appliances, which are commercially available, are limited and more costly compared with conventional ones due to low production volume.

Hybrid AC/DC microgrid is proposed as a comprised solution to minimize the number of power conversions and enhance system energy efficiency [5,6]. The Battery and solar PV are connected to the DC bus through respective DC/DC converters and wind turbine is connected to the AC bus through AC/AC conversion. AC and DC loads are supplied from respective bus directly.

The Bidirectional Interlinking Converter (BIC) is used to realize the power flow between AC and DC bus. In this work, replacement of the bulky conventional transformer by DC/DC converter with High Frequency Transformer (DHFT) is proposed. DHFT is a DC/DC conversion topology with high power density and wide range of voltage boost/buck ratio. At the same time, DHFT conversion can be divided into two stages, namely DC/AC and AC/DC.

A high frequency transformer interlinks these two stages, with which, DC sub-grid isolation can also be achieved. The DHFT is installed between the DC bus and BIC DC output. The boost ratio of DHFT is designed so that the voltage magnitude of BIC AC and DC outputs can be matched with the conventional single-stage topology. Compared with the conventional solution as illustrated, implementation of DHFT will help reduction of system weight and space occupation significantly, while retaining the system performance.

Control of Hybrid AC/DC Microgrid with DHFT

A DHFT prototype has been developed and integrated into the hybrid AC/DC microgrid. A DC programmable source has been used to simulate the BESS for DC bus voltage regulation. The DC load bank tied to the V/DC bus to emulate different loading profiles and also enables bidirectional power flow of BIC and DHFT.

The HV side of DHFT is connected to the BIC DC output.BIC AC output is tied to an AC programmable source, which is used to emulate the DG/UG for AC voltage/frequency regulation. Both BIC and DHFT will be simulated using MATLAB.

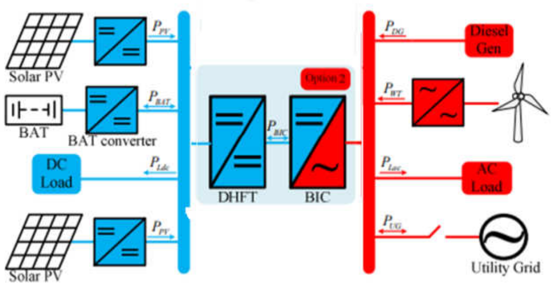

Fig.1: Schematic layout of a hybrid AC/DC microgrid.

The schematic diagram of hybrid AC/DC microgrid with implementation of DHFT is shown in fig.1. DHFT boosts the DC bus voltage to the magnitude such that the voltage at DC and AC outputs of BIC can be matched with single-stage topology.

The control algorithm of BIC remains unchanged. BIC is capable of operating in three modes, namely AC Voltage Regulation Mode (VRM), DC VRM and Power Dispatch Mode (PDM), based on the availability of AC and DC sources.

Capability of multiple-mode operation of DHFT, which is connected in series with BIC, is expected. It makes both DHFT operating modes and system operating scenarios complicated. What’s worse, instant operating mode transition in accordance to BIC operating modes set a challenge for the communication link between the DHFT/BIC and central controller.

a. Operating Scenario 1

In operating scenario 1, BESS outage has occurred due to unavailability of battery bank or converter faults. The AC bus voltage/frequency regulation is controlled by UG/DG, while the DC bus voltage is regulated by BIC in DC VRM. Therefore, the HV side of DHFT is regulated and the power flow is determined by the power balance in DC sub-grid. If PV generation exceeds DC load consumption, the excess power will flow to AC sub-grid through DHFT and BIC.

b. Operating Scenario 2

In operating scenario 2, neither UG nor DG is available. The DC bus voltage is regulated by BESS and BIC is scheduled to operate in AC VRM to control the AC sub-grid voltage and frequency. Similar to operating scenario 1, the LV side of DHFT is regulated and the HV side power flow direction and magnitude is determined based on the power balance in AC sub-grid.

DHFT Design

The criteria of DHFT design include:

- High conversion efficiency
- Rated conversion ratio with minimum voltage variations in different loading conditions
- Autonomous power flow and seamless transitions

The detailed design procedures are illustrated as follow:

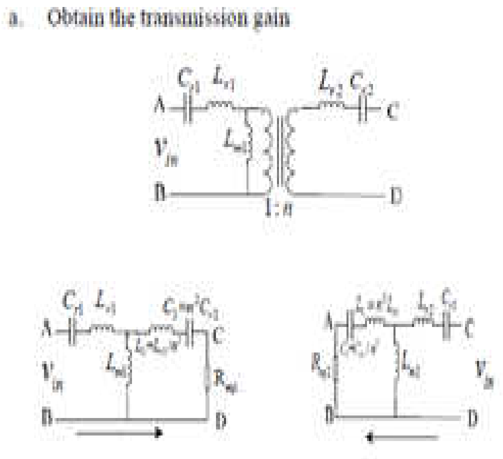

Fig.2: DHFT with CLLC Topology

The schematic diagram of DHFT with CLLC topology is the resonant circuit is comprised of the capacitors Cr1, Cr2 and leakage inductance Lr1, Lr2. *L*m1 is the magnetizing inductance for power transform from AB to CD port. The equivalent circuit diagram of power flow transitions between LV and HV sides is as shown in Fig.2. *L*1, *C*1, *L*2 and *C*2 denote the equivalent inductance and capacitance of the primary and secondary sides, respectively. Take the power flow from AB to CD.

The transmission gain of the DHFT can be normalized as: The relationship between the normalized gain and parameter *g* can be illustrated as shown in Fig.2. It can be observed that the maximum gain point varies with different *g* selection, which indicates that the resonant point is related to the secondary capacitor.

However, the maximum transmission gain has kept almost constant with different *g* values. Therefore, based on the DHFT design, there are many combinations of *Cr1* and *Cr2* that can achieve the desired transmission gain.

Table I Operating scenario of hybrid AC/DC microgrid

Scenario No.	DC bus regulator	AC bus regulator	DHFT Scenario
1	BESS	UG/DG	LV regulated
2	BIC in DC VRM	DG/UG	HV regulator
3	BESS	BIC in AC VRM	LV regulator

In the proposed hybrid AC/DC microgrid, DHFT operates under the resonant condition to ensure the maximum transmission power and reduce the switching loss. Moreover, combining the aforementioned analysis, the designed DHFT can ensure satisfactory performance with multiple choices, especially for the resonant capacitors.

A DHFT prototype has been developed and integrated into the hybrid AC/DC microgrid test bed as shown in Fig. 3. A DC programmable source has been used to simulate the BESS for DC bus voltage regulation. The DC load bank tied to the 380V/DC bus to emulate different loading profiles and also enables bidirectional power flow of BIC and DHFT.

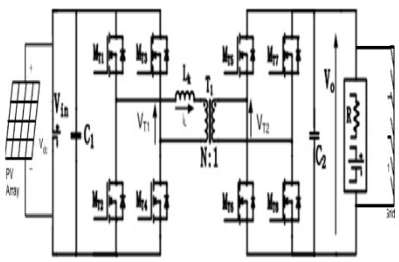

Fig.3: Schematic diagram of proposed system

Experimental Verification

A DHFT prototype has been developed and integrated into the hybrid AC/DC microgrid test bed as shown in Fig. 4. A DC programmable source has been used to simulate the BESS for DC bus voltage regulation. The DC load bank tied to the 380VDC bus to emulate different loading profiles and also enables bidirectional power flow of BIC and DHFT. The HV side of DHFT is connected to the BIC DC output as shown in the figure.

The HV side of DHFT is connected to the BIC DC output as shown in the figure. BIC AC output is tied to an AC programmable source, which is used to emulate the DG/UG for AC voltage/frequency regulation. Both BIC and DHFT are controlled with Digital Signal Processor (DSP).

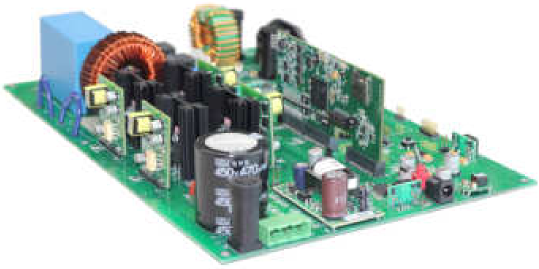

Fig.4 Lab-scale setups for experimental verifications

Table II. Parameters of experimental setups

Parameters	Values
AC bus nominal voltage	400V (Line-Line)
DC bus nominal voltage	380V
DHFT HV side nominal voltage	760V
BIC and DHFT Rated power	7kW
DHFT switching frequency	100kHz
Inductance	1.25mH
Primary side capacitance *Cr1*	0.165µF
Secondary side capacitance *Cr2*	0.0825µF

Both system power flow and DFHT HV side voltage controlled steadily. When transition of BIC power flow has been trigger, BIC power has been reduced gradually and stabilized 0.75kW from AC sub- grid to DC sub-grid

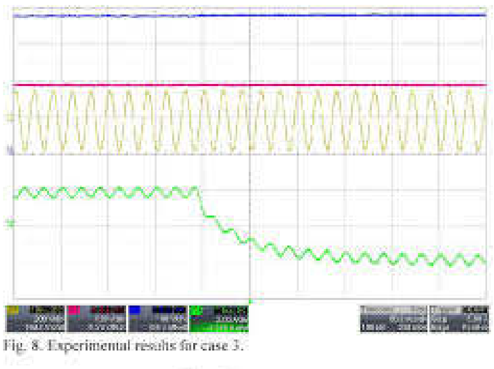

Fig.5: Experimental results of circuit 1

The DHFT HV side voltage has remained smooth with insignificant variations. BIC current ripples measured at the DC output can be eliminated with inductor installed at the DHFT HV side.

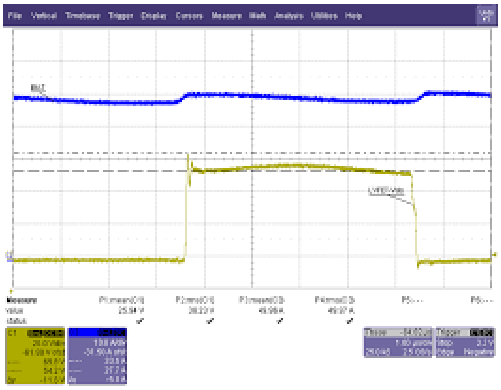

Fig. 6 Experimental results of circuit 2

Conclusion

In this paper, DHFT with CLLC topology has been proposed to replace the conventional bulky transformer in hybrid AC/DC microgrid for BIC voltage matching and galvanic isolation. Different system operation have been analyzed and open-loop control of DHFT has been recommended to simplify system control algorithm and enhance reliability. Derivations of DHFT design parameters have been carried out as the guidance of prototyping. Various experimental cases have been conducted and the performance of DHFT in hybrid AC/DC microgrid.

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