DESIGN AND DEVELOPMENT OF BI-DIRECTIONAL DC-DC CONVERTER FOR POWER SYSTEM LEARNING

Electrical Engineering and Computer Science
Power System Engineering

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1. Introduction

A lab-scale grid-connected system integrated with battery energy storage is being developed. The system is composed of a full-bridge inverter, an isolated bidirectional DC–DC converter, and a battery set. We aim to demonstrate a micro grid system experimental simulation for an easy understanding of a large-scale micro grid system. However, in order to create an exact representation of a micro grid system, the lab-scale system must fulfil the requirement of a grid-connected inverter, in which power values are assigned to the system to cope with the intermittent output from renewable energy sources. Therefore, a lab-scale prototype is developed to verify the performance of the system. Current target is to simulate and develop a module of bi-directional DC-DC converter to circulate the power flow interval between two DC buses [1]. Therefore, the controlling of the power output either as constant power or variable power in relation with the frequency of the distributed generation system is operated.

2. System Configuration

Fig. 1 shows the micro grid system configuration, which consist of both an AC and a DC network allows AC network elements such as AC generation and loads, and DC network elements such as batteries, fuel cells, PV arrays, DC loads etc. to be separated. The full-bridge inverter is connected between the DC bus and the grid. It converts the bidirectional power flow and regulates the voltage of the DC bus when the utility is in nominal operation. It also generates AC power and thus supplies uninterrupted power to the critical loads when the utility fails. In particular, power management module may direct to operate according to various modes regarding the transfer of power such as delivery mode and charging mode of the battery set.

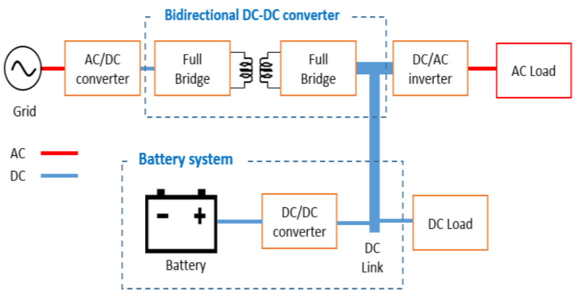

Fig. 1 System Configuration.

The experiment is simulated using PSIM software. Both the direction and the amount of power flow are controlled by controlling the phase difference between the output voltages using phase-shift method control [1]. The power transfer, P_D , of the bidirectional DC-DC converter can easily be controlled by adjusting the phase-shift-angle, δ[rad], and the equation given as

$$P_D = \frac{V_{D1} V_{D2}}{\omega L}\left(\delta - \frac{\delta^2}{\pi}\right) \qquad (1)$$

where V_{D1}, V_{D2} is the voltage amplitude of the power converter, ω is the angular switching frequency, and L is the auxiliary inductor.

3. Design of Bi-Directional DC-DC Converter

Fig. 2 shows the proposed design and development of an isolated bidirectional DC–DC converter module. This module consists of a microcontroller, two set of buffer circuits, four sets of gate drivers and their adaptor boards, two sets of full-bridge modules, and a high frequency (HF) transformer. The functions of each component were listed in Table 1. It also requires high performance, high efficiency, and small size. The electrical isolation between the AC side and battery side is needed for safety purpose.

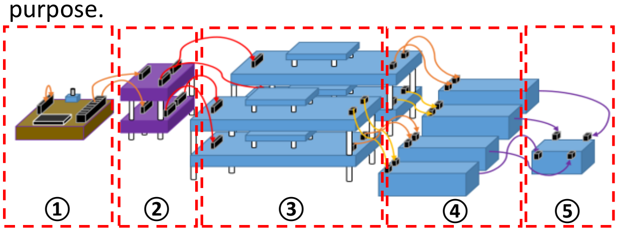

Fig. 2 Proposed DC-DC converter Module.

Table 1: Components in DC-DC converter.

Components	Function
① MOJO driver	Configuring the field-programmable gate array (FPGA)
② Buffer circuit	Convert 5V input to 15V output
③ IGBT Driver	Driver for IGBT bridge circuits
④ Full-Bridges	Switched mode power supplies
⑤ HF Transformer	Maintain galvanic isolation

4. Experimental Setup

(a) Simulation circuit using PSIM software

Fig. 3 shows the circuit used in the experiments. In order to design the voltage ratio to be 1, the winding ratio is set to 1:1. A simple switching process is used to control the phase shift angle between the two modes. By adjusting the phase-shift angle from −π to π, the author compared P_D, with the power output from input voltage side, P_1, and power output flown to the load side, P_2, to get the optimal condition ($P_1 > P_D > P_2$) for the transferring power. In the simulation system, the leakage inductance of the transformer is neglected.

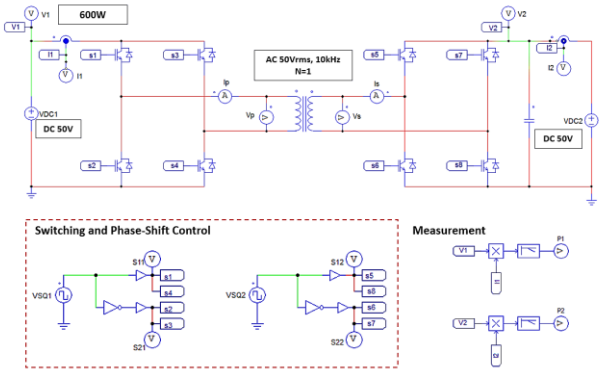

Fig. 3 50V, 600W simulation circuit.

(b) Bidirectional DC-DC converter experimental test

Fig. 4 shows the picture of developed prototype. The experimental parameters are shown in Table 2. The maximum power is designed to be 600W. The efficiency curve of DC-DC converter are measured when input DC voltage, V_{D1}, range from 10V to 50V, at phase shift angles $\frac{\pi}{10}$, $\frac{\pi}{5}$, and $\frac{10\pi}{3}$.

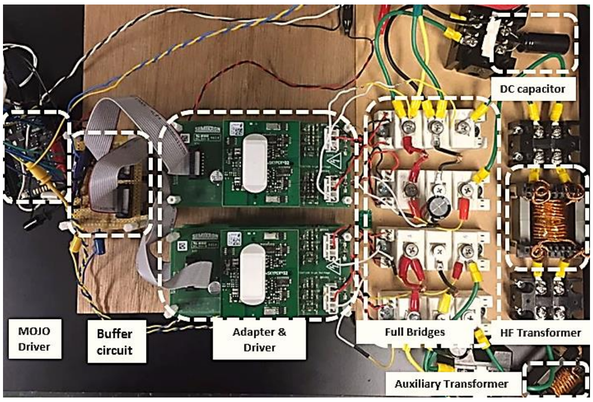

Fig. 4 Picture of developed prototype.

Table 2: Main parameters of the prototype.

Parameters	
Switching frequency f_{sw}	10 kHz
Load voltage V_s	50V
Rated power	600W
Isolated bidirectional DC-DC Converter	
Transformer T_r	31.5μH
DC capacitor C_{bat}	1500μF
Power electronic switch S_1–S_8	SKM50GB063D

5. Results and Discussions

(a) Simulation Test Result

Fig. 5 shows the graph of primary and secondary side power output and the power transfer that fulfil the optimal condition. The maximum power transfer is at $|\delta| = \frac{\pi}{2}$. So, the converter full range of bidirectional power transfer can be gained by controlling the phase shift in $-\frac{\pi}{2}$ to $+\frac{\pi}{2}$ range. In these ranges, the author decided to choose three different values of phase shift angles ($\frac{\pi}{10}$, $\frac{\pi}{5}$, and $\frac{10\pi}{3}$) in order to compare the power output and efficiency in primary and secondary side of the converter in the experimental test.

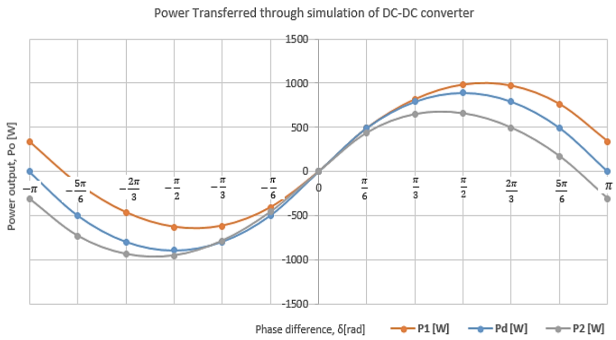

Fig. 5 Power transfer when $f_{sw} = 10kHz$.

(b) Experimental Test Result

The experiment is done by shifting the fundamental phase shift manually with controller of chip, TQG144BIV1313, for three different phase shift angles. The efficiency curve of the prototype is shown in Fig. 6. The results show that higher voltage can increase the efficiency. However, in order to apply more than 50V in the converter, it should satisfy the requirement conditions such as wide range of voltage and current limit of power supply.

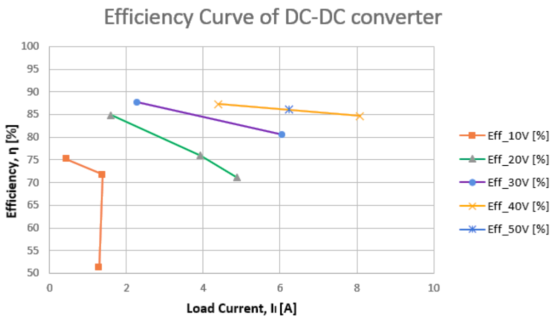

Fig. 6 Efficiency Curve of DC-DC converter.

6. Conclusions and Future Issues

This paper has presented discussion and simulation for output power at three different phase shifts. Experimental result shows determination of power transferred through DC-DC converter between two DC circuits. The calculation of this power is based on average values of currents in DC circuits by taking into account the voltage drops on semiconductor devices and the dead time. However, it still faces DC-voltage limitations when the converter is operated in wide range of voltage variation. In the future, the control system is aimed to imitate a power conditioner, which including protection system in order to create a more stable and safer experimental set-up.

Reference

[1] Jou H-L, Chang Y-H, Wu J-C, Wu K-D: Operation strategy for a lab-scale grid-connected photovoltaic generation system integrated with battery energy storage. Energy Conversion and Management 2015;89(0):197-204.

Research Achievements

[1] N. A. A. Malek, G. Fujita: Bi-Directional Power Flow Experimental Simulation using Grid-connected Inverter Module with Battery Energy Storage, ICEE 2016, ID 90393.

[2] N. A. A. Malek, G. Fujita: System Grid-Connected Inverter with Bi-directional Power Flow Experimental Simulation with Battery Energy Storage, Intensive Workshop in 10th South East Asian Technical University Consortium Symposium (SEATUC) Tokyo, 24th February 2016.

[3] N. A. A. Malek, N. Katayama, S. Kogoshi, G. Fujita: Examination of the Catalyst Layer Forming Method of the Anion Exchange Membrane Fuel Cell by Using the Electrostatic Spraying Deposition, The International Conference on Electrical Engineering, Informatics, and Its Education (CEIE) 2015, D-1.