Simulation of Dual Active Bridge Converter for Energy Storage System

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Abstract: *The increased demand of an intermediate storage of electrical energy in battery systems, in particular due to use of renewable energy, has resulted in the need of dual active bridge converters or bidirectional DC to DC power converters. The most cost effective solution for electrical energy storage is battery. The battery output is converted to AC for connecting to electrical loads. Charging and discharging of the battery can be carried out by bidirectional power converters. DAB converter can be used for battery charging and uninterruptable power supply for hybrid vehicles, telecommunication, industrial, space and defence applications. This thesis investigates different isolated bidirectional DC–DC converters with a rating of voltage 220V, frequency 1 kHz and power of 1600W. Closed loop control blocks for various applications of DAB circuit have been proposed and validated by simulation.*

Keywords — *Dual Active bridge (DAB) Converter, bidirectional DC–DC converters.*

I. INTRODUCTION

In order to reduce the dependence on non-renewable fossil fuel and the amount of greenhouse gas emission, the demand for higher penetration of renewable energy has been growing rapidly during the last two decades. The major sources of renewable energy include wind energy, photovoltaic energy, hydrogen fuel cell energy, tidal energy, and geothermal energy. Most of these energy resources are utilized in the form of electric energy. Because of the unpredictable, and distributed nature of most renewable energy resources, the higher penetration of renewable energy will bring some challenges to the existing electric power system. Global climate change and depleting fossil fuel reserves are driving society's quest for a sustainable energy infrastructure. The incorporation of renewable energy is limited in many ways due to the variable and intermittent nature of its output. Hence, energy storage systems such as lithium ion batteries, super capacitors and electric vehicles have to be used to compensate the source variations.The increase demand of an intermediate storage of electrical energy in battery systems, in particular due to the use of renewable energy, has resulted in the need of dual active bridge converters or bidirectional DC-DC power converters.Therefore these applications introduce power converter with bi-directional power transfer property. Bidirectional DC-DC converters recently gates awareness due to application of bidirectional power transfer between different dc sources buses. The demand for development of complex, compact and efficient power system implementation has encouraged scientists in bi-directional converter development. This paper is organized as follows. Section II analysis the DAB circuit configuration. Section III presents the generalized analysis based on per unit system. PID controller is analysed in section IV. Section V shows the simulation results of battery charging and discharging. Section VII summarizes the contribution of this work.

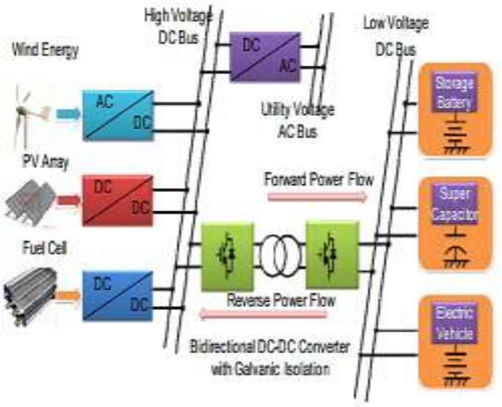


Fig: 1 Typical application of bidirectional DC-DC converter for power distribution

II.DUAL ACTIVE BRIDGE CONVERTERS

Circuit Configuration

A DAB converter consists of two switching bridges and one high-frequency transformer. Each switching bridge is made up of four high-frequency active controllable switching device(IGBTs) in an H-bridge connection. However, instead of using uncontrollable switching devices (such as diodes) bridge in the other side of transformer, DAB converters use two active bridges formed by active controllable devices. This is why the name "Dual Active Bridge" is given to this kind of converters.

A transformer is used to provide galvanic isolation between the input side and the output side of a DAB converter. A high-frequency transformer is preferred to reduce the weight and volume of the magnetic core. The leakage inductance has two purposes: (1) it is used as energy storage components in DAB converters and (2) it reduces the dv/dt across switching devices during commutation transients, facilitates soft switching, and reduces switching losses.

Figure:2 shows the circuit schematic of a dc-dc DAB converter. The IGBT- diode pairs can conduct current bidirectional. Therefore, the circuit shown in Figure: 2 is able to conduct bidirectional current. Furthermore, DAB converters have symmetrical dual active H-bridge configuration, which help achieve bidirectional power flow. On the other hand, such configuration can only block positive voltage. Therefore, the topology shown in Figure:2 is only for dc-dc DAB converters.

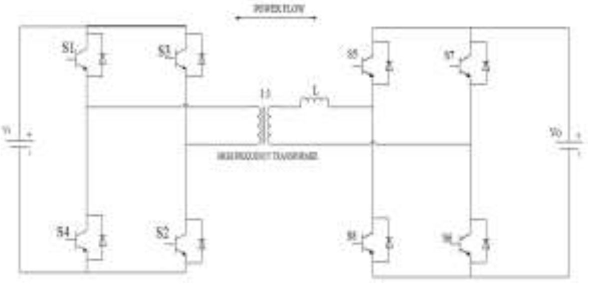
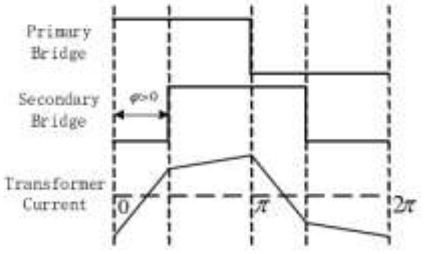
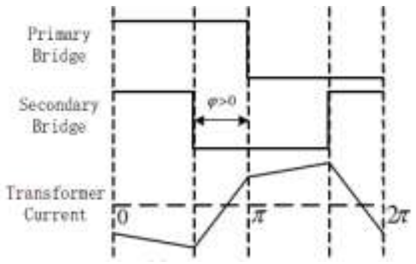


Fig: 2 DAB converter schematic

A DAB converter is controlled by Phase-Shift Modulation (PSM). Both the direction and the amount of power flow is regulated by controlling the phase shift between the those H-bridges. Power flows from the leading bridge to the lagging bridge. Two operating modes, corresponding to two directions of power flow of a DAB converter, respectively, are given in Figure 3.(a) and Figure 3.(b). In Figure 3.(a), positive power flow is defined as power transfer from the left to the right for the converter shown in Figure 2, while in Figure 3.(b), negative power flow is defined as power transfer from the right to the left.



(a) Positive power flow



(b) Negative power flow

Fig: 3 Operation modes

III. Steady State Analysis

This work derives a per-unit steady-state model of a DAB converter for circuit analysis and converter design. This model works for both dc-dc DAB converters and ac-ac DAB converters. By using a per-unit model, the parameters of both bridges of an DAB converter can be scaled up/down easily.

Steady-State Model of DC-DC DAB Converters

Let v_i, v_o, v_{pri} and v_{sec} be the input voltage, output voltage, transformer primary winding voltage and transformer secondary voltage, respectively (as shown in fig:2.1). $X_{pri} = w_s L_{pri}$ and $X_{sec} = w_s L_{sec}$ are the transformer leakage impedances due to leakage inductance at primary and secondary winding, respectively, where w_s represents switching frequency. Assume that DAB converter is operating in Q1. During interval 1 the current at transformer primary side is

$$i_{\Phi,pri} = i_{0,pri} + \frac{v_i - v_{pri}}{X_{pri}}\Phi \quad \text{……….} (1)$$

Where $i_{\Phi,pri}$ and $i_{0,pri}$ are the primary side current at time $w_s t = \Phi$ and $w_s t = 0$, respectively. Similarly, the current at transformer secondary side is

$$i_{\Phi,sec} = i_{0,sec} + \frac{v_{sec} - v_o}{X_{sec}}\Phi \quad \text{………..}(2)$$

Where $i_{\Phi,sec}$ and $i_{0,sec}$ are the secondary side current at time $w_s t = \Phi$ and $w_s t = 0$, respectively.

A per unit system at both windings can be defined as

$$I_{b,pri} = \frac{S_b}{V_{b,pri}} \quad \text{…………} \quad (3)$$

$$I_{b,sec} = \frac{S_b}{V_{b,sec}} \quad \text{…………} \quad (4)$$

$$Z_{b,pri} = \frac{V_{b,pri}^2}{S_b} \quad \text{…………} \quad (5)$$

$$Z_{b,sec} = \frac{V_{b,sec}^2}{S_b} \quad \text{……….} \quad (6)$$

Where S_b is base apparent power, $V_{b,pri}$ and $V_{b,sec}$ are base voltage at primary and at secondary side, respectively, $I_{b,pri}$ and $I_{b,sec}$ are base current at primary and at secondary side, respectively, and $Z_{b,pri}$ and $Z_{b,sec}$ are base impedance at primary and at secondary side, respectively.

By using eq (3), (4), (5) and (6) all voltage and current variables, V_i, V_o, V_{pri} , V_{sec}, $i_{0,pri}$, $i_{0,pri}$ $i_{0,sec}$ $i\Phi_{,pri}$ $i\Phi_{,sec}$ can be converted into their corresponding per-unit variables, $v_{i,pri,}$ $v_{0,pu}$ $v_{pri,pu}$ $v_{sec,pu}$ $i_{0,pri,pu}$ $i_{0,sec,pu}$ $i_{\varphi,pri,pu}$ $i_{\varphi,sec,pu}$ respectively. It is also intuitive that

$$i_{0,pri,pu} = i_{0,sec,pu} = i_{0,pu} \qquad \text{.....} (7)$$

$$i_{\Phi,pri,pu} = i_{\Phi,sec,pu} = i_{\Phi,pu} \qquad \text{......} (8)$$

$$v_{pri,pu} = v_{sec,pu} = v_{t,pu} \qquad \text{.... ..}(9)$$

The transformer leakage reactance can be lumped as $X_{pu} = X_{pri} / Z_{b,pri} + X_{sec} / Z_{b,sec}$. Using the per unit system defined above and substituting all per unit variables into (1) and (2), the per unit transformer current is

$$i_{\varphi,pu} = i_{0,pu} + \frac{v_{i,pu}+v_{0,pu}}{X_{pu}}\varphi \qquad \text{.....} (10)$$

Similarly during second interval i.e from φ to π, the transformer current is

$$i_{\pi,pu} = i_{\varphi,pu} + \frac{v_{i,pu}+v_{0,pu}}{X_{pu}}(\pi - \varphi) \qquad \text{.........}(11)$$

In steady state the transformer current is symmetrical every half switching period

$$i_{\varphi,pu} = -i_{0,pu}$$

Therefore $i_{\varphi,pu}$ and $i_{0,pu}$ are calculated as

$$i_{0,pu} = \frac{1}{2X_{pu}}\left((\pi - 2\varphi)v_{0,pu} - \pi v_{i,pu}\right) \qquad \text{.......} (12)$$

$$i_{\varphi,pu} = \frac{1}{2X_{pu}}\left(\pi v_{0,pu} - (\pi - 2\varphi)v_{i,pu}\right) \qquad \text{.......} (13)$$

From eq (12) and (13) the input current averaged over one switching period is

$$\bar{i}_{i,pu} = \frac{1}{2\pi}\left(\pi i_{\varphi,pu} + (2\varphi - \pi)i_{0,pu}\right) = \frac{v_{o,pu}}{X_{pu}}\varphi\left(1 - \frac{\varphi}{\pi}\right)$$

.... (14)

The amount of power transferred to the load is controlled by phase shift angle between two bridges φ, the input voltage, and the output voltage as described in below equation

$$P_o = \frac{v_{i,pu}v_{o,pu}}{X_{pu}}\left(\varphi - \frac{\varphi^2}{\pi}\right) \qquad \text{.............} (15)$$

Ideally, when the loss of a converter is insignificant, output power is equal to input power

$$P_i = v_{i,pu}\bar{i}_{i,pu} = P_o = v^2_{o,pu} / R_{pu} \qquad \text{......} (16)$$

Where $R_{pu} = R / Z_{b,sec}$ and R is load resistance. Using per unit notation the ideal dc voltage transfer ratio is

$$\gamma = \frac{v_{0,pu}}{v_{i,pu}} = \frac{R_{pu}}{X_{pu}}\varphi\left(1 - \frac{\varphi}{\pi}\right) \qquad \text{.............} (17)$$

The above equation shows the voltage transfer ratio of DC to DC DAB converter.

IV.PID CONTROLLER

PID controllers typically use control loop feedback in industrial and control systems applications. The controller first computes a value of error as the difference between a measured process variable and preferred set-point. It then tries to minimize the error by increasing or decreasing the control inputs to the process, so that process variable moves closer to the set point.. To increase performance, for example to increase the responsiveness of the system, PID parameters must be adjusted according to the specific application. An open-loop controller, also called a non-feedback controller, is a type of controller which computes its input into a system using only the current state and its model of the system. The controller does

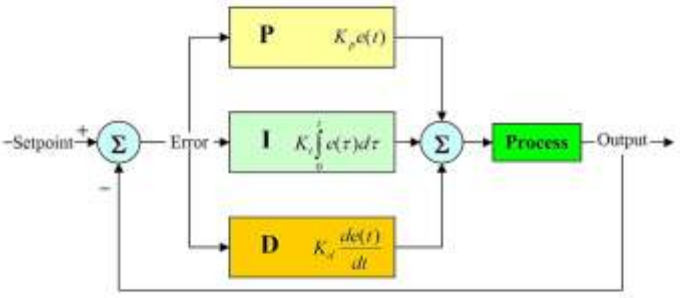
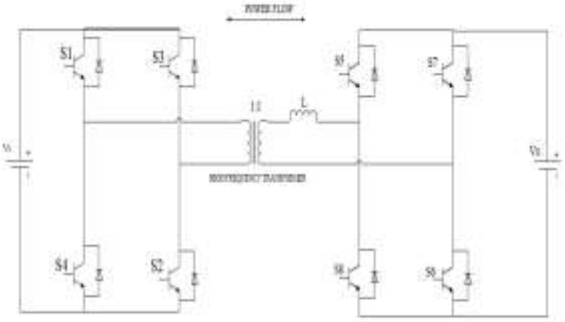


Fig: 4.PID controller block diagram

not receive a feedback signal from the process and it only has a set-point and a fixed output signal. In a closed-loop system, also called a feedback system, the controller has a feedback signal from the process. The controller has a set-point, a feedback input signal, and a varying output signal. The output signal increases or decreases proportionally to the error of the set-point compared to the input signal.

V.SIMULATION

The result of the galvanic isolated dual active bridge DC-DC (DAB) converter. The simulation circuit and its corresponding waveforms are as follows:



The phase shift between primary voltage(V1) and secondary voltages(V2) is shown in the fig (6). The phase shift between the two voltages is 20 degree.

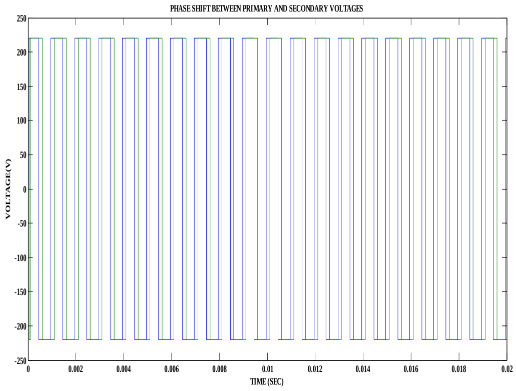
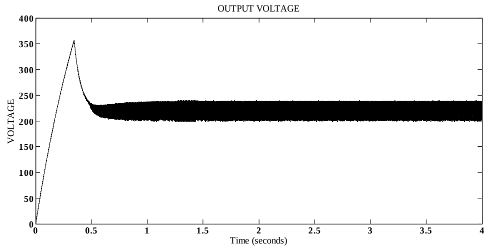


Fig (6)

The output voltage and current is show in the fig (7).The output voltage is 220V and output current is 3.6 A. The output power is shown in fig (8). The output power is 1600 watts



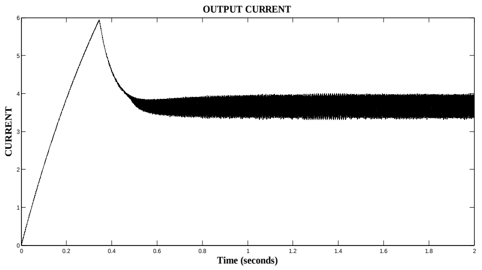


fig.(7)

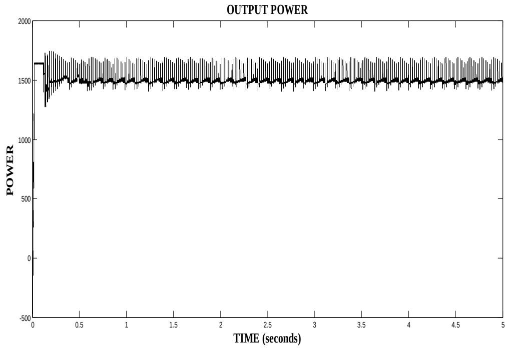


Fig.(8)

(i) DAB for energy storage system

Battery charging circuit

Fig: 9 (a) shows the battery charging circuit for the DAB converter. In this circuit we are using a Lithium Ion battery for energy storage purpose. Power flows from primary side to secondary side and thus the battery charges. Simulation results are given in fig (10).

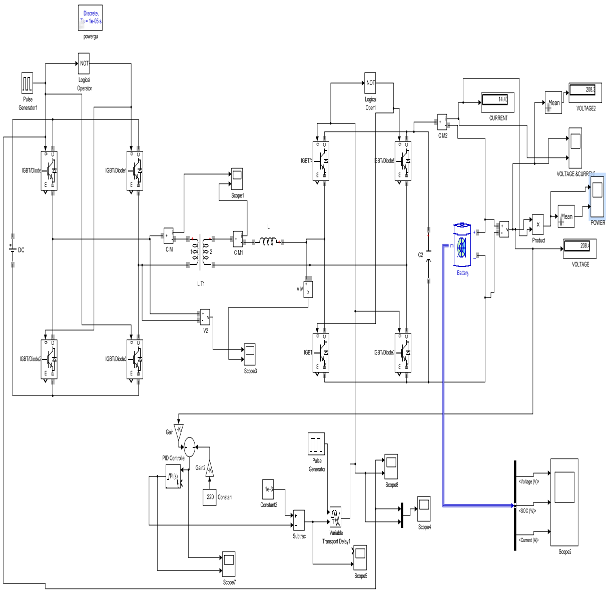


Fig:(9) Battery charging circuit for DAB converter

Simulation Results

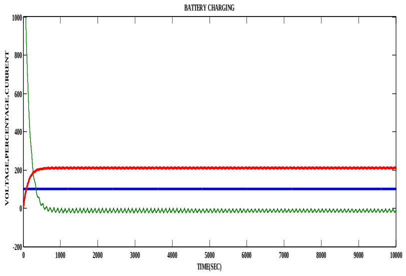


Fig.(10)

The above shown fig: 10 is the output waveform of battery. The first waveform is the charging output voltage of DAB converter, second waveform is the state of charge (SOC) and the third waveform is the charging current.

Battery discharging circuit

Fig: 11 shows the battery discharging circuit for the DAB converter. In this circuit we are using a Lithium Ion battery and this battery provides the voltage to flow from secondary to primary. Thus the battery discharges to provide the Power flow from secondary side to primary side.

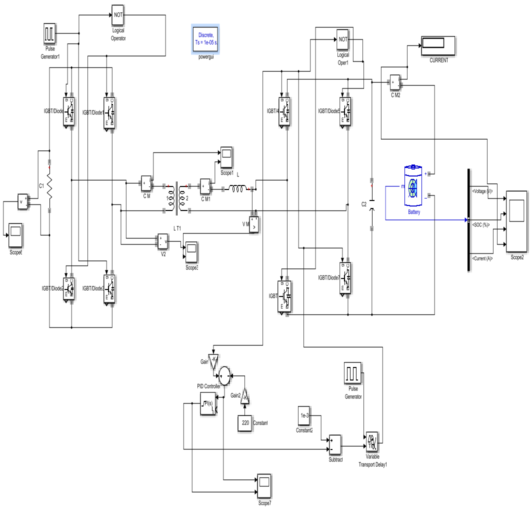


Fig:11 Battery discharging circuit for DAB converter

Simulation Results

The below shown fig: 12 is the output waveform of battery. The first waveform is the charging output voltage of DAB converter, second waveform is the state of charge (SOC), third waveform is the discharging current and fourth waveform is the output current of DAB converter..

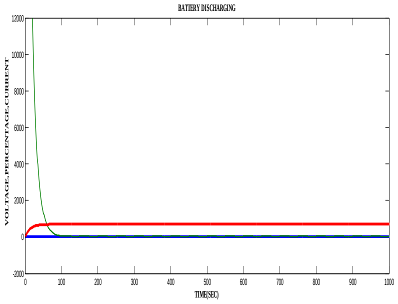


Fig.(11)

VI. CONCLUSIONS

The main objective of this paper is to analyse different aspects of DAB converters and to provide a set of tools to design DAB converters for energy storage system application. This work presents a proof-of-concept study of applying dc-dc DAB converters. This thesis investigates different isolated bidirectional DC–DC converters with a rating of voltage 220V, frequency 1 kHz and power of 1600W.

In this project, a DAB converter is simulated by using MATLAB Simulink. Bidirectional power flow i.e. power flow from primary side to secondary side and from secondary side to primary side of the DAB converter circuit is simulated. The application of DAB converter for energy storage application has been demonstrated by simulation of DAB along with battery in charging and discharging mode. The simulation studies on DAB converter for various applications have been performed.

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