

Performance Evaluation of Modulation strategies for Dual Active Bridge Multiport DC-DC Converter

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ABSTRACT

Multiport DC-DC converters have recently gained attention to interface more than one power source with a load. By using these converters, it is possible to diversify the energy sources so that the power system availability can be increased. Furthermore, utilization of renewable and alternative sources can be increased by combining units with different technologies or by integrating energy storage to feed the load when the power sources are unavailable. This paper proposes a dual active bridge DC-DC converter for renewable energy applications. It is a DC-AC-DC converter which allows energy transfer between the source and the load. The performance of the converter will be analyzed by comparing various modulation strategies like phase shift, triangular and trapezoidal methods. The design of high frequency transformer has been discussed. The proposed topology is verified by simulation results.

Keywords

Multiport DC-DC converter, dual active bridge, phase shift, triangular and trapezoidal

I. INTRODUCTION

In recent years, a lot of emphasis has been made on renewable energy resources. Although there are a numerous advantages, renewable energy resources have certain drawbacks. They are basically intermittent in nature. But modern energy applications demand constant voltage at constant frequency. This paper proposes a multiport DC-DC power converter circuit that can deal with the intermittent nature of renewable energy. The advantage of multiport DC-DC converters are high efficiency, less component count, compact, low cost, reduced filter size and improved performance compared to the usage of several independent converters for renewable energy source[1]. Several types of

multiport converters have been discussed in the literature. This paper focuses on a dual active bridge DC-DC converter which is a buck and boost bidirectional converter isolated by a high frequency transformer. Various modulation strategies have been discussed for the dual active bridge DC-DC converter. The performance parameters have been analyzed in terms of output voltage ripple and switching losses. A suitable high frequency transformer is designed. Simulation studies have been carried out using MATLAB to verify the theoretical results.

II. OPERATION OF DUAL ACTIVE BRIDGE DC-DC CONVERTER

A dual active bridge (DAB) converter with high power density and soft switching operation is proposed as a bi-directional DC to DC interface to convert electric energy between a low voltage battery and a high voltage DC bus [2,3]. It is a DC-AC-DC converter which allows energy transfer between the source and the load. It is a buck and a boost bidirectional converter isolated by a high frequency transformer. The source side and the load side both are full- bridge circuits, operated at a fixed frequency. The two full bridges are connected via a high frequency transformer. Full bridge circuits have minimal voltage and current stresses in the devices and minimum VA rating of the transformer[4]. High frequency transformer can integrate different voltage levels with the turn ratio of the transformer. It also provides electrical isolation, which may be required by the industry standard. Finally, the leakage inductor of the transformer can be used as an energy transfer element. In every cycle, a small fraction of energy from the source is stored in this leakage inductor before it is transferred to the load. The inductance can be added by using external inductors connected in series with the transformer. Fig.1 shows the circuit for DAB converter.

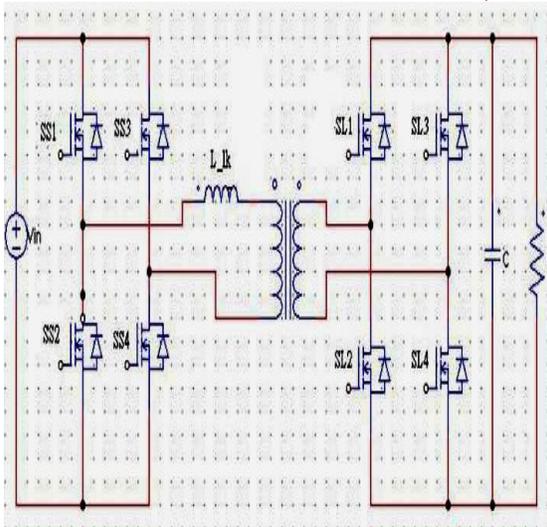


Figure .1 Dual active bridge DC-DC Converter

The switches of the DAB circuit are operated at a constant frequency. The switches are operated at a fixed frequency and with a fixed duty cycle of 50%.

III.MODULATION STRATEGIES FOR DAB DC-DC CONVERTER

Three types of modulation strategies have been analyzed for DAB DC-DC converter [5,6,7] as shown in Fig.2.

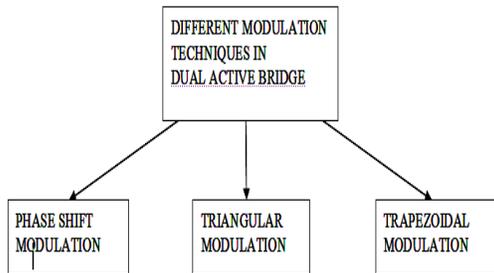


Fig.2 Types of modulation techniques for DAB

A. Phase Shift (PS) modulation

Phase shift modulation is the widely used technique in dual active bridge converter. For phase shift operation, rectangular transformer voltages $v_{T1(t)}$ and $v_{T2(t)}$ with switching frequency f_s and phase shift ϕ are applied to the transformer

and the converter inductance L . The power transfer is controlled by the phase shift angle ϕ . The higher the phase difference, the higher is the power transferred. It is given by the equation,

$$P = \frac{V_1 V_2}{n} \phi \cdot (\pi - \phi) / 2\pi^2 f_s L \quad (1)$$

The switching pattern for phase shift modulation is shown in Fig.2.

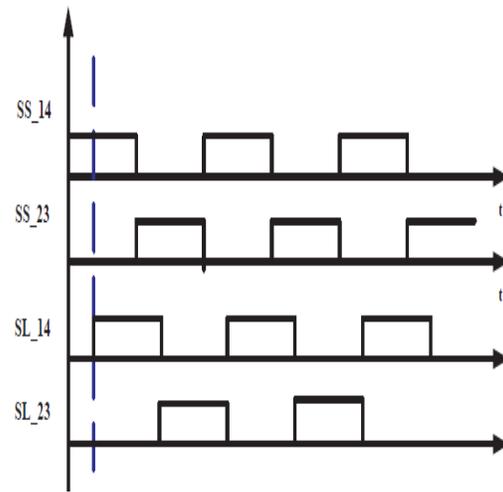


Fig.2 Gating pattern for phase shift Modulation

The advantages of PS method are:

- Phase shift modulation is very simple to implement.
- It is possible to use half bridge circuits to generate the high frequency transformer voltages $v_{T1(t)}$ and $v_{T2(t)}$.
- Less number of power electronic devices.

The disadvantages of PS method are :

- A high level of reactive power circulates in the high frequency transformer when the operating point is significantly different to the nominal operating point.
- For phase shift modulation it is not possible to directly influence the shape of the transformer current since it depends on the DC voltages V_1 and V_2 as well as on the phase shift ϕ .

B.Triangular Modulation

Triangular modulation is used when the voltages V_1 and V_2 are significantly different. This modulation method can be implemented when the transformer has a turns ratio given by

$$V_1 \ll V_2/n \tag{2}$$

The switching pattern for triangular modulation is shown in Fig.3.

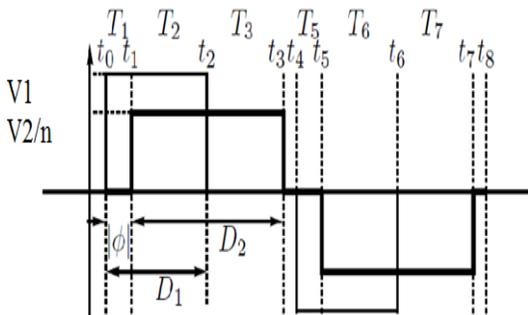


Fig.3 Switching pattern for triangular modulation

The advantages and disadvantage of triangular modulation are :

- This method allows for the implementation of ZCS for the low voltage side, which is desired for low switching losses, high switching speed, and low EMI.
- In this method the parasitic inductors of the low voltage side switches are utilized as part of the converter inductance L . It is particularly interesting for the specific converter because of the low value of L .
- Ineffective converter utilization.

C. Trapezoidal modulation

The trapezoidal modulation method can be implemented when the transformer has a turns ratio given by

$$V_1 \approx V_2/n \tag{3}$$

The advantages of trapezoidal modulation are:

- Good converter efficiency is achieved. This is because the full bridge circuits are operating with large duty cycles and

results in a lower RMS current than for triangular modulation.

- Switching losses are less compared to phase shift modulation.

The switching pattern for trapezoidal modulation is shown in Fig.4.

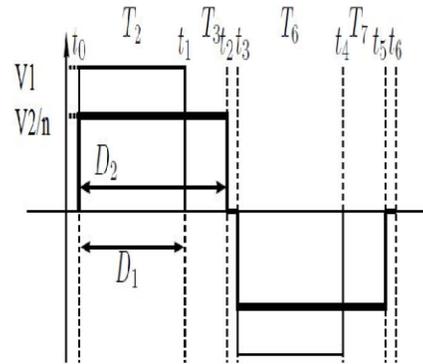


Fig.4 Switching pattern for trapezoidal Modulation

IV. DESIGN OF HIGH FREQUENCY TRANSFORMER

The optimum design of a high-power and high-frequency transformer [8,9], which means

- 1) selection of the smallest standard core shape relevant to the throughput power, frequency, and transformer operating temperature,
- 2) calculation of the optimum flux density providing minimum transformer loss and
- 3) calculation of the optimum wire diameters of the windings.

The design equations are given from which the area of the core, window spacing, primary and secondary turns are determined. Assuming emf per turn $E_t = 7.5V$, the output KVA is calculated from the equation,

$$Q = 2.22fK_w A_w B_m A_t \delta * 10^{-3} \tag{4}$$

where $\delta = 2.2 A/mm^2$
 $B_m = 1.55 Wb/m^2$

f=20khz

| | | |
|------------------------|---|--------|
| Width of the flux path | A | 7.78mm |
|------------------------|---|--------|

$$\begin{aligned} \Phi_m &= E_t / 4.44f \\ K_w &= 10 / (30 + KV \text{ of HV}) \\ A_i &= \Phi_m / B_m \end{aligned}$$

The area of the window is determined from the values obtained above,

$$A_w = Q / 2.22fK_w B_m A_i \delta * 10^{-3} \quad (5)$$

Thus the net gross section area is obtained as given

$$A_{gi} = \frac{A_i}{\text{Stacking factor}} \quad (6)$$

where stacking factor is assumed as 0.9. The transformer secondary turns are calculated using,

$$T_s = E_s / E_t \quad (7)$$

The primary turns for the transformer is determined as

$$T_p = E_p \frac{T_s}{E_s} \quad (8)$$

Thus from the above equations the high frequency transformer design values are obtained and are shown in table 1.

Table 1 Design Equations for high frequency transformer

| Parameter | Notation | Value |
|-----------------------|----------|----------|
| Height of the window | Hw | 40mm |
| Width of the window | Ww | 18.2mm |
| No of primary turns | Tp | 8 turns |
| No of secondary turns | Ts | 20 turns |

Fig.5 shows the design model of high frequency transformer.

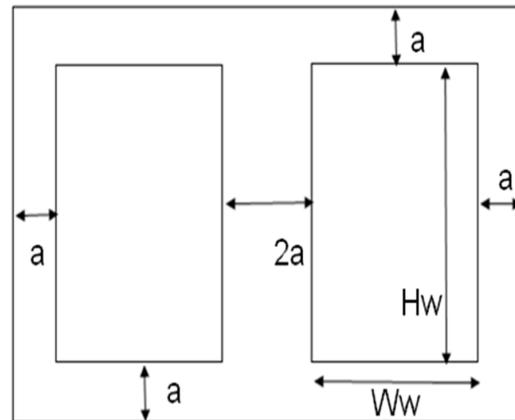


Fig.5.Design model of high frequency transformer

IV. EVALUATION OF PERFORMANCE PARAMETERS FOR DAB DC-DC CONVERTER

The output voltage ripple and switching losses are evaluated for the three modulation strategies[10,11]mentioned in section-II. SIMULINK model of DAB DC-DC converter is shown in Fig.6.

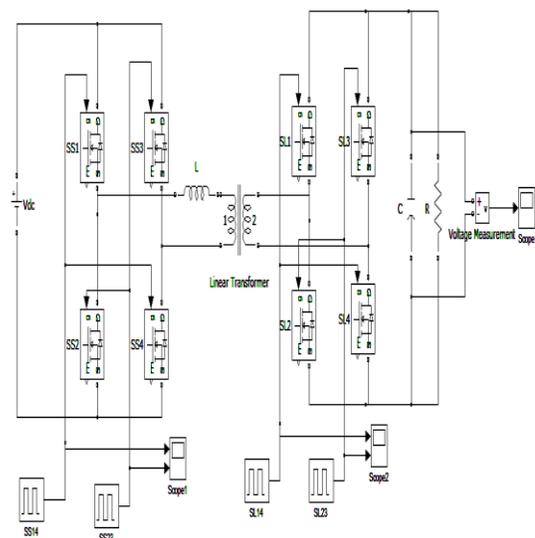


Fig.6 SIMULINK model of DAB DC-DC Converter

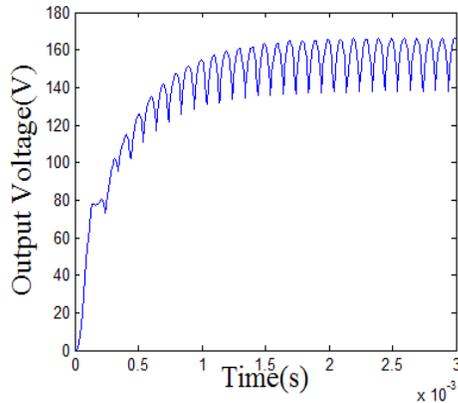


Fig.7. Output voltage ripple waveform for PS method of DAB

The output voltage ripple waveform for triangular method is shown in Fig.8.

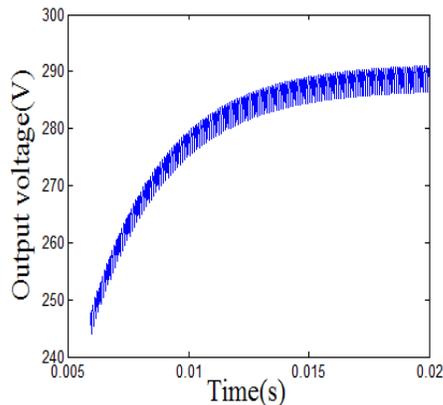
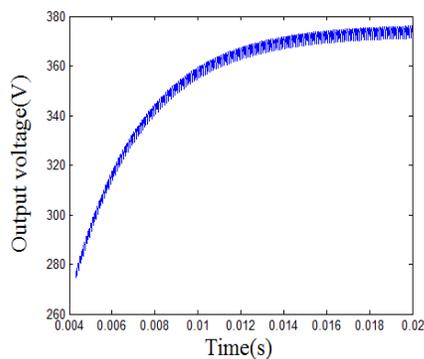


Fig.8 Output voltage ripple waveform For Triangular method for DAB

The output voltage ripple waveform for triangular method is shown in Fig.9.



The output voltage ripple waveform for PS method is shown in Fig.7.

Fig.9 Output voltage ripple waveform For Triangular method for DAB

The output voltage ripple waveform is compared for all the modulation techniques which is shown in Table –II.

Table II Comparison of output voltage ripple of DAB

| Type of modulation | Output voltage ripple |
|--------------------|-----------------------|
| Phase shift | 1.89% |
| Triangular | 0.15% |
| Trapezoidal | 0.13% |

The secondary current of the three modulating techniques is given in the Figs 10, 11 &12.

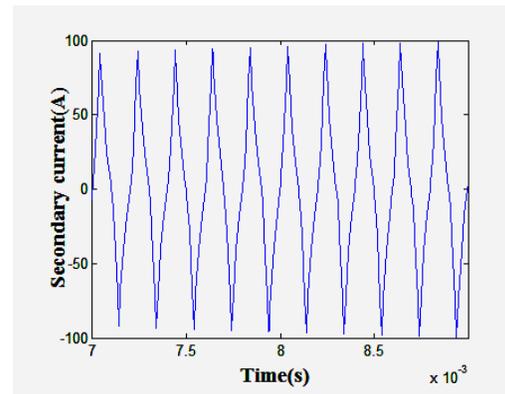


Fig.10. Secondary current waveform for PS method

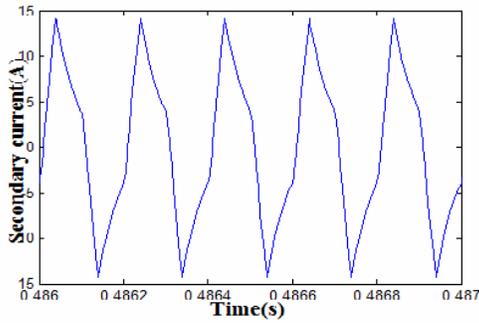


Fig.11. Secondary current waveform for triangular method

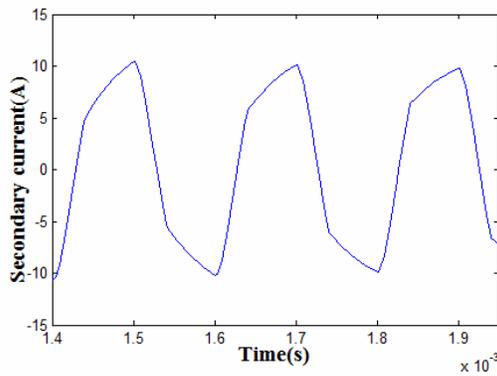


Fig.12. Secondary current waveform for trapezoidal method

The switching circuit for an IGBT and a diode is shown below

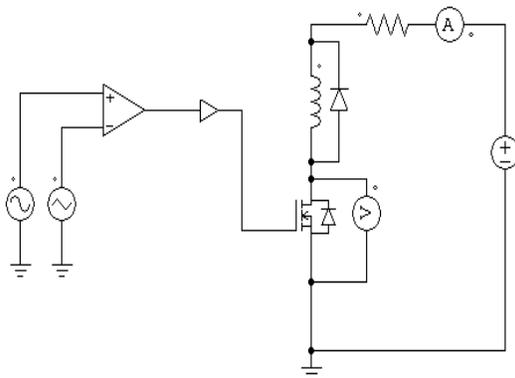


Fig.13 IGBT Switching circuit

The equations governing the calculation of switching loss for an IGBT are discussed as follows.

$$E_{on} = \int_0^{t_{on}} P(t).dt = (1/2).V_{CE}.I_C.t_{on} \quad (9)$$

$$E_{off} = \int_0^{t_{off}} P(t).dt = (1/2).V_{CE}.I_C.t_{off} \quad (10)$$

$$E_{sw} = E_{on} + E_{off} = (1/2).V_{CE}.I_C.(t_{on}+t_{off}) \quad (11)$$

The switching loss of an IGBT is calculated from the equation

$$P_{sw} = f_{sw}.E_{sw} \quad (12)$$

Using the above equations , the switching loss is calculated for the various modulation strategies which is shown in table III.

Table III Switching loss Calculation

| Modulation technique | Switching losses |
|------------------------|------------------|
| Phase shift modulation | 50.92mJ |
| Triangular modulation | 46.51mJ |
| Trapezoidal modulation | 44.51mJ |

From Table III, it is found that the switching loss of the trapezoidal modulation is lower and the output voltage ripple (table II) is found to be lower .Therefore, trapezoidal modulation can be employed for DAB DC-DC converter for better performance.

V.CONCLUSION

A dual active bridge DC-DC converter has been investigated for renewable energy applications. Various modulation strategies for dual active

bridge DC-DC converter has been analyzed. It is found that the trapezoidal modulation provides a lower output voltage ripple and reduced switching losses compared to other methods. The design of high frequency transformer has been discussed. From the simulation results, it is observed that the trapezoidal modulation is a better choice for DAB DC-DC converter.

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BIOGRAPHY



Dr.R.Seyezhai obtained her B.E. Electronics & Communication Engineering) from Noorul Islam College of Engineering, Nagercoil in 1996 and her M.E in Power Electronics & Drives from Shanmugha College of Engineering, Thanjavur in 1998 and Ph.D from Anna University, Chennai. She has been working in the teaching field for about 13 Years. She has published several papers in International Journals and International Conferences in the area of Power Electronics & Drives. Her areas of interest include SiC Power Devices, Multilevel Inverters, Modeling of fuel cells, Design of Interleaved Boost Converter, Multilport DC-DC Converter and control techniques for DC-DC Converter.