Comparative Study of Different Bidirectional DC-DC Converters

Rahul Sahu, Jeeban Nayak and Arnab Ghosh

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COMPARATIVE STUDY OF DIFFERENT BIDIRECTIONAL DC-DC CONVERTERS

Rahul Kumar Sahu
Department of Electrical Engineering
NIT Rourkela,Odisha
Rahulsahu0500@gmail.com

Jeeban Kumar Nayak
Department of Electrical Engineering
NIT Rourkela,Odisha
Jeeban1994@gmail.com

Arnab Ghosh
Department of Electrical Engineering
NIT Rourkela,Odisha
aghosh.ee@gmail.com

Abstract—This paper demonstrates the comparison of different bidirectional DC-DC converters which are Full Bridge DAB, Hybrid DAB, Multilevel DAB and Triple active bridge (TAB) converter. Each of these converters have different structures, working principle, number of switches, different switching actions, different advantages and disadvantages. In this paper, the operation, diagrams and simulation results of all the four converters operating in open loop mode are shown. All the four converters are operating with an input voltage of 100V, frequency of 50kHz, power of 1kW, transformer turns ratio of 1:2 (except for TAB which has 1:2:2) and rest other important parameter values are mentioned in the respective tables .

Keywords—Hybrid DAB, Full Bridge DAB, Multilevel DAB and TAB.

1) Introduction

The increase of the global population and economy has a direct impact on the demand for power. As a result, energy producing methods are constantly evolving in an effort to meet the growing need for energy, which is present even in distant areas. Global warming is an impact that is a significant factor and demands consideration. In this regard, growing public awareness has resulted in the advancement of sustainable energy sources [1].

Energy storage device charging, and discharging require high-efficiency power converters. For use in high-power-density power conversion The single-phase, full-bridge bidirectional separated dc-dc converter was invented in [2].

The usage of high-frequency transformers in place of traditional low-frequency transformers is thought to be the emerging trend in next-generation power conversion in recent years.[3] Even though research efforts and the creation of newer technology have improved the safety and performance of renewable energy sources, the intermittent power supply from these sources remains a significant issue[4].

On modulation techniques for DAB converters, a lot of research material is available [5] Since the waveforms of the two voltages emitted by the two active bridges are both square waves with a fixed 50% duty ratio, standard single phase shift modulation [6]-[8] offers a quick mechanism of altering the power flow. SPS may be optimised using the extended-phase-shift control. [9]-[10].

The phase shift control is enhanced by pulse width modulation (PWM) to increase the ZVS range and decrease the circulating current.[11]-[12].

The direct ac conversion offered by the ac-ac DAB converter suggested in avoids the input and output phases of the SST and offers benefits in terms of size and efficiency[13]. By utilising a multi-level DAB, the quantity of DAB converters in SST applications may be decreased.

The extensive use of multi-level converters has been constrained to the medium voltage level due to the absence of marginally higher voltage and slightly elevated power semiconductor switches and diodes (is typically believed to be within the range of 2.3 to 6.6kV) [14]. Silicon carbide (SiC), a recently developed wide band-gap semiconductor, can be used to realise high-voltage, low-loss devices because of its superior qualities, comprising a superior thermal conductivity (better than metals), a speedier switching operation, a greater breakdown electric field (10 times that of Si), and a bigger power density. [15].

Reduced THD in the inverter's output compared to the two-level inverter design is one of the key advantages of multilevel inverters in high power drives. Additionally, the switches can have ratings that are lower than the dc voltage, such as half the dc bus voltage for a three-level NPC inverter. It is recommended to use a five-level dual active bridge with an NPC converter. These multilevel NPC converters may be employed by high voltage drives to achieve a certain voltage level without connecting switching devices in series, as depicted. in[14].

To sink the power variances, a separate port to bidirectional energy storage is requested. The converter termed as Triple Active Bridge (TAB), like the three-port converter, has a special appeal for each of these systems because of the advantages it provides. [16]. Even though the TAB offers advantages in a two-stage structure, the VSI converter has a slower switching frequency than the TAB, which lowers the power density.

To increase power density, [17] and [18] propose a single-stage AC-DC DAB converter with a time-variant duty ratio and fixed switching frequency.

The TAB DC/DC converter has sparked attention as a power exchanger for energy distribution systems primarily to its broad voltage range, two - way power transmission, and electrical insulation features.

B. Hybrid Dual Active Bridge Converter

Fig. 1 depicts the hybrid-DAB converter.The standard DAB circuit and the auxiliary half-bridge circuit are the two components that make up this system. The active full bridge of the DAB circuit is composed of switches S_1, S_2, S_3, and S_4 on the V_1 side, and the active half bridge comprising switches Q_1 and Q_2 and capacitors C_{21} and C_{22} on the V_2 side. Transformer leakage inductance is denoted by L_k. The auxiliary half-bridge circuit is made up of the capacitors C_{11} and C_{12} and the auxiliary switches S_5 and S_6.

A full-bridge converter topology change can be used to produce a large operating range and a lower peak current.

Because the PWM signals are proportional spanning two half switching cycles, the mode of operation is only examined for one half cycle.

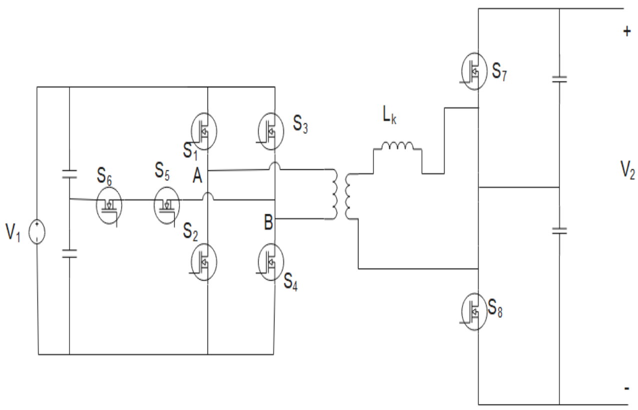


Fig. 1 Hybrid Dual Active Bridge Converter

Here, $0<\Phi<D_1$

$$0.5<m<1$$

Operating Stages: There are various operating stages and the equations for every stage is shown below:

Stage1: $t_0 < t < t_1$,

$$v_{AB} = V_1, v_{CD} = \frac{-V_2}{2} \quad (1)$$

$$\text{i(t-}t_o) = i(t_o) + V_1 + nV_2/2)(t - t_o)/L_k \quad (2)$$

Stage 2: $t_1 < t < t_2$,

$$i_s(t_1) = ni(t_1) > 0 \quad (3)$$

Stage 3: $t_2 < t < t_3$

$$v_{AB} = V_1, v_{CD} = \frac{V_2}{2} \quad (4)$$

$$i_L(t - t_2) = i(t_2) + (V_1 - \frac{nV_2}{2})(t - t_2)/L_k \quad (5)$$

Stage 4: $t_3 < t < t_4$

$$\text{i}(t_1)>0 \quad (6)$$

Stage 5:$t_4 < t < t_{5,}$

$$v_{AB} = \frac{V_1}{2}, v_{CD} = V_2/2 \quad (7)$$

$$\text{i(t-}t_4) = i(t_4) + (\frac{V_1}{2} - \frac{nV_2}{2})(t - t_4)/L_k \quad (8)$$

Stage 6: $t_5 < t < t_6$,

$$i(t_6) >0 \quad (9)$$

Now the important value of different parameters is shown in the table below:

TABLE 1

Parameters	***Values***
V_1	100 V
P	1 KW
F	50 KHz
Turns ratio	100:200
C_1,C_2	20e-6 F
C_3,C_4	40e-6 F

The switching pulses is shown in figure below.

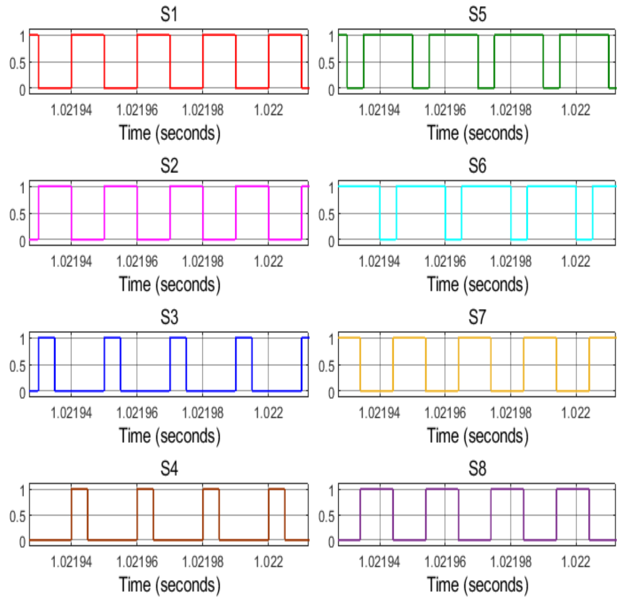


Fig. 2.Switching Pulses

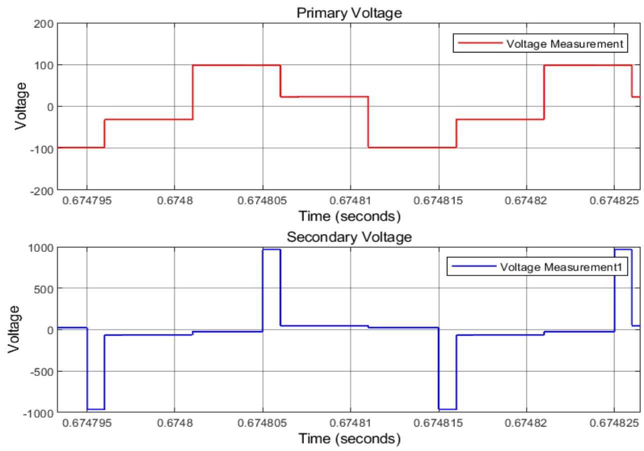


Fig.3. Primary and Secondary Voltages of the transformer

The output voltage of the hybrid DAB is shown below which is 50V.

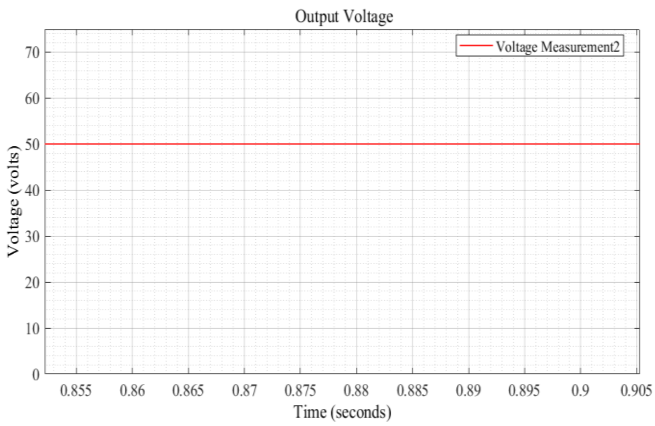


Fig.4. Output Voltage

C. Full Bridge DAB

In Figure 5, the full bridge DAB is shown and the square waves V_{in} and V_{out} are created by the converter's primary and secondary bridges, respectively. L is an inductor that stores energy. Transformer leakage inductance can function as a storage device for low power DAB converters, eliminating the need for an additional inductor in the power circuit.

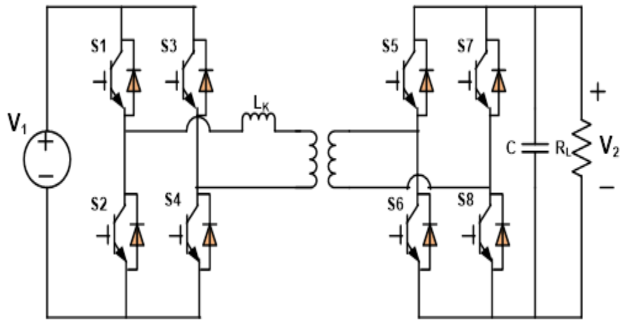
The converter's primary and secondary bridge switches all have relatively simple gating schemes.

Both full-bridges' two legs are powered by complementary square-wave pulses. energy flow In a DAB, the pulses of one active bridge are directed in relation to the other by using phase shift modulation. The control moves electricity between the two DC buses so that the leading bridge may deliver power to the trailing bridge. The voltage difference created directs the energy stored in the energy transfer inductance. by the square waves that are sent to the bridges spanning it[4].

$$M = (n*V_{in}) / V_{out} \tag{10}$$

$$P_{out} = \frac{V_{in}V_{out}D(1-D)T_S}{nL} \tag{11}$$

$$\frac{V_{out}}{V_{in}} = \frac{D(1-D)T_SR}{nL} \tag{12}$$



.Fig. 5. Full Bridge Dual Active Bridge Converter

Fig.5. is the circuit diagram of the hybrid DAB converter and fig.6. shows the primary voltage, primary current and secondary voltage of the transformer.

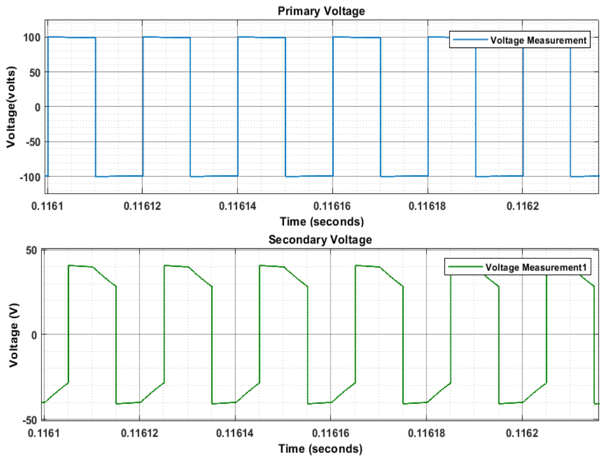


Fig.6.Primary and Secondary Voltage of Transformer

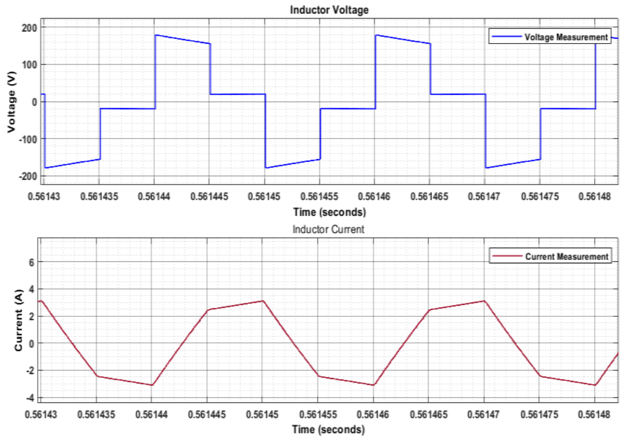


Fig. 7. Inductor Voltage and Inductor Current

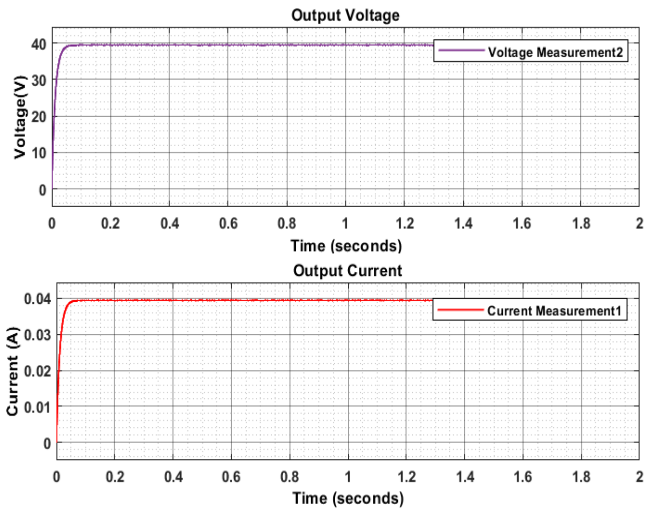


Fig. 8. Output Voltage Waveform

TABLE 2

Parameters	***Values***
V_1	100V
Turns ratio	100:200
P	1 kVA
f	50 kHz
R	1 ohm
L_k	0.0102e-3 H
C	2e-3F

D. Multilevel DAB

For the medium voltage source to provide a high output power, a multilevel converter is required. Medium voltage sources include things like batteries, supercapacitors, and solar panels. The switches that make up the multilayer inverter are many. The placement of the switches' angles is crucial in this.

When semiconductor switches can tolerate a voltage level more than their abilities to block voltage, multilevel converters are suitable for high-voltage, high power levels.

A two-level, 50% duty-cycle square wave voltage waveform is visible on the secondary bridge. The semiconductor switches used on the high voltage side of the DAB only need to resist 50% of the primary maximum dc voltage, which is one of the five-level design's key benefits. A leg-to-leg five-level stepped voltage is formed using two three-level NPC legs[19].

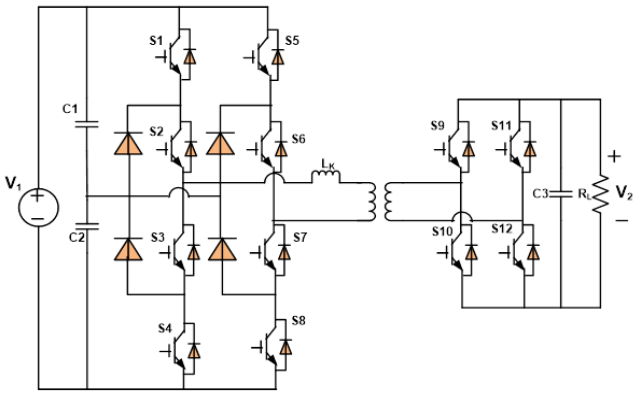


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Fig. 8. Multilevel DAB Converter

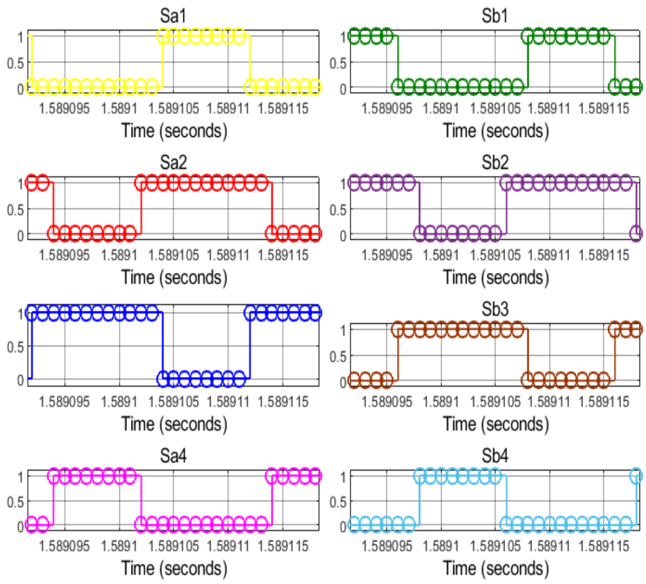

Fig.9 Switching Pulses

$$P_o = \frac{V_p V_s}{nwL}\left(\phi - \frac{\phi^2}{\pi} - \frac{\alpha^2}{2\pi} - \frac{\beta^2}{2\pi}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots(4)$$

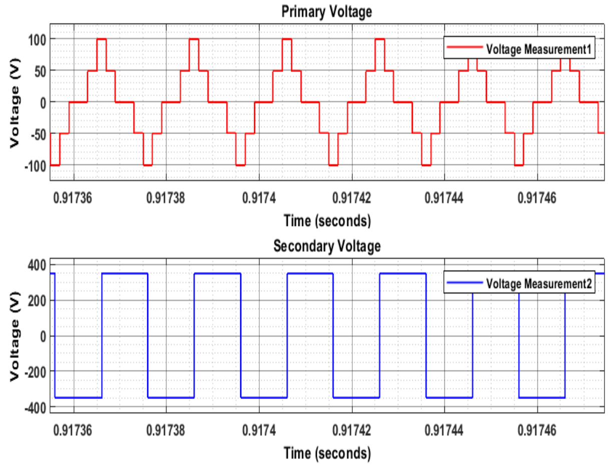

Fig. 10. Primary and Secondary Voltage of the transformer

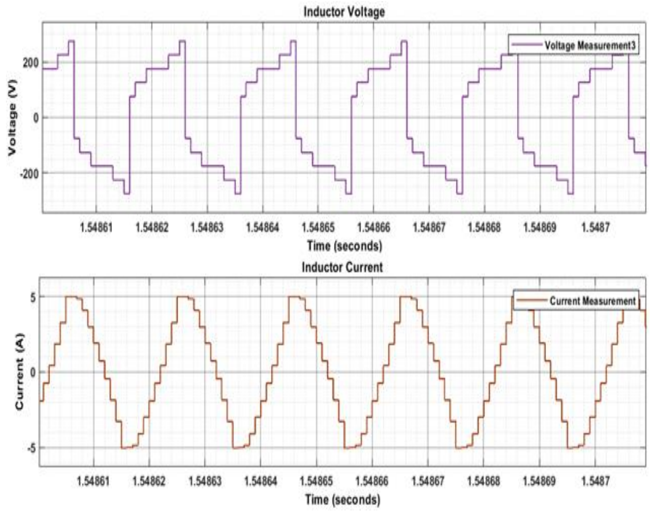

Fig.11. Inductor Voltage and Inductor current

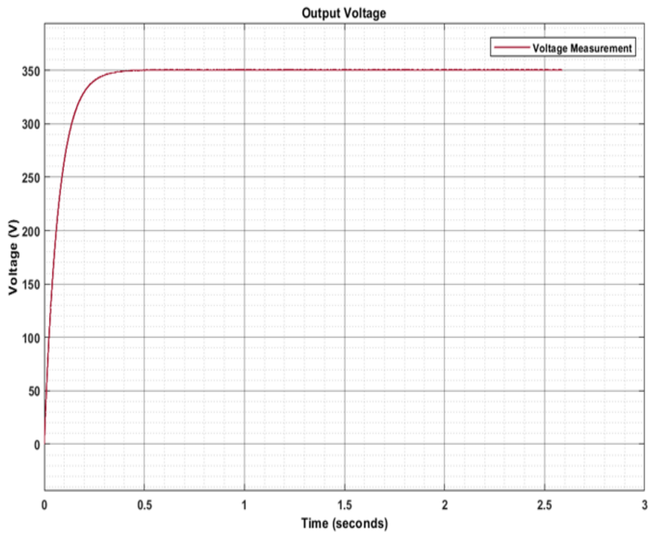

Fig.11. Output Voltage

TABLE 3

Parameters	***Values***
V_1	100 V
P	1 kW
F	50 kHz
Turns ratio	100:200
C_1,C_2,C_3	100e-6

D. Triple Active Bridge(TAB)

The TAB converter is shown in fig. 11 below. In symbol symbolizes windings on the same transformer leg. The leakage inductances of the transformer at Port m are depicted by the inductances L, The single phase -TAB converter's absolutely symmetrical geometry makes it simple to build a bidirectional power transmission between each port[20].

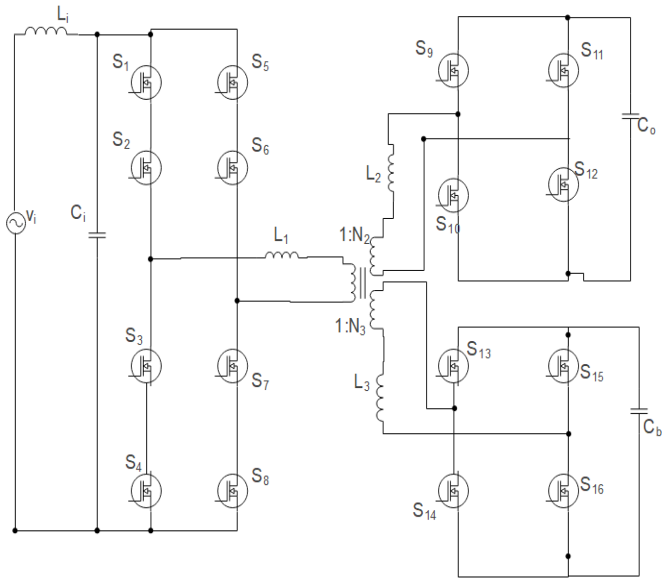

Fig.12. Triple Active Bridge Converter

The core purpose is to create a bidirectional single-stage TAB AC-DC converter for RES systems with a single-phase grid. First, a converter was assessed, proceeded by a parametric study of the TAB AC-DC converter. [20].

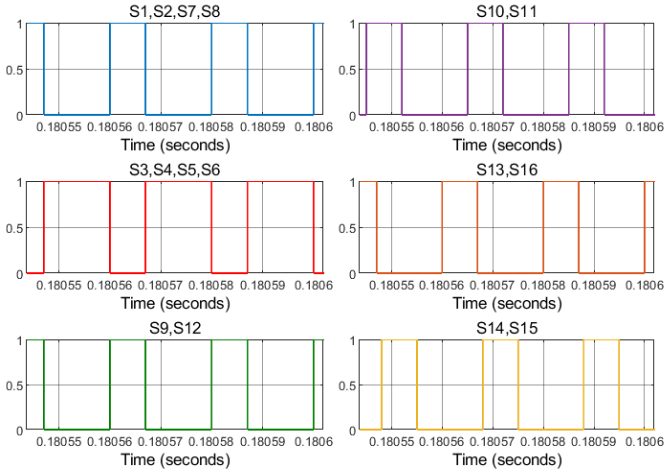

Fig.13. Switching Pulses

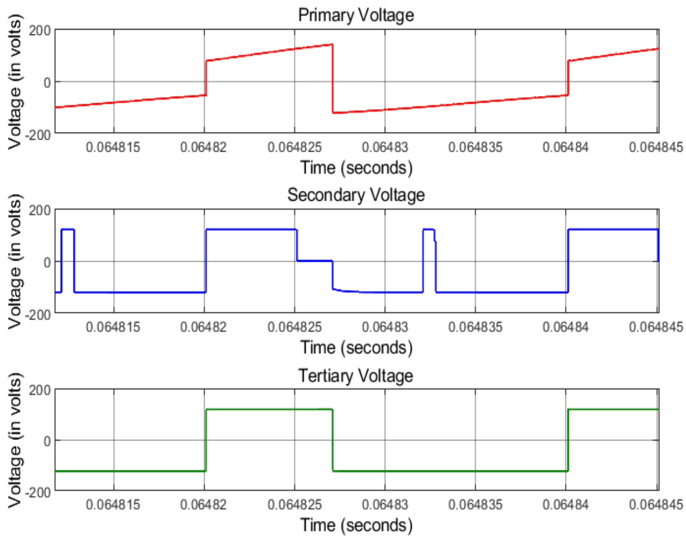

Fig.14. Transformer Voltages

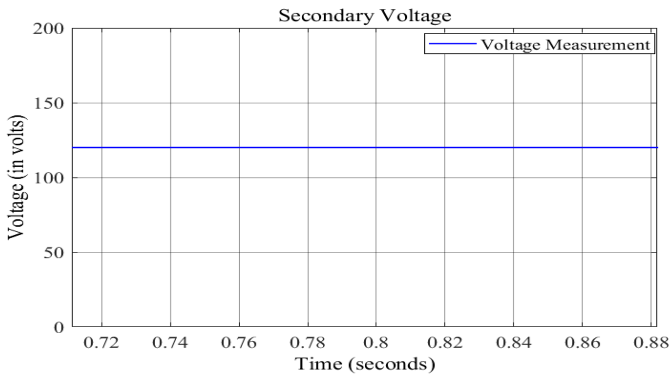

Fig. 15. Secondary Output Voltage

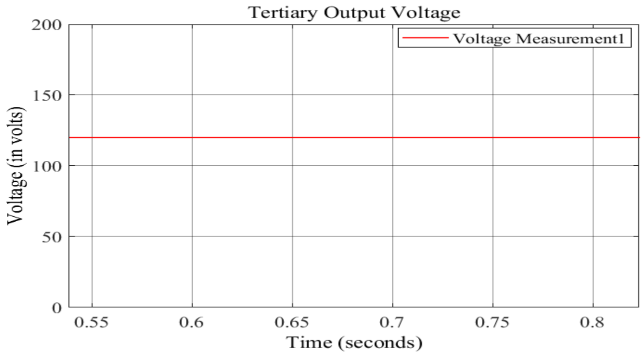

Fig.16. Tertiary Output Voltages

TABLE 4

Parameters	***Values***
Vi	100sinwt
Turns ratio	100:200:200
P	1 KW
F	50 KHz
L_i,L_1	0.229e-6 H
L_2,L_3	4.2633e-6 H
C_1	0.4 mF
C_2	5mF
C_3	2 mF

II. COMPARISON TABLE

The values are taken keeping the input voltage, frequency, power and turns ratio of the transformer in all the four converters same which are:

Vin= 100 V

Converters	***Input Capacitances***	***Output Capacitances***	***Output Voltages***
Hybrid DAB	0.020mF,0.02mF	0.04mF,0.04mF	50 V
Full Bridge		2e-3F	40 V

DAB			
Multilevel DAB	0.1mF,0.1mF	0.1mF	350 V
TAB	0.4mF	5mF,2mF	120V

f=50kHz

Turns ratio=1:2 except TAB, for TAB turns ratio is 1:2:2

P=1kVA

III. RESULTS AND DISCUSSIONS

Fig.4,Fig.7,Fig.10,Fig.14 represents the output voltages of all the four DAB converters respectively. As we can see the output voltages vary a lot.

As we can see that the output voltage of hybrid DAB is around 50 V, the output voltage of Full bridge DAB is 40 V, the output voltage of multilevel DAB is around 350V and that of TAB is around 120V.

Further advancements can be made to attain realistic ZVS conditions while accounting for the tiny charging/discharging current for the power switches' drain-to-source capacitors.

IV. CONCLUSION

The simulation findings of the preceding are presented in this publication mentioned topologies of DAB converters are done and shown by keeping the input voltage, frequency, power and turns ratio same. As we can see that the output voltages vary a lot so we can use these converters based on the requirements of the voltages. For full bridge DAB and hybrid DAB the output voltage is very less so we can use this for low voltage applications and similarly the output voltage of TAB is greater than the previous two so it can be used for medium voltage applications, and we can use multilevel DAB for high voltage applications.

V. ACKNOWLEDGMENT

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