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Comprative Analysis of Different Switching Strategies with feedback linearized controller for Dual Active Bridge DC-DC Converter

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Abstract: This paper focuses on different switching strategies of dual active bridge DC-DC converter. The structure of non-linearity of the device and power flow is a critical problem in BDC. This paper presents a comparative analysis on Alternate phase-shift modulation (APM) schemes such as triangular current modulation (TRM), modified triangular current modulation and Hybrid modulation scheme. A feedback linearized controller is designed to attain better dynamic response for different load. This controlling analysis of isolated bidirectional full bridge converter (IBDC) is controlling of power under different switching strategies to improve their performance of converter for nonlienarity.

Keywords: Isolated bidirectional full bridge converter (IBDC), Alternate phase-shift modulation (APM), triangular current modulation (TRM).

1 INTRODUCTION

Dual active bridge converter is a type of isolated converter which is very popular and attractive towards technology for conversion stage of voltage. It can be used for various application like aerospace application, PV plants, hybrid and electric vehicles etc [1]. The DAB converter is a type of bidirectional, controllable, DC-DC converter contains eight switching devices, inductor to transfer energy, high frequency transformer for isolation purpose and a dc-link capacitor.[2] There is a famous technique which is used for back to back bidirectional converters isolated with high switching frequency transformer. It can be either voltage fed or current fed full bridge converter [3]. In fig.1. represents basic topology of DAB converter having two full bridge converters in both sides of high switching transformer. Transmission of power in DAB is proportionate with the number of switches means more switch more power transmission at the same time there is a concern of switching losses.[4] It can be handled by either silicon carbide (SiC) or gallium nitride (GaN) power switch. Transfer of energy can be handled with the help of adjustment of the phase shift of primary and secondary windings of the transformer.

The paper [6] discuss about hybrid modulation scheme to extend the power range of operation of BDC. A feedback linearized controller is designed to attain better dynamic response for different load. The detail modulation theory and controller design are represented by paper experimental verification of proposed modulation and control scheme is done in this paper. The paper [7] discuss about classification of converters such as isolated and non-isolated converter and each divided into eight group. A brief comparison of non-isolated and isolated converters. This paper also discusses about the control strategies and their comparison. This paper [8] discusses a full set of equations for calculation of gain and phase of buck converter in continuous and discontinuous modes. The paper [9] discuss about mathematical modelling, small signal analysis, stability analysis of open and closed loop transfer function of the system thorough compensation technique. Since most modern system uses more than one type of output capacitor, and this can affect the stability of power system, solutions are presented for up to three different types of capacitors.

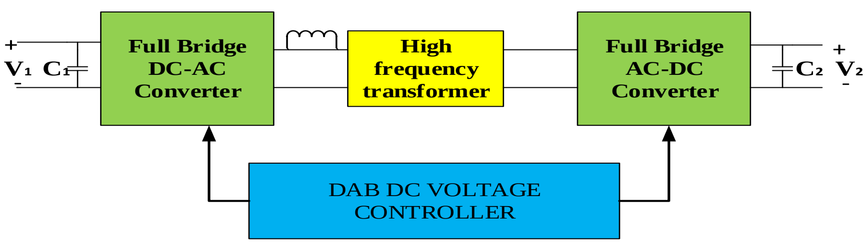

Fig.1. Layout of Dual Active Bridge Converter

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- In the layout, the first stage performs DC to AC conversion.
- In second stage stepping up of the AC voltage takes place with the help of high frequency transformer.
- In the third stage, AC to DC rectification takes place.

II. WORKING PRINCIPAL (POWER FLOW ANALYSIS)

Fig. 2 (a). shows the representation of Dual Active Bridge Converter where two DC-AC converters are connected to two DC voltage sources V_1 and V_2 and interfaced with an inductor L_t. To transfer the power output voltage V_1 and V_2 must be supplied by H_1 and H_2 to the inductor L_t. So here DAB may be changed with two individual Alternating voltage sources V_1 and V_2 interfacing with the inductor L_t as depicted in figure 2 (b). The BDC voltage-current relationship can be analysed with the help of phasor representation of fundamental component of voltage and current to clarify the characteristics of the BDC [10]. Fig.2 (c) represents phasor diagram of fundamental components of voltage and current. From phasor diagram fundamental power flow can be written as follows between two AC sources.

$$P_{12} = \frac{V_1 V_2}{X_{Lt}} \sin\varphi \qquad (1)$$

Where, V_1 = amplitude of the fundamental voltage of primary side
V_2 = amplitude of the fundamental voltage of secondary side
Φ = phase shift between the secondary and primary voltage
$X_{Lt} = wL_t$

From equation 1 it can be seen that P_{12} varies with variation in fundamental phase angle Φ. So, there are two cases with respect to phase angle.

1 If ($\Phi > 0^0$) means V_2 is lagging wrt V_1 transfer of power from source V_1 to V_2 takes place (Forward power flow).
2 If ($\Phi < 0^0$) means V_2 is leading wrt V_1 and transfer of power from source V_2 to V_1 takes place (reverse power flow).

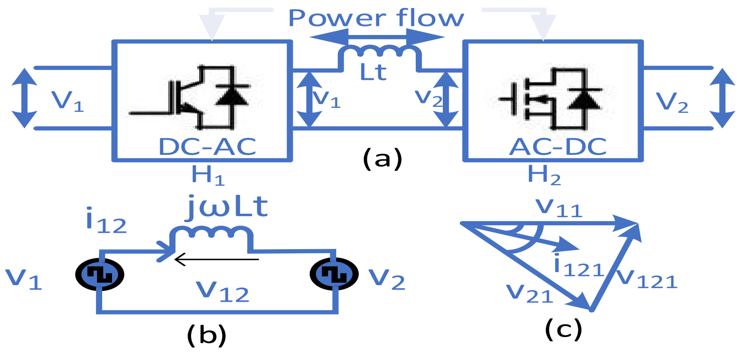

Fig.2.[11] (a) Basic block diagram.(b) Equivalent circuit model. (c) Phasor diagram

Power flow in DAB can be engaged by phase shifting of the pulses of one bridge wrt to the other bridge. This type of technique is named as phase shift modulation. As pulses of switches S_1, S_4 are of the primary bridge and S_5 and S_8 are of the secondary bridge decides the shifting of the secondary bridge by either by Φ or by – Φ.

III. ALTERNATE PHASE SHIFT MODULATION FEEDBACK LINEARIZED CONTROLLER SCHEMES FOR ULTRACAPACITOR

For wide input and output voltage range to minimized the switching and conduction losses an alternate phase shift modulation scheme is introduced. Various technique is used to minimized the conduction losses and for modification of switching strategies.[11] For this there is two approach in first we use additional component like snubber circuit and resonant circuit. In this technique there is risk of increase in circulating current and this leads to increase in conduction losses . In second technique modification of switching control is done without addition of any extra component this technique is named as APM. In APM there should be phase shift between primary and secondary voltage. For APM scheme modification in DAB converter is required which is shown in Fig 3.

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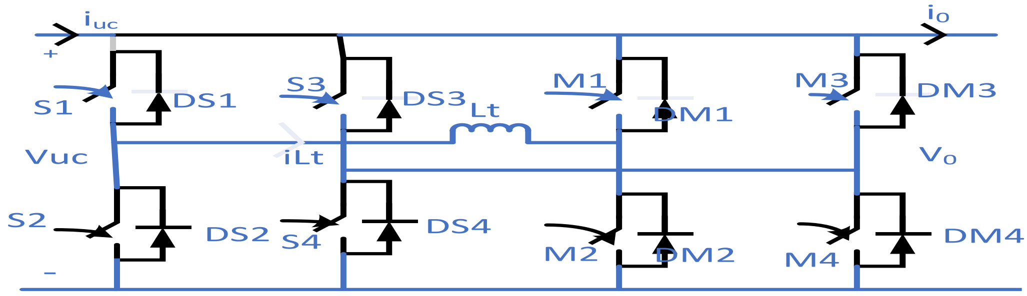

Fig.3. Modified circuit of the BDC with two H-bridges

There is various APM scheme which are as follows-

- Triangular current modulation
- Hybrid modulation scheme
- MTRM hybrid modulation scheme
- TRM-TZM hybrid modulation

1. Triangular current modulation

Triangular current modulation is a type of alternate phase shift schemes in which reduction of circulating current takes place with the help of maintaining the triangular waveform in primary winding of the transformer [13]. The applied waveforms are shown in the Fig.4. It may be splited into six intervals over one complete cycle when $V_1>V_2$ for TRM scheme for BDC. Where the $v_{pri}(t) = (V_1 = V_{uc})$ and $v_{sec}(t) = (V_2 = V_0/n)$. There are three-time interval in and the inductor current is given as follows.

$$i_{Lt}(t) = \begin{cases} \frac{V_1}{\omega L_t} t & 0 < t < t_1 \\ \frac{-V_2}{\omega L_t}(t - t_1) + i_{Lt}(t_1) & t_1 < t < t_2 \\ 0 & t_2 < t < t_3 \end{cases} \quad (2)$$

And transfer power is given by equation (3) when $V_1 > V_2$ in UCDM

$$P_{uc} = \frac{V_1(V_1 - V_2)t_1^2}{2\pi\omega L_t} \quad (3)$$

Transferred power in relation to φ where $t_1 = 2\varphi$ when $V_1 > V_2$

$$P_{uc}^{PTRM} = \frac{2\varphi^2 V_1^2 V_2^2}{\pi\omega L_t (V_1 - V_2)^2} \quad (4)$$

$$\varphi_{max}^{TRM} = \frac{1}{2}\frac{(V_1 - V_2)}{V_1} \quad (5)$$

$$P_{uc\_max}^{TRM} = \frac{\pi V_2^2}{2\omega L_t V_1}(V_1 - V_2) \quad (6)$$

By seeing equation (6) there is three cases in respect with V_1 and V_2

When $V_1>V_2$ power can be transferred and TRM can be used in this case and BDC is in UCDM. In second case $V_1<V_2$ and third case $V_1=V_2$ TRM cannot be used in both cases. To operate BDC under TRM a higher turn ratio should be there.

$$n > \frac{V_0}{V_{UC\_min}} \quad (7)$$

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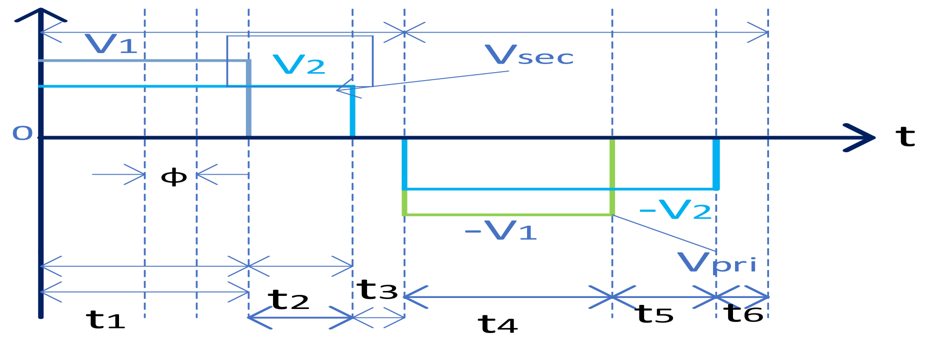

Fig. 4. Waveforms of the TRM scheme, when $V_1 > V_2$

For $V_1 < V_2$ switching pattern has to be modified to attain TRM operation which is shown in Fig.5. Now for this case t_1, t_2 and t_3 have to be recalculated as like previous case but it is more complex than previous one.

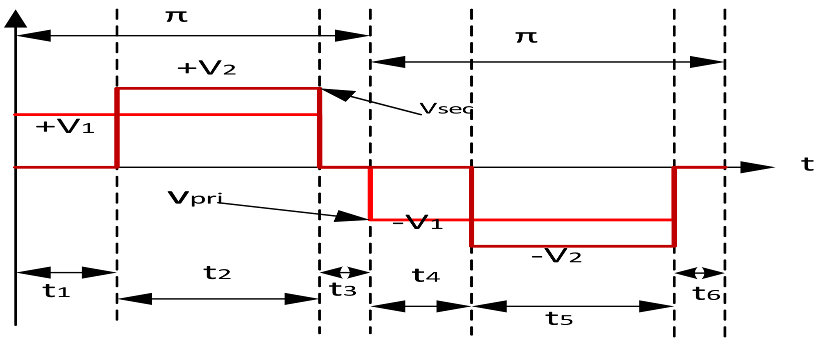

Fig.5. Transformer voltage for $V_1 < V_2$ of TRM scheme in UDCM

2. Hybrid modulation

The requirement of hybrid modulation scheme is to reduce the conduction losses and for improving the soft-switching operation but there is problem with maximum transferable power because it is less than the maximum possible power of the BDC. That's why it cannot be use for high power applications. [14] So, for to elimination of this problem hybrid modulation schemes are use. There are two types of hybrid modulation scheme such as MTRM (Modified Triangular Current Modulation) and TRM-TZM (Triangular current modulation-Trapezoidal current modulation) hybrid modulation scheme.

3. Modified Triangular Current Modulation (MTRM)

In MTRM technique modification in gate pulse is done to operate BDC when $V_1 = V_2$, modified TRM scheme named as ''proposed TRM'' (PTRM). Half cycle is divided in three parts such as t_0, t_1, and t_3. In this technique there is no overlap of primary and secondary voltage and inductor current is given as follows-

$$i_{Lt}(t) = \begin{cases} \frac{V_1}{\omega L_t} t & t_0 < t < t_1 \\ \frac{-V_2}{\omega L_t}(t - t_1) + i_{Lt}(t_1) & t_1 < t < t_2 \\ 0 & t_2 < t < t_3 \end{cases} \quad (8)$$

$t_2 = 2\varphi - t_1$ and $t_1 = \frac{2\varphi V_2}{V_1 + V_2}$ and transfer power is given as $P_{uc}^{PTRM} = \frac{V_1^2 t_1^2}{2\pi\omega L_t}$ maximum phase shift and maximum transferable power is is given as follows-

$$\varphi_{max}^{PTRM} = \pi/2 = t_1 = t_2$$

$$P_{uc}^{TRM} = \frac{2\varphi^2 V_1^2 V_2^2}{\pi\omega L_t (V_1 - V_2)} \quad (9)$$

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By seeing maximum transferable power MTRM technique gives positive power transfer for UCDM for any values of V_1 and V_2 Although this technique has disadvantage of large RMS values and peak current and can be used for light load. Maximum transferable power is given as-

$$P_{uc\_max}^{PTRM} = \frac{V_1^2 V_2^2}{2\omega L_t (V_1+V_2)^2} \quad (10)$$

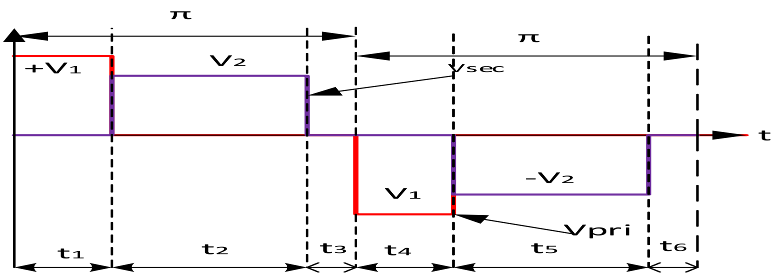

Fig.6. Waveform of voltage when $V_1 > V_2$ of PTRM scheme

In modified triangular current modulation scheme duty cycle is varied between 0% to 50% with respect to phase shift (φ). For light load circulating current is minimized but it could not be achieved for medium and heavy load. [15]. But it diminishes the BDC power transfer ability because there is no phase shift between bridges, however only changes the root mean square voltage crossways the bridge to control power flow.

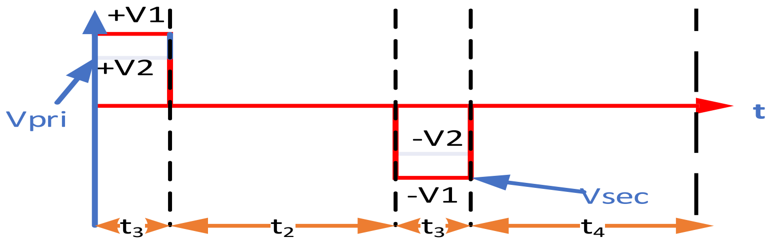

Fig.7. when $V_1 > V_2$ in case of MTRM scheme

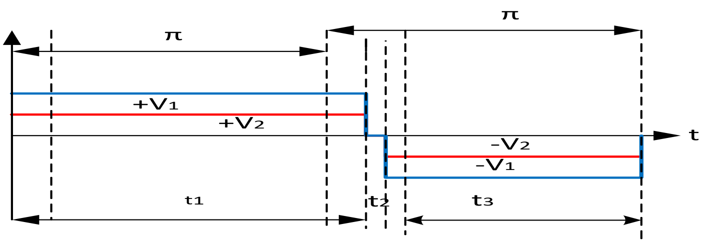

Fig.8. Waveform when $V_1 > V_2$ in case of MTRM scheme with ZCS

4. Feedback linearized controller:

A feedforward linearized controller has been atached with switching strategy to control the power fluction due to current oscilation. The block diagram has been shown in Figure 9.

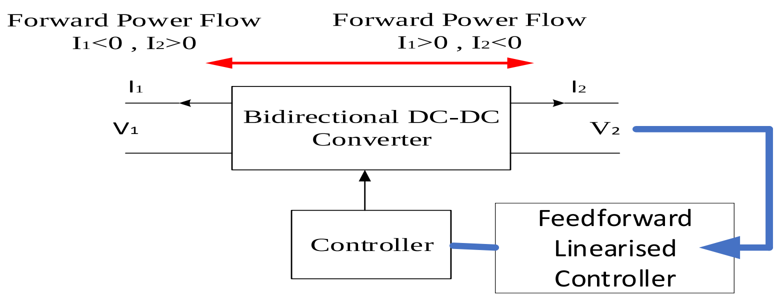

Fig. 9 Feedback linearized controller

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IV. SIMULATION AND RESULT ANALYSIS

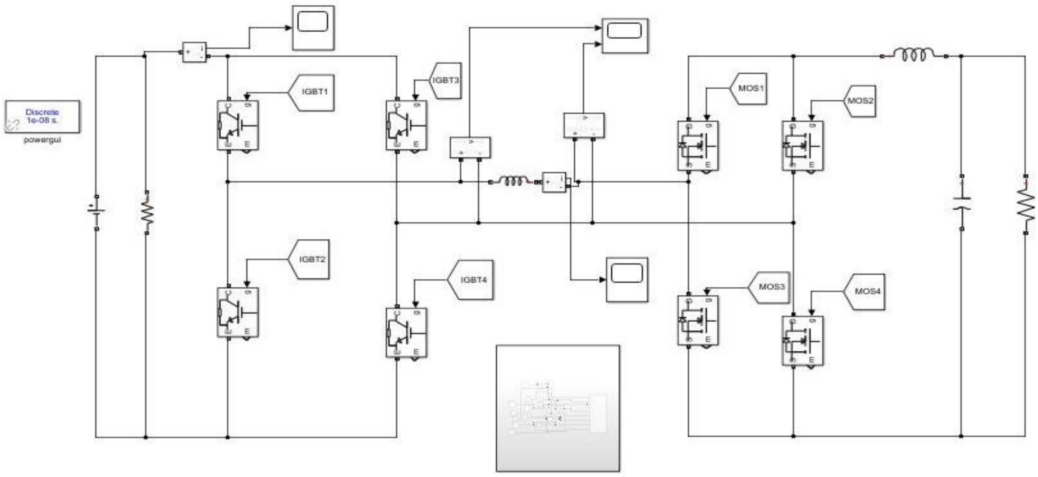

Fig.10. Simulation model of modified DAB

Result under TRM scheme based linearised feedback controller

(a) Result under TRM scheme based linearised feedback controller shown in Fig. 11, when $V_1>V_2$ in this case inductor current increasing during interval t_1 and reach to its peak value that is I_{pk}, after it starts decreasing during interval t_2 and goes to zero and remain zero till time interval t_3. After it increases linearly in negative direction and goes to a $-I_{pk}$ peak current till completion of interval t_4 and after it goes to zero during interval of t_5.

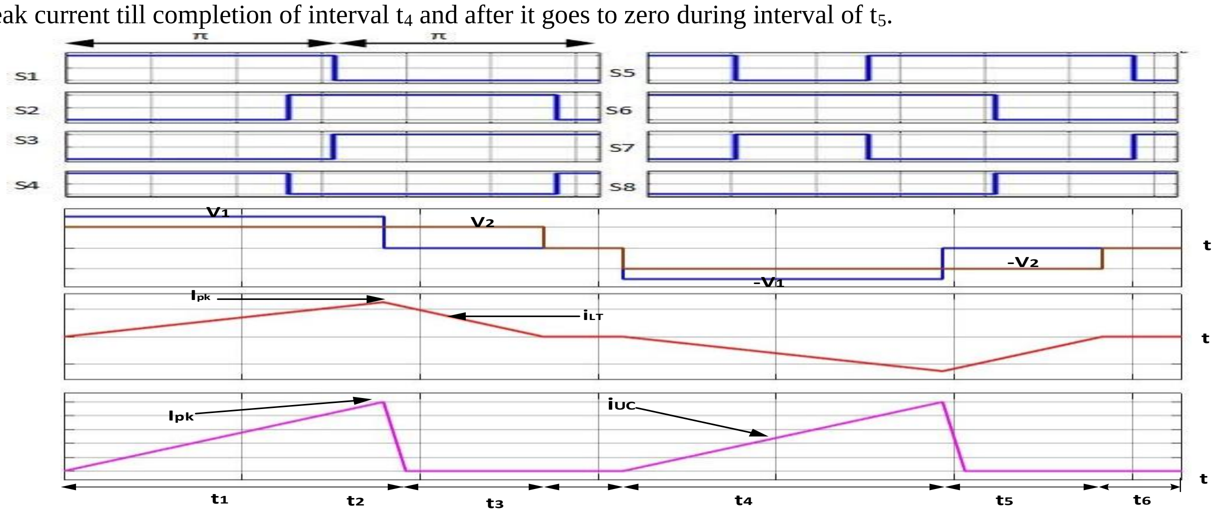

Fig.11. Result under TRM scheme based linearised feedback controller when $V_1>V_2$

(b) Result under TRM scheme based linearised feedback controller shown in Fig. 12, when $V_1 < V_2$ in this case inductor current increasing during interval t_1 and reach to its peak value that is I_{pk}, after it starts decreasing during interval t_2 and goes to zero and remain zero till time interval t_3. After it increases linearly in negative direction and goes to a $-I_{pk}$ peak current till completion of interval t_4 and after it goes to zero during interval of t_6 and remain zero till interval of t_7.

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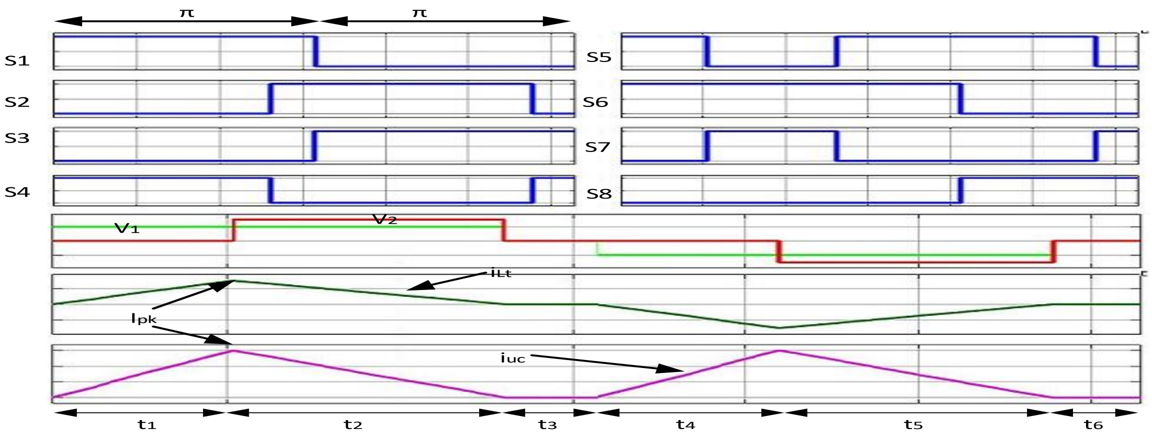

Fig.12. Result under TRM scheme based linearised feedback controller when $V_1 < V_2$

Result under MTRM scheme based linearised feedback controller

(a) Fig.13. represent key waveform of MTRM scheme based linearised feedback controller when $V_1 > V_2$ without ZCS.

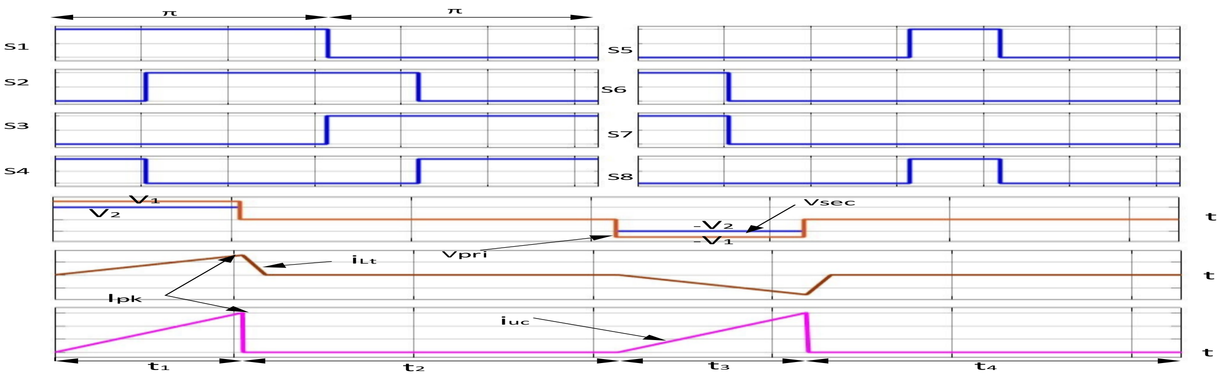

Fig.13. Waveform under MTRM scheme based linearised feedback controller when $V_1 < V_2$

(b) Fig.14. represent key waveform of MTRM scheme based linearised feedback controller with ZCS realisation

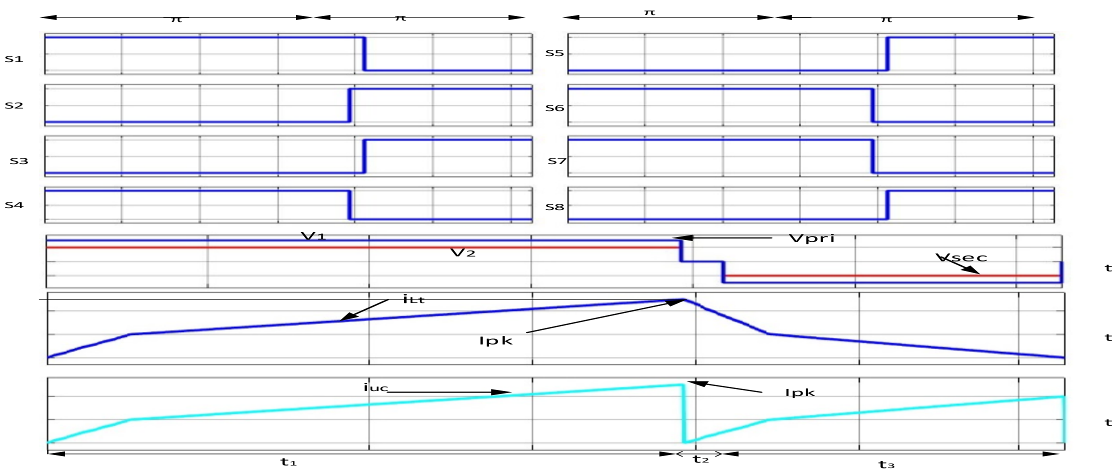

Fig.14. Waveform under MTRM scheme based linearised feedback controller when $V_1 > V_2$

Result under TZM scheme based linearised feedback controller

Fig.15. Represent different waveforms under TZM scheme based linearised feedback controller when V_1>V_2 in which inductor current increasing during interval T_1 and attain I_{pk} further current increases during interval T_2, in interval T_3 it

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decreases and remain zero during entire T_4 interval. Now in second half current decreases in negative direction during interval T_5, T_6 and in half of interval it goes to zero and remain zero till completion of entire T_7 interval.

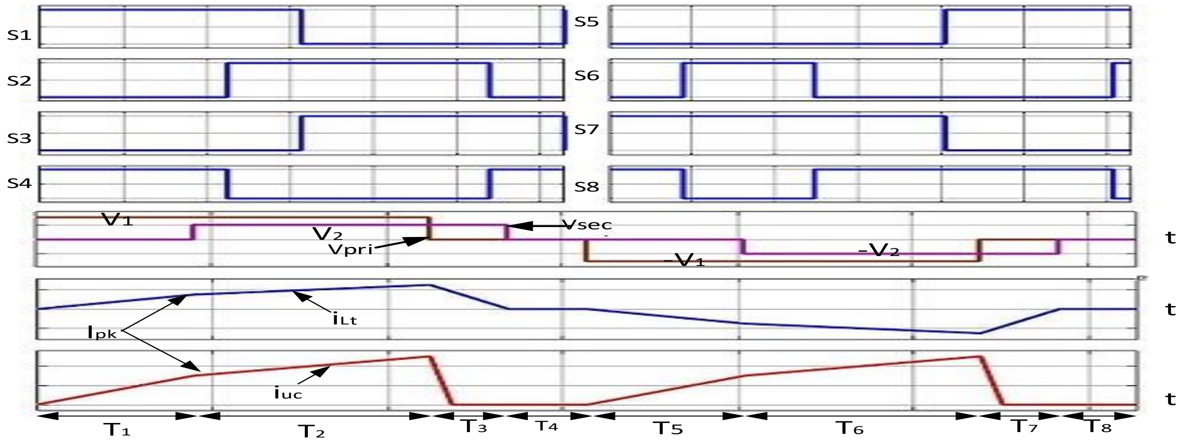

Fig.15. Different waveform of TZM scheme based linearised feedback controller when $V_1 > V_2$

V. CONCLUSIONS

Dual active bridge converter is a type of isolated converter which is very popular and attractive towards technology for conversion stage of voltage. In paper different switching pattern are discuss. All have its some limitations and its advantage which are discussed. Controlling of power is discussed under different switching strategies to improve their performance of converter.Alternate phase-shift modulation (APM) scheme is discussed here such as triangular current modulation (TRM), modified triangular current modulation and Hybrid modulation scheme.TRM has limitation of lower power transfer capabilities. But the hybrid modulation can extend the range of power transfer capabilities.

REFERENCES

[1] T. Wu, Y. Chen, J. Yang and C. Kuo, "Isolated Bidirectional Full-Bridge DC–DC Converter With a Flyback Snubber," in IEEE Transactions on Power Electronics, vol. 25, no. 7, pp. 1915-1922, July 2010.

[2] Gupta, R., Singh, N. Fuzzy logic feed-forward impedance shaping of DAB converter in DC microgrid with CPL load. J. Power Electron. (2023). https://doi.org/10.1007/s43236-023-00641-z

[3] A. Shukla, M. Yadav and N. Singh, "Control and Implementation of Bi-Directional Converter for Power Management of Unbalanced DC Microgrid," 2019 International Conference on Computing, Power and Communication Technologies (GUCON), New Delhi, India, 2019, pp. 343-349.

[4] S. Paswan, A. K. Maurya, M. Yadav and N. Singh, "Hybrid trapezoidal modulation technique for conditioning of power quality and harmonic distortion based on D-statcom," 2020 International Conference on Electrical and Electronics Engineering (ICE3), Gorakhpur, India, 2020, pp. 737-742, doi: 10.1109/ICE348803.2020.9122896.

[5] H. Mao, J. A. Abu-Qahouq, S. Luo and I. Batarseh, "New zero-voltage-switching half-bridge DC-DC converter and PWM control method," Eighteenth Annual IEEE Applied Power Electronics Conference and Exposition, 2003. APEC '03., Miami Beach, FL, USA, 2003, pp. 635-640 vol.2.

[6] N. Singh and V. Agrawal, "Fuel cell based high frequency and soft switching DC-AC converter for remote area places," 2013 Annual IEEE India Conference (INDICON), Mumbai, 2013, pp. 1-6.

[7] Yadav, M, Singh, N. Small-signal modeling-based hybrid optimized current and voltage controller for unbalanced DC microgrid. Wiley Int Trans Electr Energ Syst. 2021

[8] Alam MA, Singh N. Analysis of switching topology for advanced isolated bi-directional DC-DC converter. In 2018 2nd International Conference on Electronics, Materials Engineering & Nano-Technology (IEMENTech) 2018 May 4 (pp. 1-8). IEEE.

[9] "Power Electronics for Renewable and Distributed Energy System", Springer Nature, 2013

[10] T. Lodh and T. Majumder, "A high gain high-efficiency negative output flyback-Cuk integrated DC-DC converter," 2016 International Conference on Signal Processing, Communication, Power and Embedded System (SCOPES), Paralakhemundi, 2016, pp. 63-68.

[11] O. A. Ahmed, J. A.M. Blejjs ‘‘Power flow control Methods for an ultracapacitor bidirectional converter in DC microgrids—A comparative study’’ in Renewable and Sustainable Energy Reviews volume 26 oct 2013.

[12] Zhifu, Wang & Yupu, Wang & Yinan, Rong, 2017. "Design of closed-loop control system for a bidirectional full bridge DC/DC converter," Applied Energy, Elsevier, vol. 194(C), pages 617-625.

DOI: 10.17148/IARJSET.2023.107132

[13] R. T. Naayagi, A. J. Forsyth and R. Shuttleworth, "High-Power Bidirectional DC–DC Converter for Aerospace Applications," in IEEE Transactions on Power Electronics, vol. 27, no. 11, pp. 4366-4379, Nov. 2012.
[14] S. L. Patil and A. K. Agarwala, "Push pull boost converter with low loss switching," 2008 IEEE International Conference on Industrial Technology, Chengdu, 2008, pp. 1-6.
[15] S. Moon, S. Jou and K. Lee, "State-space average modeling of bidirectional DC-DC converter for battery charger using LCLC filter," 2014 International Power Electronics Conference (IPEC-Hiroshima 2014 - ECCE ASIA), Hiroshima, 2014, pp. 224-229.