IJIREEICE ISSN (O) 2321-2004, ISSN (P) 2321-5526

International Journal of Innovative Research in Electrical, Electronics, Instrumentation and Control Engineering

ISO 3297:2007 Certified ⁙ Impact Factor 8.021 ⁙ Peer-reviewed / Refereed journal ⁙ Vol. 11, Issue 7, July 2023

DOI: 10.17148/IJIREEICE.2023.11720

Stability Analysis of Dual Active Bridge DC-DC Converter Using TCM Modulation Technique

Ravishankar Gupta[1], Divyanshi Srivastava[2], Nikita Prajapati[3], Mukh Raj Yadav[4]

Research Scholar, EE Department, MMMUT, Gorakhpur, India[1]

Research Scholar, EE Department, MMMUT, Gorakhpur, India[2]

Research Scholar, EE Department, MMMUT, Gorakhpur, India[3]

Assistant Professor, EEE Department, NIMS University, Jaipur, India[4]

Abstract: This paper addresses triangular current modulation technique (TCM) to reduce circulating current and losses in the dual active bridge converter (DAB). The converter is designed through small signal analysis. Stability is the challenging issue in DAB, due to the nonlinear behavior of the converter. The stability is convinced by the PI controller with a variation of switching inductance. Triangular current modulation is a type of alternate phase shift scheme in which the reduction of circulating current takes place with the help of maintaining the triangular waveform in the primary winding of the transformer. In buck mode, the system response is always stable, but in the case of the boost mode of the converter, the system will be unstable due to nonlinearity. The system can make sure to be stable with the help of the PI controller under the variation of switching inductors.

Keywords: Small signal analysis (SSA), TRM (Triangular current modulation) Dual active bridge converter (DAB)

I. INTRODUCTION

The study of bidirectional converter is an attractive field of research now a days in power electronics due to its compatibility with various application like aerospace, EV (Electric vehicles), UPS (uninterruptable power supply), hybrid electric vehicles (HEV), PV arrays, wind turbine and many more in residential, commercial, and industrial application [1-2]. For transferring of energy from generators to energy storing device like supercapacitor and batteries and form energy storing element to electric motors utilization of bidirectional converter is done in case of Electric vehicles. For attaining these requirements of high step-up voltage ratio having high conversion efficiency is essential. Galvanic isolation is used for isolation that is voltages-fed full bridge (VFFD) and current fed full bridge (CFFB) DC-DC converter [3-4]. There are various types of IBDC such as push pull, semi, full bridge, and Flyback converter [5]-[7]. Table 1 shows their characteristics application advantage and disadvantage. Flyback converter has superior structure, less costly, and have better transient behavior [7]. Though, as of the leakage inductance of the transformer, they generally undergo excessive voltage oscillation and switching losses [8]. Major problem associated with push pull converter is that the switching device withstand two times the applied voltage. However, there is no issue with low input voltage application. The half bridge BDC converter has one arm and work as positive and negative one by one [8]. Here output switching voltage is half of input voltage. Although because of alteration in switching function of switch the positive and negative voltage of transformer is not equal in one complete cycle means average voltage is not equal to zero, so cancellation of positive and negative cycle will not take place which results in saturation of magnetic core. In case of full bridge there is power switches on two leg these switches assure steadiness of bridge arm’s turn on and turn off process [9]. By using full bridge, magnetic saturation problem of half bridge converter can be removed and acquire soft switching and current two times of half bridge converter. A brief comparison of DAB is shown in table no 1.

Types of DABs	Advantage	Disadvantage
DAB	Most popular one More switches	More variation, high ripple current
Dual half bridge	Less ripple in current, short circuit and over current protection	Additional circuit is required to start
Half full bridge	Soft switching, less switch required,	High ripple current, unbalanced current stress
Multiport-DAB	Source utilization improved	More complex

Table no.1 A brief comparison of DAB converter

II. GENERAL TOPOLOGY

A general layout of DAB converter is shown in Fig.1. The Fig. 2. Represents the DAB converter and it has non- linear element like diodes and switches, so DAB is a non-linear system. As it is a non-linear device, it is a challenging task for mathematical modeling and acquiring transient stability analysis of model so for approximate analysis of the system is done. Firstly, when apply DC voltage (V1) source to the H1 bridge it converts direct voltage to an alternating voltage source and fed it to primary winding of the transformer then via secondary winding it goes to the secondary bridge and there it converts from AC to DC voltage V2 [10].

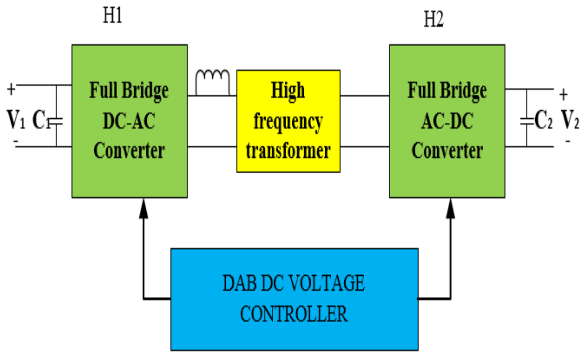

Fig.1. Block diagram of DAB

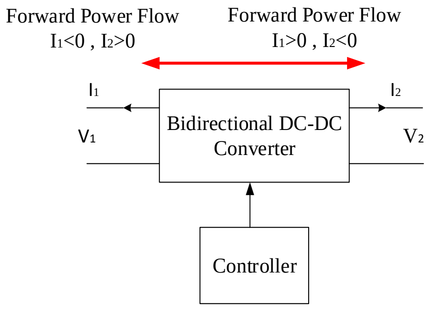

Fig. 2. Schematic diagram of power flow analysis

Fig. 2. Shows basic diagram of power flow in DAB converter. To deal with nonlinearities of system small-signal analysis is done. [11]. For small signal analysis suppose converter system is performing in the environs of a stable operating point, and when any type of disturbance takes place then the converter behaves linearly in the environs of the stable operating point [12]. Therefore, with the help of small signal analysis of converter transfer function of dynamic model of the system is obtain and now go for designing of closed loop system with the help of classical control.

A. *Triangular modulation Technique*

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. The applied waveforms are shown in the Fig. 3. 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 $v_{sec}(t) = (V_2 = V_0/n)$.

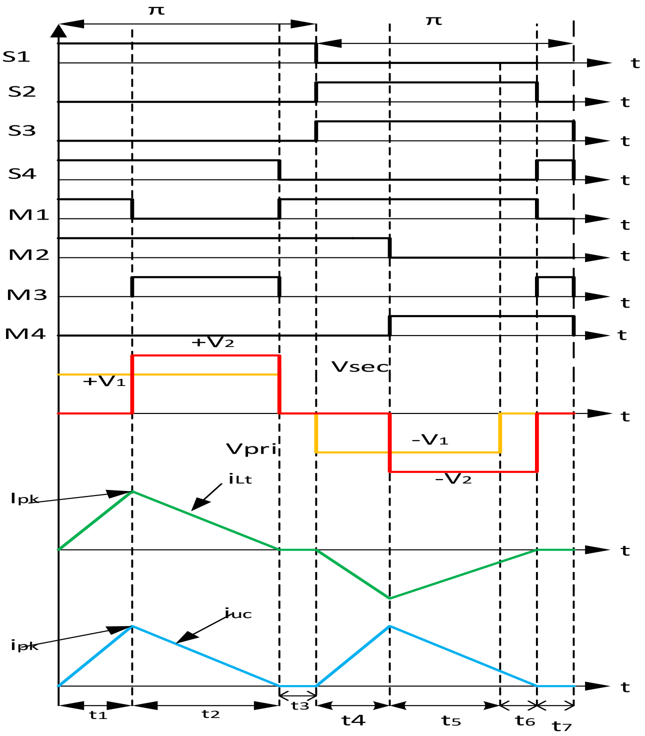

Fig 3. Triangular waveform

DOI: 10.17148/IJIREEICE.2023.11720

III. DYNAMIC MODELING AND GENERAL OPERATION

In full bridge BDC energy transfer takes place in two modes, in first mode, that is buck mode like buck converter and second mode, that is boost mode like boost converter.

A. Dynamic analysis of buck mode

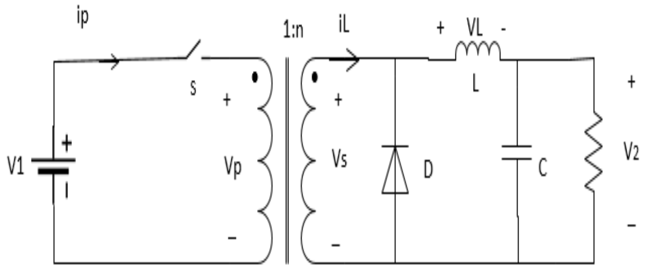

Fig.4 Equivalent model of converter in buck mode

During turn on time applied energy is transmitted to load and inductor, and during turn off time inductor fed back his energy to the load [13-14]. The transmission of energy takes place with the help of isolated transformer as compared with the basic buck converter. Turn ratio of ideal transformer is 1: n which is shown in Fig.4. The basic equation of transformer is given as follows.

$$V_P = V_1, \frac{V_P}{V_S} = \frac{1}{n}; \frac{I_P}{I_S} = \frac{n}{1}; i_s = i_l$$

Current and voltage relation of capacitor and inductor are

$$\upsilon_1(t) = L\frac{di_l(t)}{dt}, \upsilon_1(t) = L\frac{di_l(t)}{dt}, \qquad (1)$$

Firstly, average voltage and current of inductance is find out and after it for linearization of the model small signal analysis and perturbation scheme is applied and then by using Laplace transform transfer function G_{vd} (s) is find out for buck mode in continuous conduction mode shown as follows [15]

$$G_{\upsilon d}(S) = \frac{\upsilon_2^{'}(S)}{d^{'}(S)} = \frac{nV_1}{LCs^2 + \frac{L}{R}S + 1} \qquad (2)$$

B. Dynamic analysis of boost mode

Fig. 5. shows basic version of full bridge DC-DC converter in boost mode [15]. In turn on time energy is conveyed to inductor only and during turn off time energy is conveyed from source and inductor to the load. The transfer function of boost mode in Fig 5 can be finding out in similar way as in the previous mode. Here $G'_{vd}(s)$ is the transfer function of boost mode can be expressed as [16].

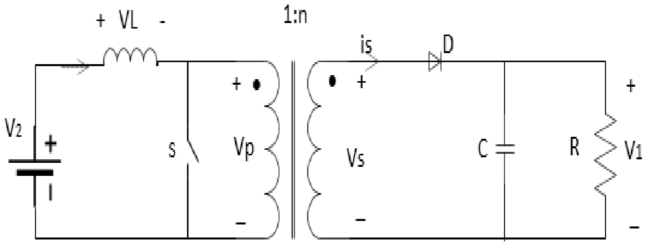

Fig.5. Equivalent model of converter in boost mode

$$G'_{vd}(S)=\frac{v'_1(s)}{d'(s)}=V_2\frac{1-\dfrac{n'^2}{R(1-D)^2}}{LCn's^2+\dfrac{Ln'}{R}s+\dfrac{(1-D)^2}{n'}} \quad (3)$$

IV. STABILITY BEHAVIOR AND CONTROLLING

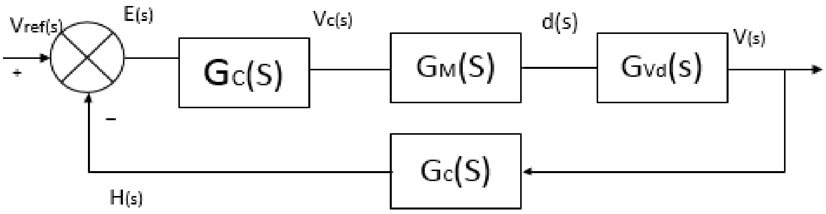

Fig 6. Schematic Circuit for Controller

Figure 6. shows the negative feedback voltage controller. G_{vd},(s) d(s), v(s), G_m(s) and Gc(s) forms transfer function. Open loop gains from Fig. 6. Is

$$G(s)=G_c(s)G_m(s)G_{vd}(s) \quad (4)$$

And feedback is H(s). Open loop transfer function is as follows- (5)

$$G_0(s)=\frac{136.8421}{1.02*10^{-10}*s^2+810^{-5}s+1} \quad (5)$$

Where $G_0(s)=G_m(s)G_{vd}(s)H(s)$

In above equation parameter values are L=8 µH, C=15 µF, G_m= (1/1140), H (s)= 177.2727 and load resistance is 0.1Ω. Now, go for bode plot of G_0(s) with the help of MATLAB.

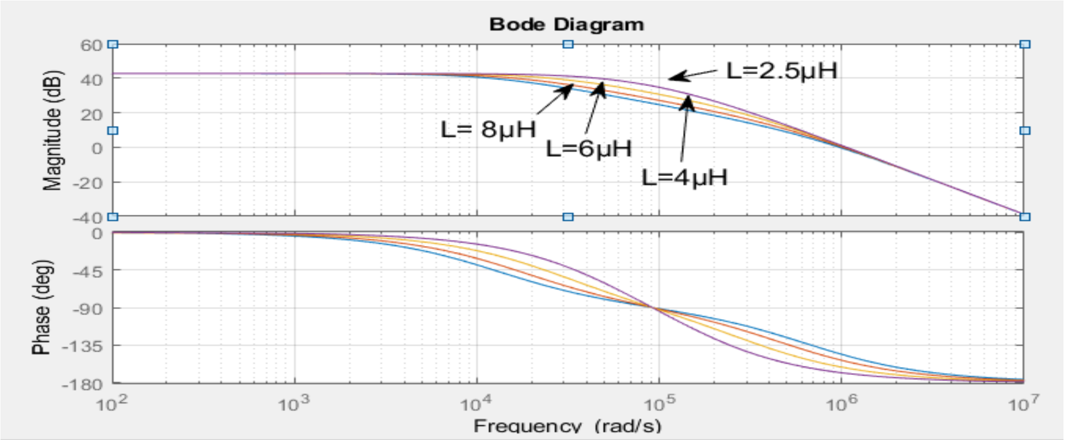

Fig. 7 Bode diagram of G_0(s) in buck- mode

Phase margin (PM), gain margin (GM) phase cross-over frequency, and gain cross over frequency and the bode plot shows that the system is stable from Fig 7.

Table. 2 shows the phase margin with respect to change in the value of inductor value ‘‘(3)’’ shows the transfer function of boost mode and by putting parameter values L=8 µH, C=15µF, R=.1, V_2=100, turn ratio one

$$G'_{vd}(s) = \frac{1-3.2*10^{-4}*s}{1.2*10^{-10}*s^2+8*10^{-5}*s+0.25} \quad (6)$$

Table. 2 Inductor Value Vs Phase margin for Buck mode

Inductor value (µH)	Phase margin (degrees)
2	5.67
2.5	19.9
4	25
8	34.7

Now go for Bode plot of equation ‘‘(6)’’ and it shows that the system is not stable, and plot is shown in fig 8. To overcome stability issues, we must have cross-over frequency not greater than the corner frequency [17]. By doing this reduction of bandwidth of the model takes place and improve the dynamic response of the model to attain the stability of the system compensation is required by which addition of real zero and integrator is done to the system by doing this stability of the system is achieved. Now compensated equation looks like ‘‘(7)’’

$$\mathrm{G}'_0(\mathrm{s}) = \frac{100+.188s-7.04*10^{-5}s2}{1.2*10^{-10}*s^2+8*10^{-5}*s+0.25} \quad (7)$$

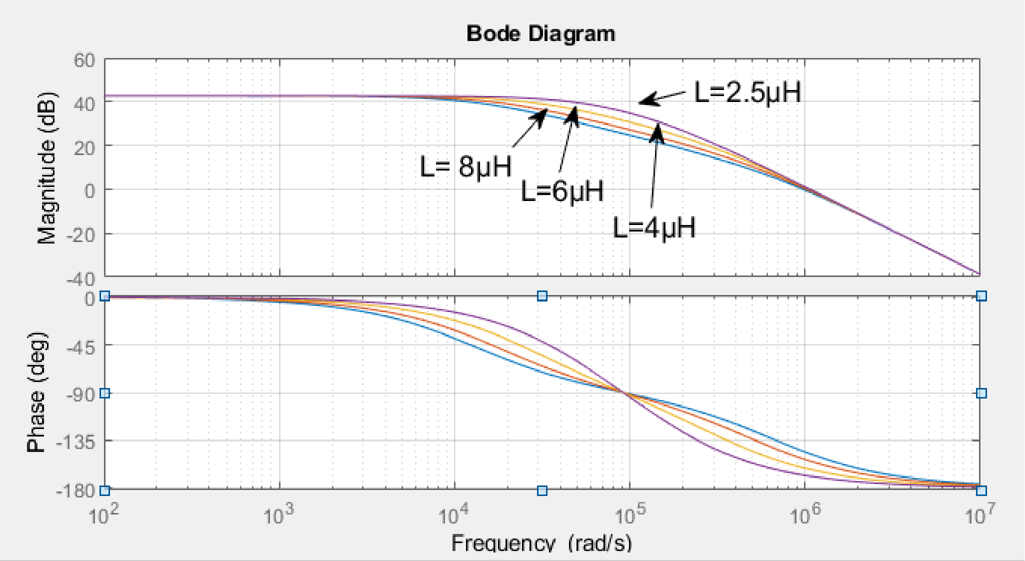

Fig. 8. Bode Plot of boost mode

Table 3 shows the Phase margin for different values of inductor in boost mode.

Table. 3 Inductor Value Vs Phase margin for Boost mode

Inductor value (µH)	Phase margin (degrees)
2	115
2.5	119
4	123
8	121

Fig. 9. Shows the compensated bode plot of the ‘‘(6)’’ .

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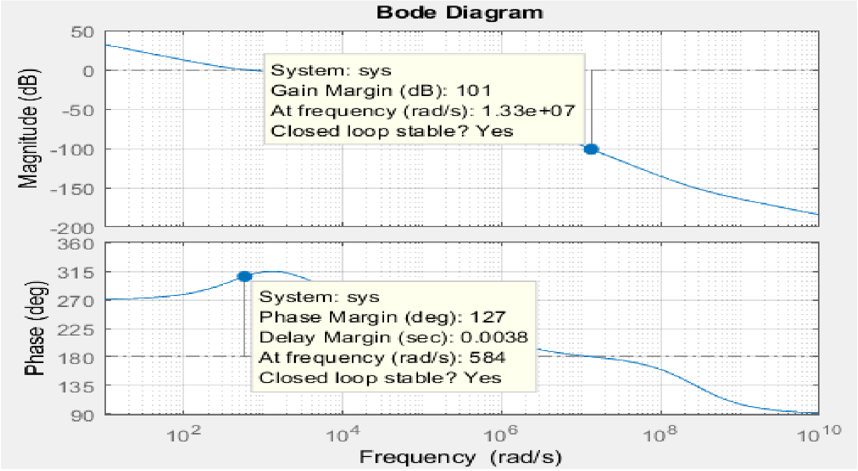

Fig. 9. Bode Plot After Compensation

V. SIMULATION AND RESULT ANALYSIS

With the help of MATLAB/SIMULINK simulation model of full bridge converter is designed which is shown in Fig. 10. Fig. 11 and Fig. 12 shows output voltage of converter in buck and boost mode respectively. Fig. 12 shows output voltage of converter in boost mode and acquired its stability much faster than buck mode. ‘‘Fig.14’’ and ‘‘Fig.15’’ shows primary and secondary side voltage of high switching transformer respectively when step voltage of 220 V is applied.

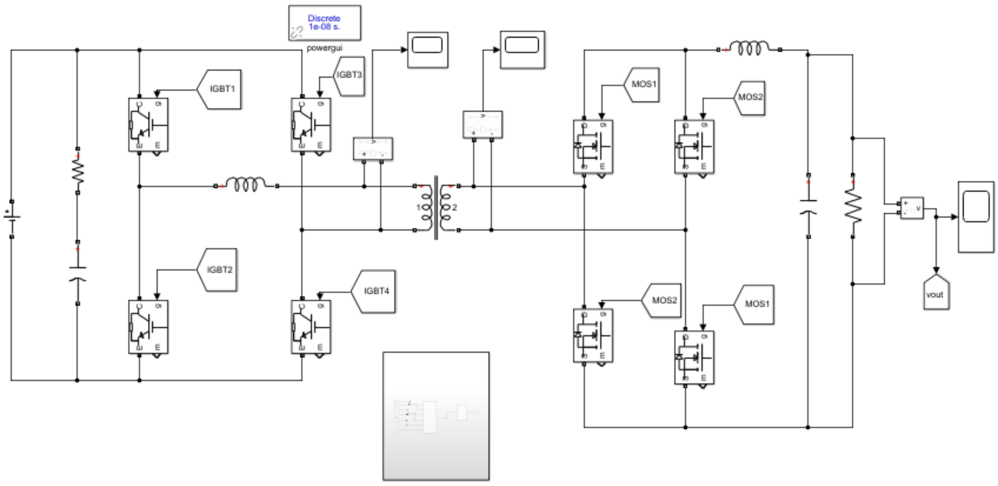

Fig.10. Simulation of DAB Converter

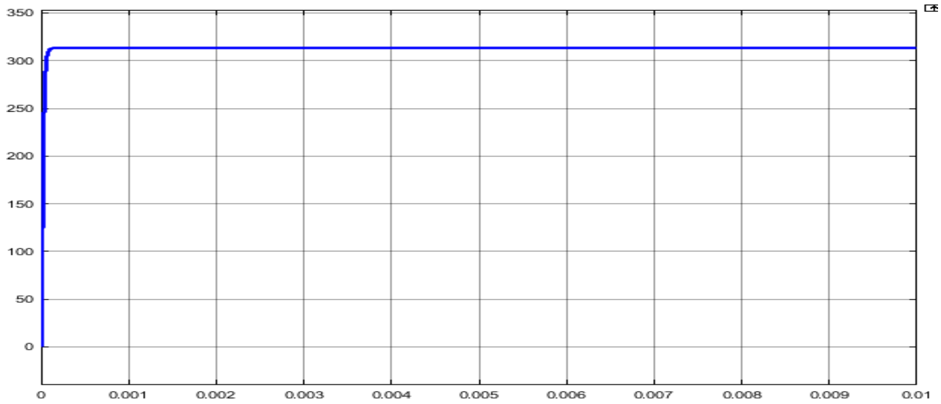

Fig. 11. Output voltage of boost mode

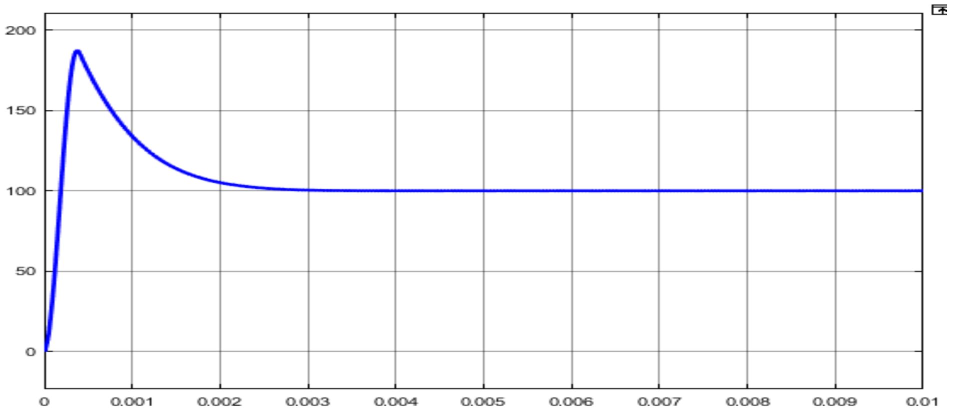

Fig. 13. Output voltage of buck mode

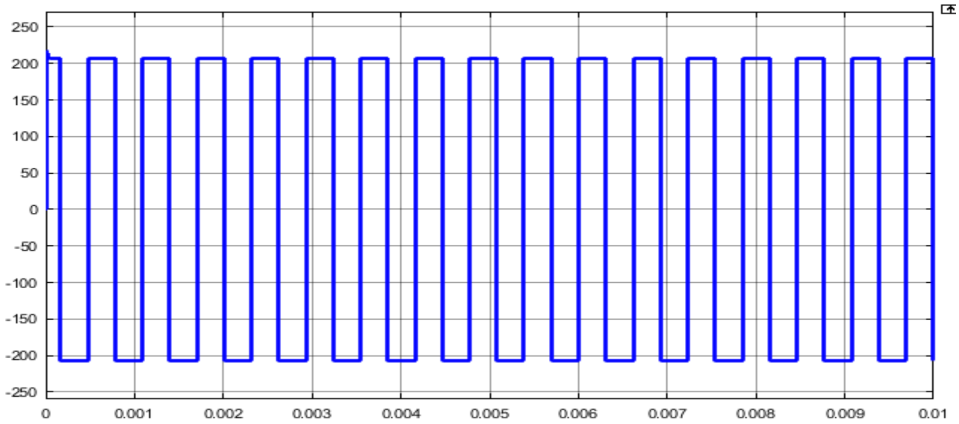

Fig.14. Primary side voltage of high switching transformer

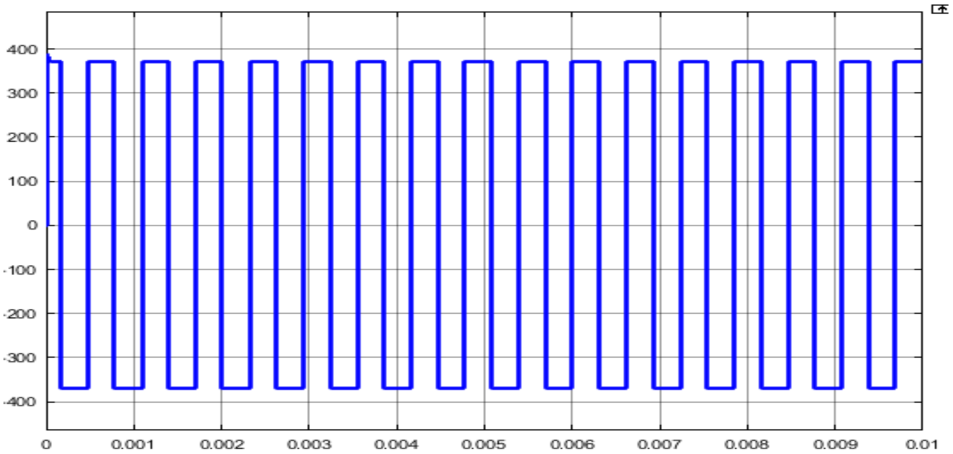

Fig.15. Secondary side voltage of high switching transformer

VI. CONCLUSION

This paper represents determination of mathematical model of bidirectional full bridge dc to dc converter with the help of a small signal analysis method and state space average model transfer function in various mode. After it based on formation of different mode mathematical model is analyze and designing of closed loop control system takes place with the help of compensation technique this leads to get better dynamic as well as steady state characteristics. And after its simulation model is designed which validates the closed-loop control system.

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