Analysis and Simulation of Two Quadrant Converter for the Characterization of Inductors

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Abstract— Inductors which are also known as chokes are one of the building blocks of any power electronics system. The choke coil is particularly useful in filter circuit in which it is desired to separate the alternating current from the direct current in the pulsating current delivered by a conversion source. In power supply, DC bias current is much larger, and chokes which are used as output filters experiences the humming noise due to variable output current flowing through it and high switching transients and the vibrations causes by magnetostriction factor. In order to make a coil that will operate with higher value of dc bias current, it is necessary to reduce the permeability of the core. The performance of power converters greatly depends on the behavior of the inductors. Hence analysis of 100V/50A Two Quadrant Converter has been carried out by calculating its parameters and losses and further simulated by PSpice tool.

Key words: Two Quadrant Converter, Characterization of Inductors/Choke, Type D Chopper, Three Phase Six Pulse Full Bridge Rectifier

I. INTRODUCTION

In the low to medium power range, a dc source of supply is often required which contains negligible ripple which can be controlled in magnitude. For this application, switched mode power supplies (SMPS) circuits are used which is an electronic circuit that convert power using switching devices that are turned on and off at high frequencies, and storage components such as inductors or capacitors to supply power when the switching device is in its non-conduction state. An SMPS is based on dc chopper with a rectified and possibly transformed output. The output voltage amplitude is controlled by varying the duty ratio of the chopper. This may be achieved by means of pulse width modulation (PWM) or frequency variation with constant pulse width, PWM is commonly used. Basically SMPS is a device in which energy conversion and regulation is provided by power semiconductors that are continuously switching “on” and “off” with high frequency.

DC-DC converter is a type of switched mode power supply that converts one voltage level of DC to another level of DC i.e. stepping up or stepping down or both. *DC to DC converter* is very much needed nowadays as many industrial applications are dependent upon DC voltage source. The performance of these applications will be improved if we use a variable DC supply. It will help to improve controllability of the equipments also. The primary power received from AC main is rectified and filtered as DC input. It is then switched at a high frequency and fed to the primary side of the step-down transformer. The step-down transformer is only a fraction of the size of a comparable 50 Hz unit thus relieving the size and weight problems. We have the filtered and rectified output at the secondary side of the transformer. It is now sent to the output of the power supply. A sample of this output is sent back to the switch to control the output voltage.

A. Type D Chopper

Type D Chopper is a type of DC-DC Converter and also known as Class D Converter. The circuit diagram of Type D chopper as shown in fig. 1 followed by its mode of operations as shown in fig. 2 and its waveforms as shown fig. 3 and 4. When the two switches S_1 and S_2 are on, then the output voltage V_0 will be equal to V_i. When $V_0 = -V_i$, the two switches will be off but both the diodes D_1 and D_2 will start conducting. The average output voltage V_0 will be positive when the switches S_1 S_2 turn on, then the time t_{on} will be more than the turn off time t_{off} as shown in the wave form below. As the diodes and switches conduct current only in one direction, therefore the direction of load current will be always positive. The power flows from source to load as the average values of both V_0 and I_0 is positive. From the waveform it is seen that the average value of V_0 is positive thus the fourth quadrant operation of type D converter is obtained.

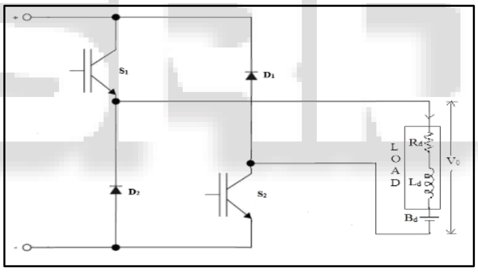

Fig. 1: Type D Chopper Circuit

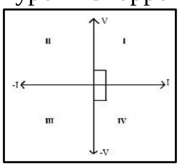

Fig. 2: Mode of Operations of Type D Chopper

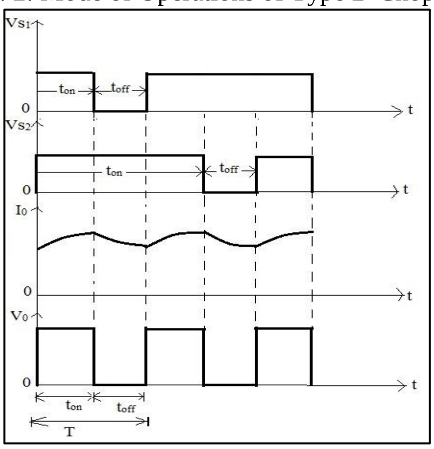

Fig. 3: Waveform of Type D Chopper when both switches S_1 and S_2 are turned on ($t_{on} > t_{off}$)

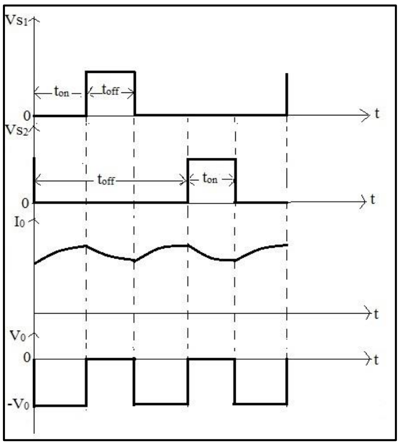

Fig. 4: Waveform of Type D Chopper when both switches S_1 and S_2 are turned off ($t_{off} > t_{on}$)

II. RECTIFICATION

Here, Rectification is done by Three Phase Six Pulse Full Bridge Rectifier because of the lowest ripple content in its waveforms, higher DC voltage, better transformer utilization factor (TUF), better input power factor etc as compared with other rectifiers. It is also known as Uncontrolled Three Phase Six Pulse Full Bridge Rectifier.

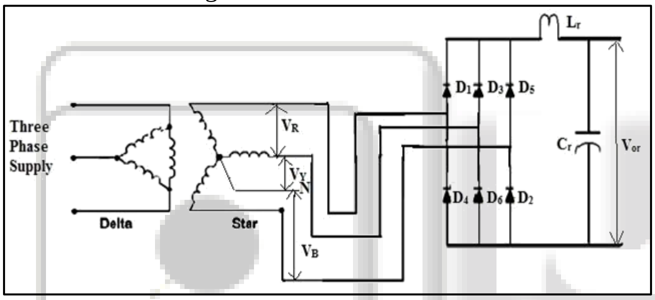

Fig. 5: Three Phase Six Pulse Full Bridge Rectifier

The circuit diagram of Three Phase Six Pulse Full Bridge Rectifier is shown in Fig. 5.

Since the voltage and current ratings of two quadrant converter is 100 V and 50 A.

Let efficiency of converter = 90%, therefore output DC of rectifier is considered as 110 V.

- Input power of converter = Output Power / 0.9 = (100V × 10A) / 0.9 = 1.111 kW
- For +10 % line variation,
  I_{min} = 1.111 kW / 110 V = 10.10 A
- For −10 % line variation,
  I_{max} = 1.111 kW / 90 V = 12.35 A
- Change in maximum current,
  ΔI_{max} = 20 % of 12.35 A = 2.47 A
- Change in minimum current,
  ΔI_{min} = 20 % of 10.10 A
- Therefore,
  $\Delta I_{min} = 2.02\ A = I_{0r(min)}$
- Peak to peak output current of rectifier,

$$I_{0pkr} = I_{max} + \frac{\Delta Imax}{2}$$

$$I_{0pkr} = 12.35 + \frac{2.47}{2}$$

$$I_{0pkr} = 13.585\ A$$

Since, $V_{0avg} = V_{0r} = 1.35\ V_{LL}$

Therefore, V_{LL} = 110 / 1.35 = 81 V

And

$$V_{ph} = \frac{81}{\sqrt{3}} = 46.76\ V$$

- Average diode current,
  $I_{Davg} = I_{0avg} / 3 = 12.35 / 3 = 4.1\ A$
- R.M.S value of diode current,
  $I_{Drms} = I_{0r} / \sqrt{3}\ (I_{0r} = I_{0avg}) = 12.35 / \sqrt{3} = 7.13\ A$
- Power dissipated in diode,
  $P_d = V_f \times I_f\ (I_f = I_{Davg}) = 1.2 \times 4.1 = 4.92\ W$

PIV rating of diode = $V_{LLpk} = \sqrt{2} \times V_{LL} = 114.55\ V$

According to transformer turn ratio formula (in phase),

$$\frac{V_1}{V_2} = \frac{I_2}{I_1}$$

$$\frac{415}{81/\sqrt{3}} = \frac{12}{I_1/\sqrt{3}}$$

Primary current,

$$I_1 = 2.34\ A$$

Output power of transformer,

$$P_{ot} = \sqrt{3}\ V_{LL}\ I_{sec}$$

$$= \sqrt{3} \times 81 \times \sqrt{\frac{2}{3}} \times 12.35$$

$$= 1.414\ KVA$$

Inductance and capacitance of low pass LC filter are,

$$L_r = \frac{0.0135 \times 81}{2\pi(50) \times 2.02}$$

$$= 1.7\ mH$$

$$C_r = \frac{1}{1.7 \times 10^{-3}(2\pi \times 10)^2}$$

$$= 150\ mF$$

III. DC-DC CONVERSION

The Two Quadrant Converters find a wide scope in industries, power electronics area, etc. Nowadays bidirectional converters i.e. two quadrant converters have a higher end over them since the energy from the load during regenerative braking is fed back to the source, thus obtaining energy efficient system. These converters have advantages over their counterpart the linear power supplies. They have high efficiency, light weight, wide voltage control range and cost less.

Here, Type D Chopper is used as Two Quadrant Converter because of the Bipolar Voltage Switching phenomenon which helps in characterization of inductors or chokes used as output filter.

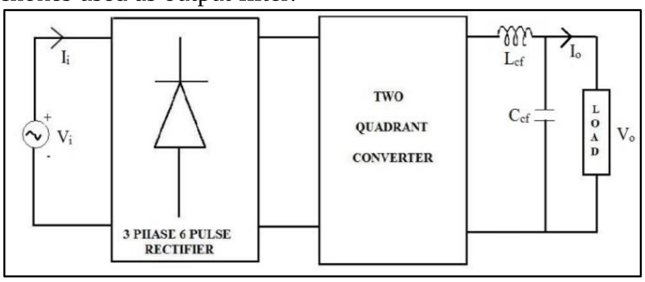

Fig. 6: Schematic Diagram of Two Quadrant Convert

The Schematic Diagram of Two Quadrant Converter is shown in fig. 6 where AC supply is converted to DC and further DC-DC conversion takes place followed by low pass LC output filter named as L_{cf} and C_{cf} respectively.

Since the voltage and current ratings of two quadrant converter is 100V/50A. Therefore,

$$V_{CE} = 100V \text{ and, } I_C = 50A$$

Since,

A. Conduction Loss

$$P_{cond} = V_{CEsat} \times I_{c(avg)} = P_{cond} = 3 \times 50 = P_{cond} = 150\ W$$

B. Switching Loss

$$P_{sw(off)} = \frac{1}{2} \times V_{CE} \times I_C \times f_{sw} \times t_{d(off)} \times N$$

$$P_{sw(off)} = \frac{1}{2} \times 100 \times 50 \times 25000 \times 600 \times 10^{-6} \times 2$$

$$P_{sw(off)} = 75W$$

C. Switching Loss

$$P_{sw(on)} = \frac{1}{2} \times V_{CE} \times I_C \times f_{sw} \times t_{d(on)} \times N$$

$$P_{sw(on)} = \frac{1}{2} \times 100 \times 50 \times 25000 \times 60 \times 10^{-9} \times 2$$

$$P_{sw(on)} = 7.5W$$

D. Capacitance Loss

$$P_c = \frac{1}{2} C \times V_{CE}^2$$

$$P_c = \frac{1}{2} \times 0.8 \times 10^{-9} \times 100^2$$

$$P_c = 4 \times 10^{-6}\ J$$

Since, $D = t_{on} / t_{on} + t_{off}$ and taking switching frequency as 25kHz hence, t_{on}= 30 us, t_{off} = 10us and $T_s = t_{on} + t_{off}$ = 40us

$$L_{cf} = \frac{V_{ic}(2D-1)D \times T_s}{\Delta I}$$

$$L_{cf} = \frac{100(2(0.75)-1)0.75 \times 40 \times 10^{-6}}{10}$$

(Taking ΔI = 20% of output current)

$$L_{cf} = 165 \times 10^{-6}\ H$$

$$C_{cf} = \frac{\Delta I}{16 \times f_{rip} \times \Delta V}$$

(Taking ΔV = 10% of output voltage)

$$C_{cf} = \frac{10}{16 \times 50000 \times 10}$$

(Ripple frequency, f_{rip} = twice of f_{sw})

$$C_{cf} = 1.25 \times 10^{-6}\ F$$

$$\omega_c = \frac{1}{2\pi\sqrt{L \times C}}$$

(Where, ω_c=corner frequency)

$$\omega_c = \frac{1}{2\pi\sqrt{165 \times 10^{-6} \times 1.25 \times 10^{-6}}}$$

$$\omega_c = 11082.12\ \text{rad/sec}$$

Therefore, corner frequency in Hz, $f_c = \frac{\omega_c}{2\pi}$

(Since, $\omega = 2\pi f$)

$$f_c = \frac{11082.12}{2\pi}$$

$$f_c = 1.763\ \text{kHz.}$$

IV. SIMULATION RESULTS

A. Software Used: PSpice

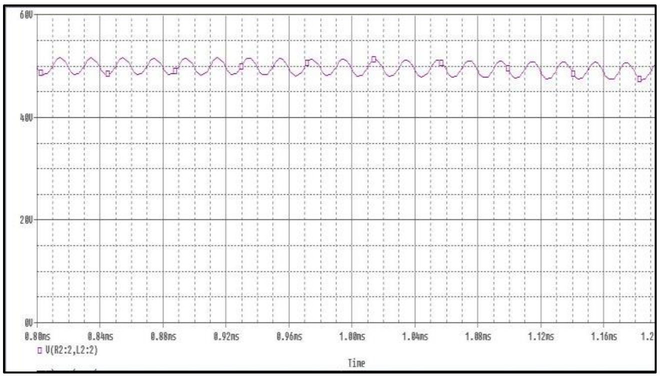

Fig. 7: Simulated Result of Output Voltage Waveform of Two Quadrant Converter after Filter action

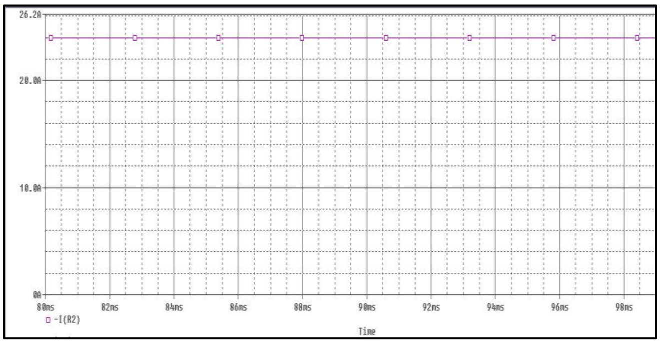

Fig. 8: Simulated Result of Output Current Waveform of Two Quadrant Converter after Filter action

The comparison between simulated voltage and the theoretical voltage are shown by plotting a graph between duty ratio (x-axis) and output voltage (y-axis) with a resistive load of 2 Ω:

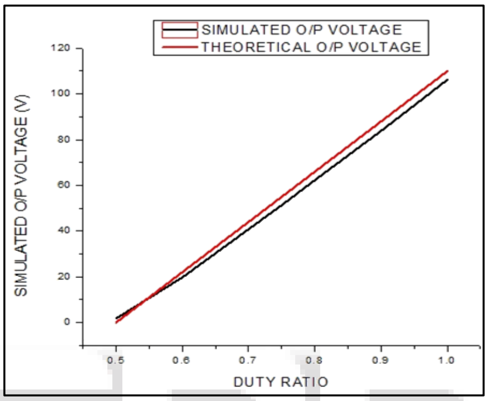

Fig. 9: Graph showing comparison between Simulated DC voltage versus Theoretical DC voltage.

The comparison between simulated current and the theoretical current are shown by plotting a graph between duty ratio (x-axis) and output current (y-axis) with a resistive load of 2 Ω:-

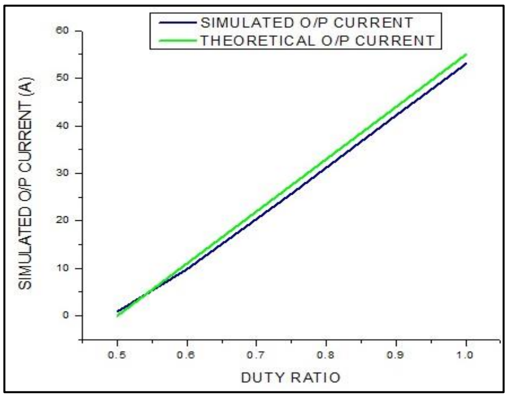

Fig. 10: Graph showing comparison between Simulated DC current versus Theoretical DC current.

V. CONCLUSION

The analysis of 100 V/50 A Two Quadrant Converter has been carried out by firstly calculating its parameters as well as its losses and simulated through PSpice tool, which verifies the theoretical results and as a result the behavior of prototype inductor as a output filter in Two Quadrant Converter can be investigated for instant variation as a function of DC magnetization, frequency, loss estimation etc. and due to this characterization, it may be possible to increase the performance of the Two Quadrant Converter.

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