MODELLING AND SIMULATION OF A DC CHOPPER USING MATLAB/SIMULINK

Maruan bin Ibrahim
Faculty of Electrical Engineering
Universiti Teknologi MARA
40450 Shah Alam, Malaysia
ibrahimmaruan@yahoo.com

Abstract-A 4 Quadrant DC-to-DC converter is used to control the DC motor drive that require forward and reverse motoring as well as forward and reverse braking. DC motor drive system controlled by Pulse Width Modulation (PWM) technique are expected to replace the conventional phase controlled system. This is due to their simple control, high reabiality,low cost and fast response. This paper present work on development of four quadrant DC-to-DC converter using the Power System Block Set (PSB) within the MATLAB/Simulink (MLS) enviroment.T he output is being synthesized using Pulse Width Modulation(PWM) technique.
The FQDC is supplied by a **V DC voltage source; the load takes the form of a pure resistive, inductance with battery E representing a back emf of a dc motor.

Keyword(s)- Four quadrant DC Chopper (FQDC),MATLAB/Simulink (MLS),Power System Block Set (PSB),Pulse Width Modulation (PWM), DC Chopper

I. INTRODUCTION

A Four Quadrant DC-to-DC converter is used to control the DC motor drive that require forward and reverse motoring as well as forward and reverse braking.DC motor drive system controlled by Pulse Width Modulation (PWM) technique. The Matrix Converter (MC) is an advanced circuit topology that offers many advantages such as the ability to regenerate energy back to the utility, sinusoidal input and output current and controllable input current displacement factor[1].In Matrix Converters the switching algorithm need to be carefully calculated to ensure that the switches do not short circuit the voltage sources and do not open circuit the current sources, thus the continuous current at the output terminal are needed[2].

In this work ,DC-to-DC converters also know as DC Chopper were presented to operate as a variable dc voltage from a fix dc voltage using SPMC topology. Main focus will be the operational DC Chopper functions in the first and third quadrant, nevertheless the operation of the second and fourth quadrant are also described. To as certain it feasibility simulation model were developed using MATLAB/Simulink to study the behavior of the proposed technique.

II. DC-DC CONVERTER

a) Conventional DC Chopper

A DC chopper converts directly from DC-to-DC and also know as dc-to-dc converter. It is considered a dc equivalent of an AC transformer with a continuously variable turn's ratio. A conventional dc chopper is as illustrate in fig;2.The input voltage of matrix converter operated at figure:2 is

$$Edc=Ri \text{ t } Ldi/dt \text{ t } E$$

For passive R,L and E load.[2]

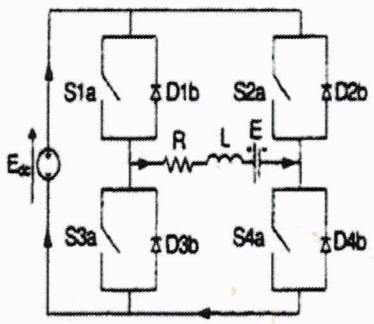
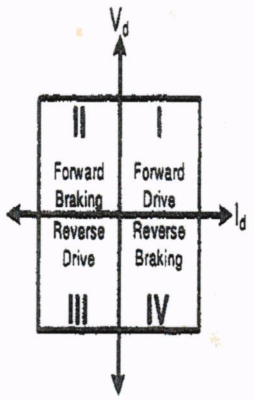


Figure 2: Conventional dc chopper (i

DC chopper may be classified according to the number of quadrant of the Vd-Id diagram are shown in fig:3a and polarities as in fig:3b in which there are capable of operating. The polarity of the output voltage and the direction of energy flow cannot be changes. By referring to combination shown in fig: 3b, if the load is a separately excited motor of constant field, then the positive voltage and positive current in the first quadrant, give rise to a "forward drive". Changing the polarity of both the armature voltage and the armature current result in a "reverse" drive (quadrant 111) while in quadrant 11 and 1V, the direction of energy flow is reversed and the motor operates as a generator braking rather than driving.



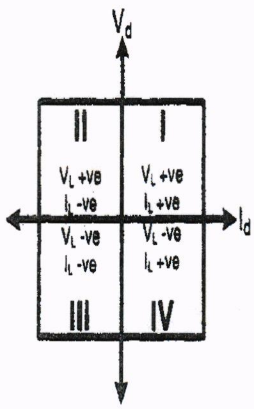


Figure3a: Four quadrant operation

Figure3b: The polarities

b) Pulse Width Modulation (PWM)

The output of the dc chopper maybe controlled using the (PWM),generated by comparing a triangle wave signal with an adjustable dc reference and hence the duty cycle of the switching pulse could be varied. This algorithm is required to provide a stream of PWM train to turn on and off the switches that will synthesize the required dc-dc conversion. This is as illustrated in fig:5

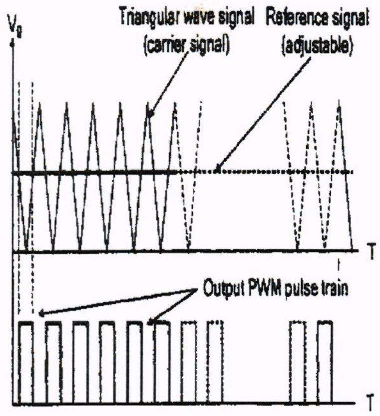


Figure 5: PWM waveform

III. PROPOSED OF SWITCHING STRATEGIES FOR DC CHOPPER

The implementation DC chopper requires different bi-directional switching arrangements depending on the desired operation requirement of the four quadrants defined. The magnitude of the output voltage of the converter is controlled by PWM variations in duty cycle. The switching sequence are designed to follow Table 1

Figs: 6 to 9 illustrates the four quadrant operation of dc chopper using SPMC topology. The dotted line flow of current in the diagram represents the safe commutation switch during each particular state that is continuously turned-on as in Table 1.The dark arrow on the switch indicate that the switch is turned-on and behaves as the power switches performing the required converter operation

switches	First Quadrant	Second Quadrant	Third Quadrant	Fourth Quadrant
S1	Modulate	Off	Off	Off
D1	Off	Continuou sly ON	Off	Off
S2	Off	Off	Modulate	Off
D2	Off	Off	Off	Continuou sly ON
S3	Off	Switching		Off
D3	Continuous ly ON	Off	Off	Continuou sly ON
S4	Continuous ly ON	Off	Off	Switching
D4	Off	Continuou sly ON	Continuou sly ON	Off

Table 1: Switching pattern for four quadrant DC Chopper

a) First Quadrant (Q1)

The load current are positive as shown in fig: 6.The load current flows from the supply to the load. To achieve this condition,S1 and S4 are turned-on and act as a power switch performing the required converter operation synthesizing the output dependent on the control algorithm being developed. During turn-off of S1,switches D3 and S4 are maintained as continuously ON during this cycle;S4 to complete the loop for current return and acts in conjunction with D3 to provide free-wheel operation whenever S1 is turned OFF.

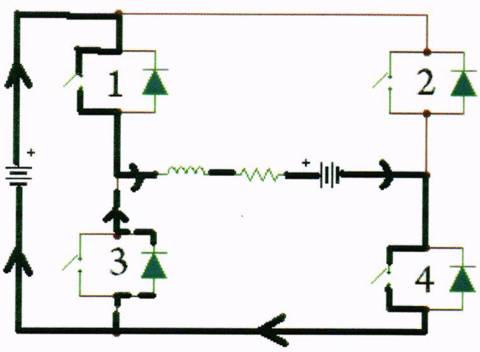


Fig 6: Q1

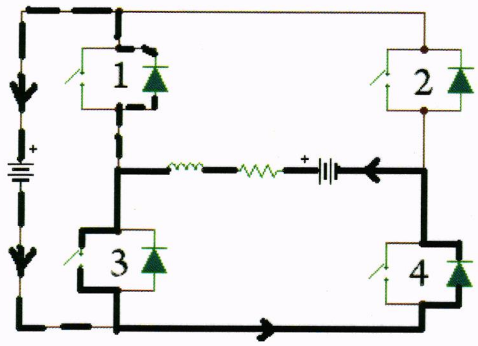


Fig 7:Q2

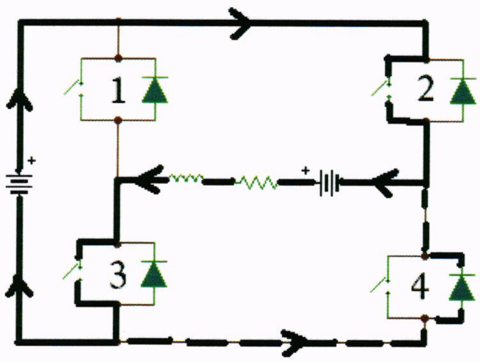


Fig 8:Q3

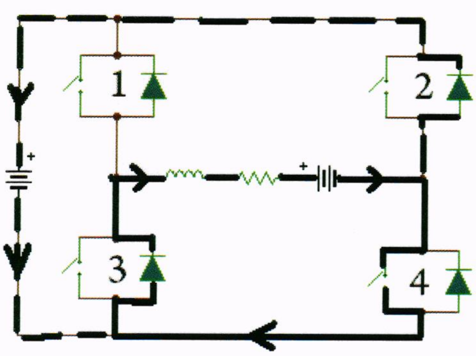


Fig 9:Q4

b) Second Quadrant (Q2)

The load voltage is positive with negative load current as shown in fig.7.The loads current flows out of the load. To achieve this condition, Switch S3 and D4 will operate while D1 will be continuously turned on, the voltage E will drives current through the load and when both switch S3 and D4 are turned off, load dissipates energy through S1b to the supply

c) **Third Quadrant (Q3)**

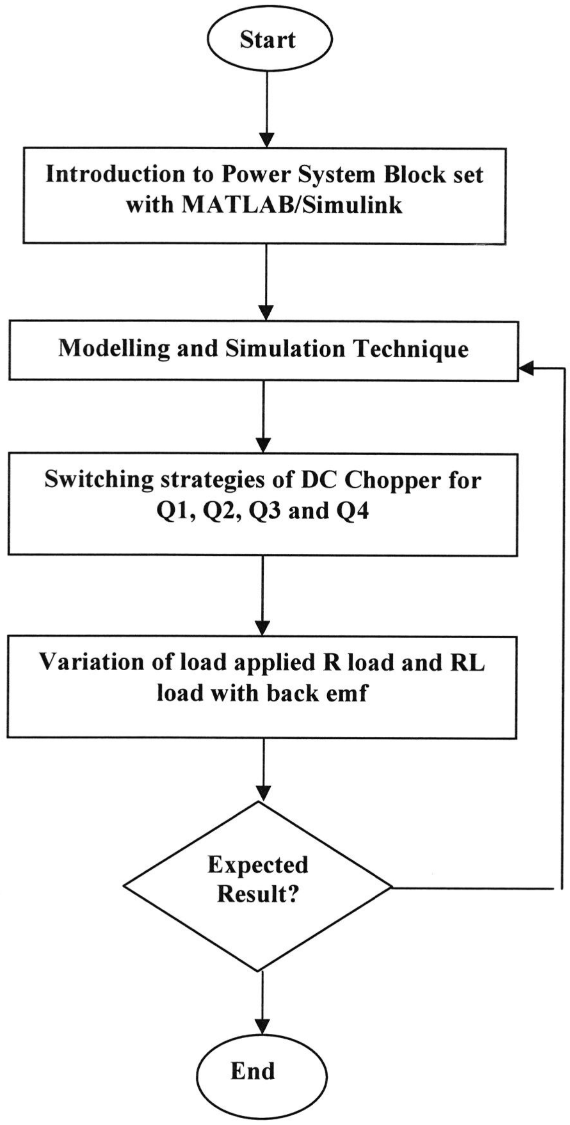
The load voltage and load current are negative as shown in fig 8,It is the reverse of first quadrant, where the load current flows from the supply to the load through a different route. To achieve this condition, S2 and S3 are turned-on and act as a power switch performing the required converter operation synthesizing the output dependent on the control algorithm being developed. During turn-off of S2, switches S3 and D4 are maintained as continuously ON during this cycle: S3 to complete the loop for current return and acts in conjunction with D4 to provide free-wheel operation whenever S2 is turned OFF.

d) **Fourth Quadrant (Q4)**

In the fourth quadrant, the load voltage is negative but the load current is positive as shown in fig 9.The loads current flows out of the load. To achieve this condition, Switch S3 and D4 will operate while S1 will be continuously turned-on, the voltage E will drives current through the load and when both switch S3 and D4 are turned off, load dissipates energy through D1 to the supply

1V. METHODOLOGY

This is flow process of modeling and simulink 4 quadrant dc-to-dc converter. Study on introduction to Power System Block set , simulation technique, driver circuit and switching strategies. This step by step modeling and simulink process.



a) Modelling and Simulation

The modeling of matrix converter as a dc chopper is by using Power System Block set (PSB) within the MATLAB/Simulink (MLS) enviroment.Figure 10 below shows the complete top level main model of dc-to-dc converter and has been simulate successfully by using the Simulink toolbox. Each of subsystem represent one of bi-directional switching. The driver 1 and driver 2 represent the driver circuit that has been used in the modeling of the matrix converter as a dc chopper.

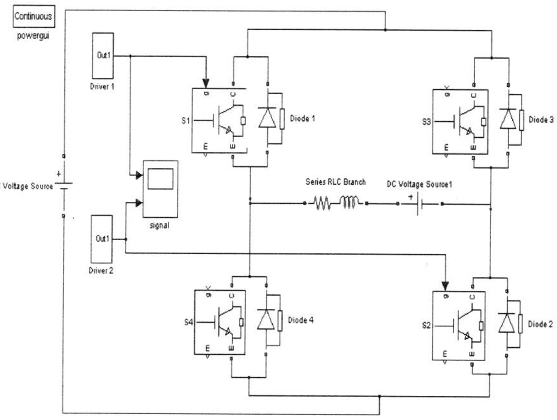


Figure 10:Top level main model of DC Chopper in MLS

b) Driver circuit Implementation design to generate the PWM pattern

The driver circuit that has been used in this dc-to-dc matrix converter is design to generate the Pulse-Width modulation (PWM) pattern. This PWM circuit is used to control the turn-on and turn-off of the switch, where the output of the driver circuit is connected to the gate of the IGBT in the matrix converter circuit. The Pulse-Width modulation controlled technique that had been used in the driver circuit is designed by comparing the triangle wave signal (2KHz) as a carrier signal with the constant references signal as the reference signal by using the MATLAB/Simulink (MLS) environment. In power system block set, the comparing of these two different signals is done by using the Relational Operator Block. The driver circuit is shown in figure 11:The operation of the driver circuit is continuously and alternately.Thus,when the driver 1 is on, the driver 2 off and vice versa. The driver 1 is operated for positive cycle and driver 2 is for negative cycle. The PWM generator model in MLS is as shown in figure 11. The constant 2 input represents modulation index, *ma* of the PWM. A constant 1 is multiplied with constant 2 using dot product block to vary the magnitude of reference signal which is compared with the triangular carrier wave in repeating signal block to produce the required PWM output. Comparison of these two different signals is facilitated by using the relational operator block with an output as shown in figure 7.2.

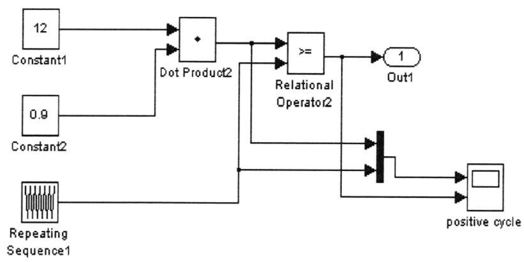


Figure 11: PWM model circuit in MLS

c) Switching strategies Implementation

Practical realization of a matrix converters requires the used of bi-directional switches by using the IGBT and diodes in series.Figure:12 show a set of two IGBT and two Diode switch, arrange in anti parallel making the module a four quadrant switch capable of bi-directional operation[6].The complete arrangement of single-phase matrix converter power switch shown in figure:12

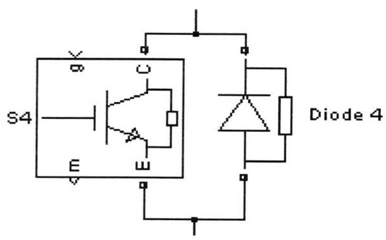


Figure:12: Unicontrolled Bidirectional switch module in MLS

This arrangement was chosen because as its allow within each switch independent control of the current in the both direction. This arrangement can than be used to reduce the switching losses during the commutation of the load current. This back-to-back bi-directional arrangement also has lower conduction loses than a diode bridge switch arrangement[3]. In this circuit configuration, the IGBTs were used because of it's a power semiconductor device that is suitable for a variety of high frequency switching application and current handling capabilities. The diodes were used to provide the reverse voltage blocking capability

V. RESULT AND DISCUSSION

The result of DC Chopper modeling for first and third quadrant operation is shown in figure below. From the simulation result ,the four-quadrant dc-to-dc converter can be modeled and implementation by using the MATLAB/Simulink. The switching techniques and controlled strategies need to calculated carefully to make sure that this power converter operated as needed. The implementation of dc-to-dc converter by using the MATLAB/Simulink is much better where the simulation time is short(a few second) with an excellent graphical interface that available with parametric identification of the system and convenient to the user without any error compared other simulink software. Below is the result obtained from the simulation

When the modulation index is increased from 0.1 to 1.0, turn-on width will be increased in steps of 10% of the modulation index. This variation is independent on the quadrant of operation; which only effects the polarities of voltage and current.

Figure 13 and figure 24 shows the variations of mean voltage and current with respect to modulation index, MI. Mean Voltage and current increased non-linear with the variation of modulation index maybe due to low values of voltage used resulting in higher possible inaccuracies in measurements. Modulation index 1.0 gives the highest mean voltage and current output.

a) Vmean of the first quadrant with R load at 3kHz

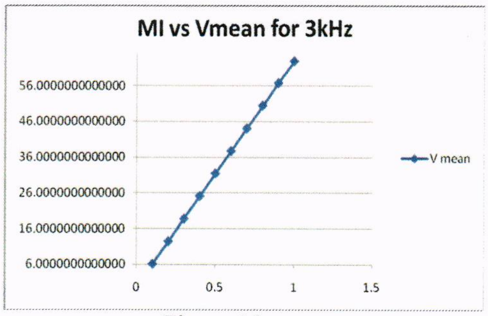


Figure 13

b) Imean of the first quadrant with R load at 3kHz

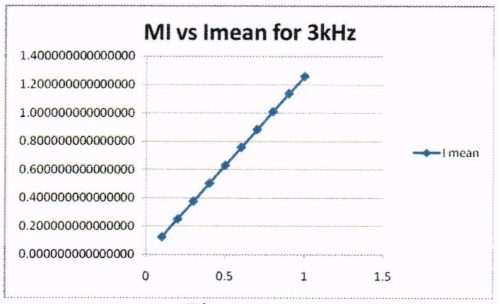


Figure 14

c) Vmean of the first quadrant with RL load at 3kHz

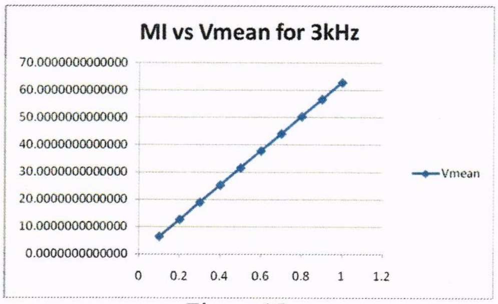


Figure 15

d) Imean of the first quadrant with RL load at 3kHz

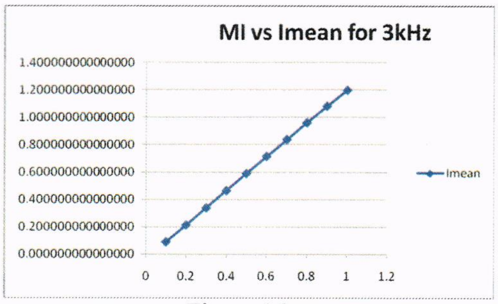


Figure 16

In quadrant 1, the load voltage is positive, $+V_L$ and the load current is positive, $+I_L$ and the current is conducting continuously.

e) Vmean of the second quadrant with RL load at 3kHz

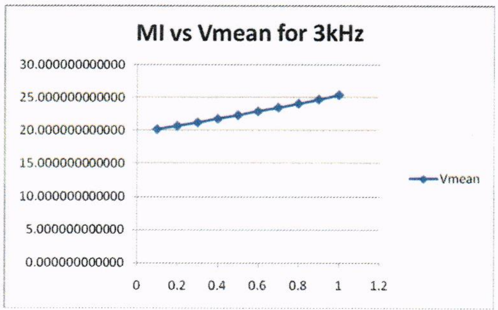


Figure 17

f) Imean of the second quadrant with RL load at 3kHz

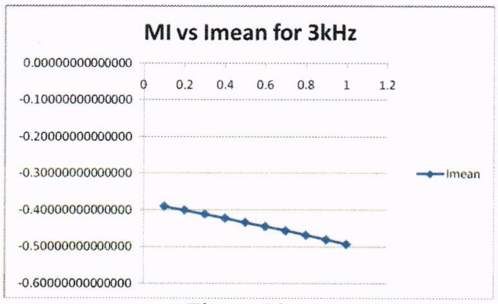


Figure 18

In quadrant 2, the load voltage is positive, $+V_L$ and the load current is positive, $-I_L$ and the current is conducting continuously.

g) Vmean of the third quadrant with R load at 3kHz

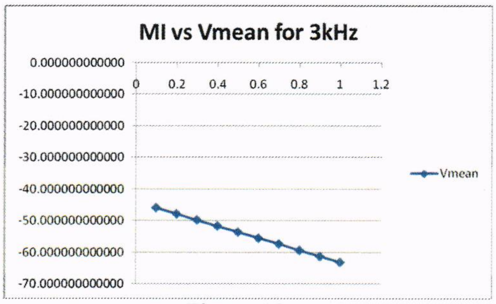


Figure 19

h) Imean of the third quadrant with R load at 3kHz

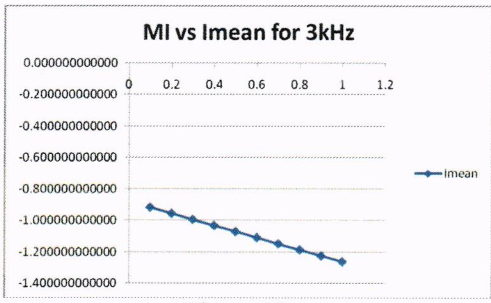


Figure 20

i) Vmean of the third quadrant with RL load at 3kHz

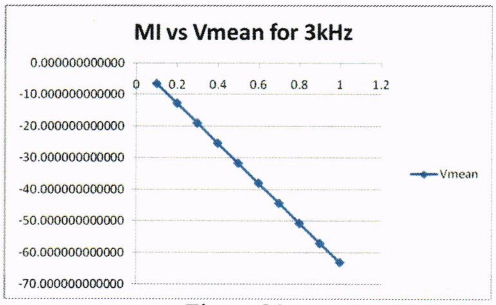


Figure 21

j) Imean of the third quadrant with RL load at 3kHz

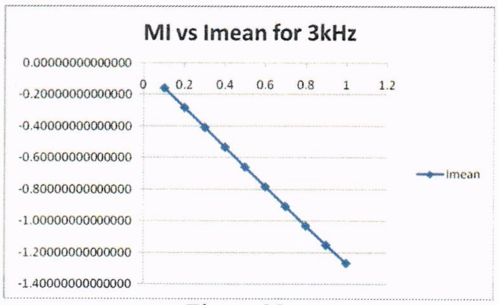


Figure 22

In quadrant 3, the load voltage is positive, $-V_L$ and the load current is positive, $-I_L$ and the current is conducting continuously.

k) Vmean of the forth quadrant with RL load at 3kHz

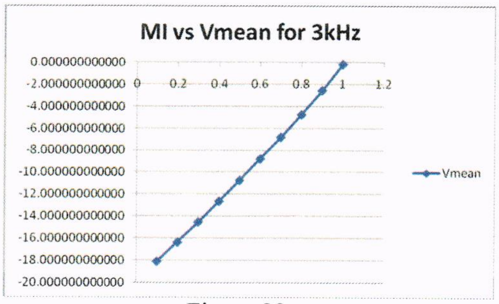


Figure 23

l) Imean of the forth quadrant with RL load at 3kHz

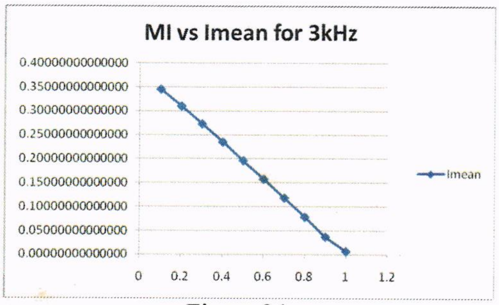


Figure 24

In quadrant 4, the load voltage is positive, $-V_L$ and the load current is positive, $+I_L$ and the current is conducting continuously.

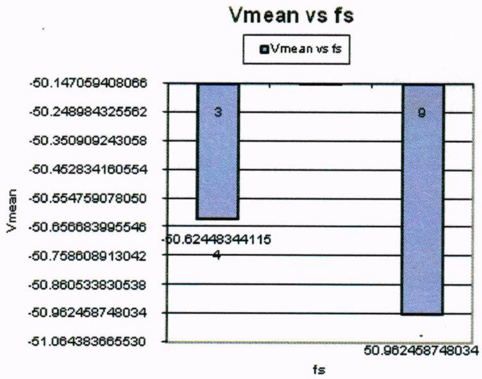


Figure 25

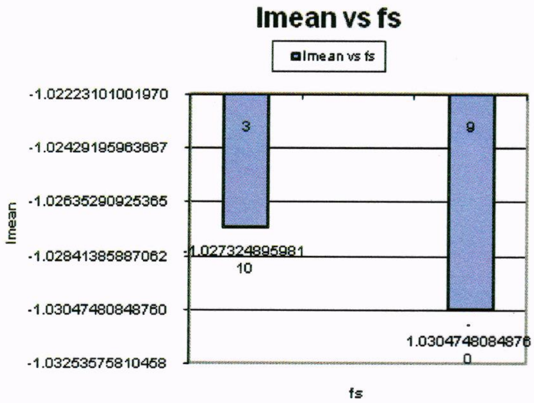


Figure 26

From the graph obtained in figure 25 and figure 26, when the fs increased, the output voltage and current increased.

VI. CONCLUSION

From the result obtained, it shows that the operation of the DC Chopper can be simulate using MATLAB /Simulink. With bi-directional switching strategy implemented for the DC Chopper, by the simulation, the behavior or the switching strategies can be studied and be applied. For the future studies, the simulation of the DC Chopper can be extended to the hardware implementation and much further studies can be conducted for making the comparison between the result for both simulation and practical.

VII. FUTURE WORKS

i) Focus on four quadrant operation in DC motor drive application for full investigations with regenerative operation capabilities.

ii) Increase voltage to normal application level.

iii) Hardware implementation with DC motor as actual load

iv) Increase the switching frequency of operation to 20 kHz a normal application level associated with the limits of standard IGBT.

VIII. REFERENCES

[1] Venturini M,"A New Sine Wave Out, Conversion Technique Which Eliminates Reactive Element," Proceedings Powercon 7,pp.E3_1-E3_15,1980.

[2] S.H Hosseini and E.Babei, "A New Generazed Direct Matrix Converte,"ISIE 2001,Pusan,Korea.Vol. 2,CAS-28(4), April

[3] Firdaus,S.Hamzah,M.K,"Modelling and simulation of a single-phase AC-AC matrix converter usingSPWM,"Student Conference on Research and Development 16-17 july 2002,SCOReD2002,PP 286-289.

[4] Bland, M.J., Wheeler, P.W., Clare, J.C., Empringham, L., "Comparison of Bi-directional Switch Components for Direct AC-AC Converters", *2004 IEEE 35th Annual Power Electronics Specialists Conference, 2004. PESC 04.* Vol. 4, 2004, Page(s): 2905-2909.

[5] Zuckerberger, A., Weinstock, D., Alexandrovitz A., "Single-phase Matrix Converter," *IEE Proc. Electric Power App, Vol. 144 (4), Jul 1997*, Page(s): 235-240.

[6] Dr. Patrick W.Wheele,"The Matrix Converter,"Powe Electronics,Machine and control group.Institute of Elevtrical Engineer.IEEE,Savoy Place,London.