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DUAL CONVERTER CONTROLLED SINGLE PHASE MATRIX CONVERTER FED DC DRIVE

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ABSTRACT

This paper presents an application of Single Phase Matrix Converter (SPMC) as a dual converter. Pulse Width Modulation (PWM) techniques are used to calculate the switch duty ratio to synthesize the output. Chosen PWM technique incorporating wave shaping is also used to ensure continuous supply current. Basic loads represented by R, R-L, motor loads are used in this investigation. The performances of chosen DC drive with SPMC based dual converter and SCR based dual converter are compared and analyzed. Selective simulation results are presented to verify the strategies developed. It is found that SPMC is a versatile topology.

Keywords: matrix converter, pulse width modulation, controlled rectifier, insulated gate bipolar transistor.

1. INTRODUCTION

Power electronic applications have become very common in modern commercial and industrial environments particularly in applications of AC-DC conversions. Electrical system is mostly AC in nature. But the traditional DC drives are still in operation, due to ease of speed control requiring forward and reverse operation. To achieve this effective control on speed and direction of chosen DC drive and AC-DC conversion, a simple controllable dual converter is used in this work.

Matrix Converter (MC) is an advanced topology that offers potential “all silicon” solutions for AC-AC conversion and hence an attractive alternative converter that provides bi-directional fully controllable operation. By manipulating operation of its bi-directional switches, additional new features could be designed and realized. It was originally based on three phase circuit topologies.

The SPMC was first realized by Zuckerberger [1]. The SPMC has then emerged for other power conversions like AC-DC [2-6] and AC-AC [7-10].

2. SINGLE PHASE MATRIX CONVERTER

This topology consists of a matrix of input and output lines with four bi-directional switches connecting the supply input to load output at the intersections as shown in Figure-1.

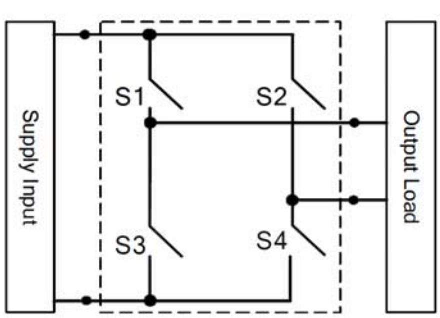

Figure-1. Circuit configuration.

Each of the individual switches is capable of conducting current in both directions whilst at the same time capable of blocking voltage. For this work, the common emitter anti-parallel IGBT-diode pair as shown in Figure-2 is used.

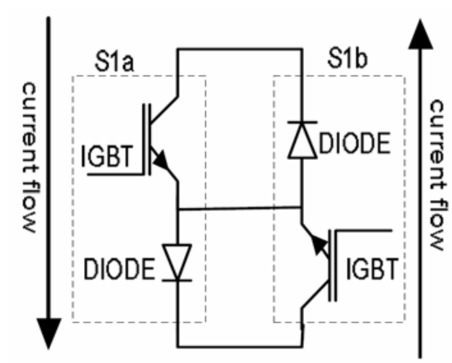

Figure-2. Bidirectional switch.

3. DUAL CONVERTER

Dual converters consist of two converters or bridges. Left bridge acts as a forward converter and other (right) acts as reverse converter. Single-phase full converters allow only two-quadrant operations. If two fully-controlled converters are connected back-to-back, then a four-quadrant operation is possible and such types of converters are called dual converters as shown in Figure-3. They are used in high power variable speed drives.

Conventional dual converter is built by employing two full bridge converters as shown in Figure-3. One of them is used to allow the current of motor to flow only in one direction whilst the other is used for reverse direction. Hence two bridge converters are required to perform four-quadrant operations. This paper presents work in implementing SPMC as a controllable

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dual converter by suitable switching schemes for bi-directional speed control of DC motor.

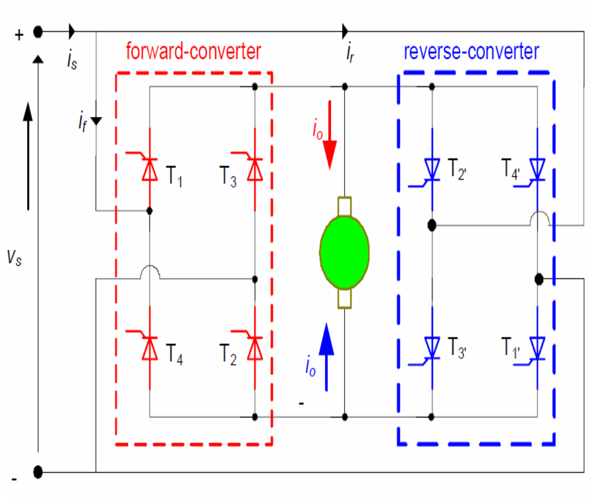

Figure-3. Typical dual converter.

4. SPMC AS A DUAL CONVERTER

In this paper the proposed dual converter as shown in Figure-4 is developed using SPMC.

The operating mode of the proposed dual converter is divided into two main operations-forward mode and reverse mode. Table-1 and Table-2 show the switching sequence for SPMC based dual converter.

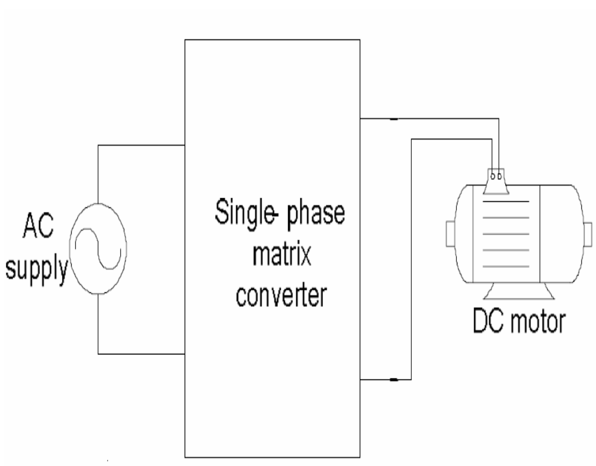

Figure-4. Dual converter using SPMC.

In the proposed method, during the positive cycle of AC input, current flows through the appropriate pair of switches S1a and S4a as indicated in Figure-5 producing positive load voltage for forward direction.

For producing the negative load voltage current flows through the switches S2b and S3b as indicated in Figure-6 (state 2). Similarly positive and negative load voltage can be obtained for AC input negative cycle as indicated in Figures 7 and 8.

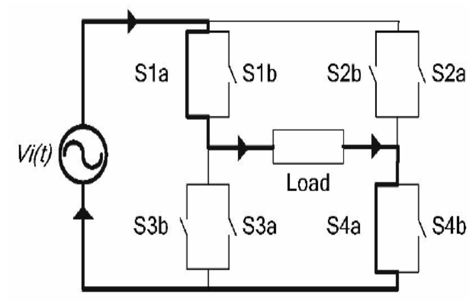

Figure-5. State-1: AC input positive cycle and positive load voltage.

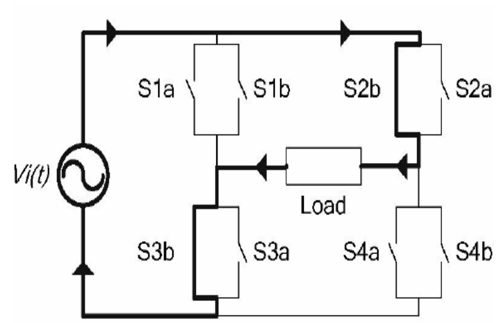

Figure-6. State-2: AC input positive cycle and negative load voltage.

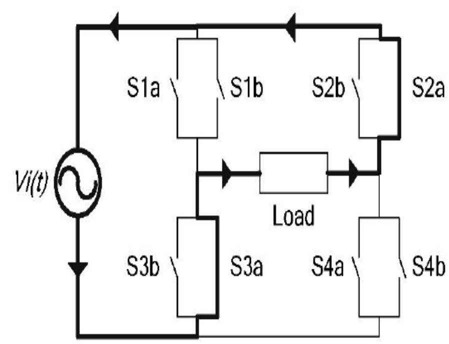

Figure-7. State-3: AC input negative cycle and positive load voltage.

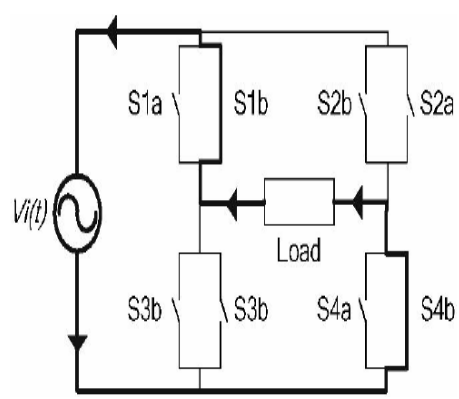

Figure-8. State-4: AC input negative cycle and negative load voltage.

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5. PULSE WIDTH MODULATION

PWM is a widely used technique for controlling the output of static power converters. PWM is immune to noise and less susceptible to voltage changes.

The harmonic content can be reduced by using PWM pulses in each half cycle of output voltage. The SPMC needs four gating signals for four bi-directional switches. By comparing an adjustable reference signal with a triangular carrier signal, the PWM pulses are generated for turning ON and OFF of power switches in SPMC as illustratred in Figure-9.

The frequency of reference signal sets the output frequency f_o. The carrier frequency f_c determines the number of pulses per half cycle. By varying the modulation index (m_a), the output voltage could be controlled.

The switching sequence suggested in Table-2 gives the operation of the SPMC based dual converter either in forward motoring or reverse motoring mode pertaining to I and II quadrant of operation. The switching pattern of the four switches can be obtained using the four possible states as shown in Figures 5 to 8.

Table-1. Switching sequence for SPMC.

Switch State	S1a	S1b	S2a	S2b	S3a	S3b	S4a	S4b
1	ON	OFF	OFF	OFF	OFF	OFF	**ON**	OFF
2	OFF	OFF	OFF	ON	OFF	ON	OFF	OFF
3	OFF	OFF	ON	OFF	ON	OFF	OFF	OFF
4	OFF	ON	OFF	OFF	OFF	OFF	OFF	ON

Table-2. Sequence of switching control for SPMC based bi-directional DC drive.

Switch "ON"	Motor rotation	State used
S1a and S4a S2a and S3a	Forward	1 and 3
S1b and S4b S2b and S3b	Reverse	2 and 4

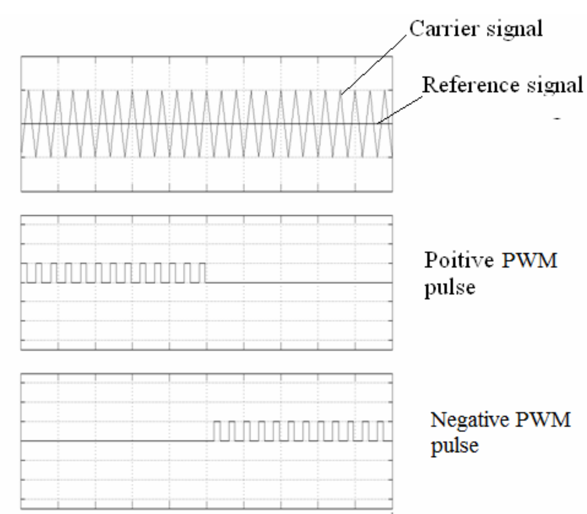

Figure-9. Formation of PWM pulses.

6. SIMULATION IMPLEMENTATION

The proposed control concept is verified through simulation using MATLAB-SIMULINK as shown in Figure-10. Power System Block Set (PSB) in MATLAB-SIMULINK (MLS) is used to model and simulate the circuit.

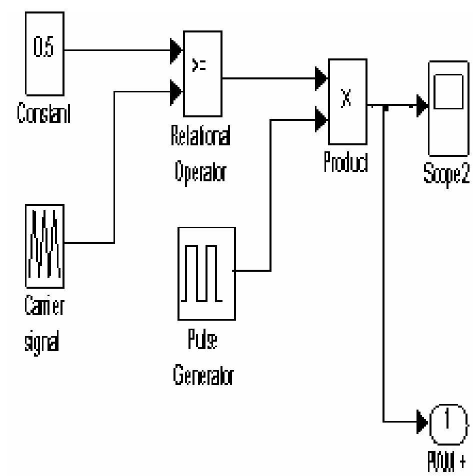

Figure-10. PWM pulse generation using PSB.

The circuit as shown in Figure-10 (simulation in MLS) is implemented with PWM to generate switching signals for controlling the power switches. The modulation index m_a is varied from 0.1 until 0.9 in steps of 0.1 in the present work.

7. RESULTS AND DISCUSSIONS

The dual converter using SPMC is energized by 230V AC supply and loaded with resistive, inductive and motor load (R = 50 ohm L = 9mH and 5HP DC motor) operated with different modulation indices m_a 0.3, 0.5 and 0.7. The simulation model as shown in Figure-11 and the subsystems as shown in Figures 12 (a) and (b) are used to study the behavior of the SPMC as dual converter under variety of load conditions as seen in results in Figures 13 to 19.

Figures 13 and 14 show sample results for m_a = 0.5 obtained from simulation to illustrate the operation of

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dual converter feeding R load. With pure resistive load no spikes are apparent. Figures 15 and 16 display sample results obtained from simulation to illustrate the operation of dual converter feeding R-L load for same m_a.

Noticeable spikes are produced due to introduction of inductive load. Figures 17 and 18 show the output voltage and current of SPMC based dual converter feeding DC motor. Figure-19 shows the speed of the DC motor in two quadrant mode.

DC motor specifications are:
Capacity = 5HP
Voltage = 230V
Current = 20A
Winding = Lap
No. of poles = four pole

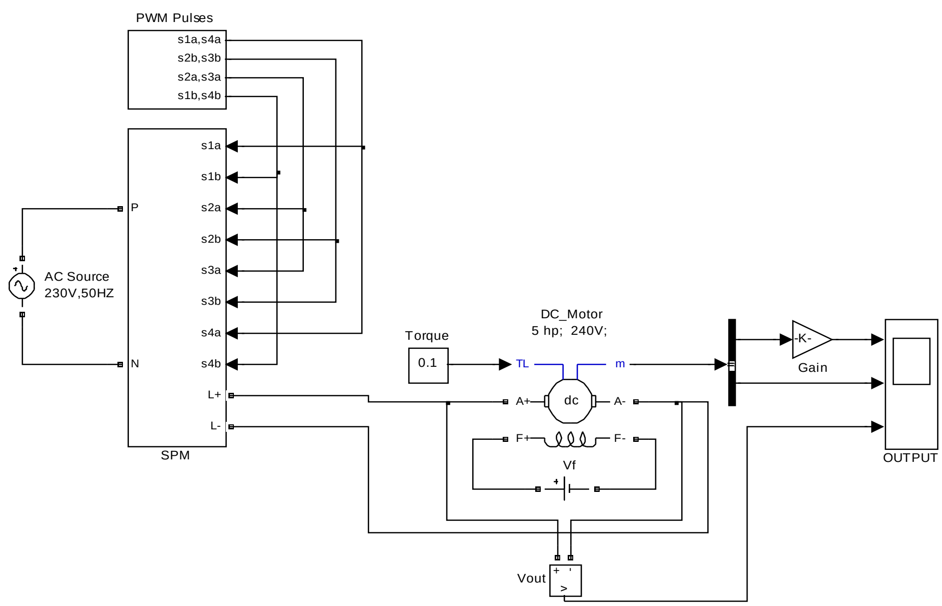

Figure-11. SPMC feeding DC motor load.

The simulation is also carried out with SCR based dual converter and results are also presented for purely resistive load, inductive load and motor load.

The output voltage and current obtained with pure resistive load and inductive load for firing angle (f_a) 30^0 are shown in Figures 20 to 23.

Figures 24 to 26 portray the armature voltage, armature current and speed obtained through simulation studies on implementation of SCR based dual converter with DC motor load for firing angle of 60^0 and next Figure shows the speed for $f_a = 30^0$.

Results for the SCR based dual converter are compared with those of SPMC based dual converter. Figures 28 to 30 show the variation of armature voltage, speed and % THD for various modulation indices of SPMC based dual converter.

Figure-31 shows the armature voltage for different firing angles and it is found that the armature voltage increases with decrease in firing angle of SCR based dual converter.

Figure-32 shows the speed of the motor for various firing angles and decrease in speed is noticed with increase in firing angle. Figure-33 shows the variation in % THD for different firing angles. The result shows that harmonics distortion increases with increase in firing angle.

On comparison of all results it is observed that the variation of armature voltage with SPMC based dual converter is smoother than that of SCR based dual converter. It is found that the magnitude of THD is lesser with SPMC based dual converter.

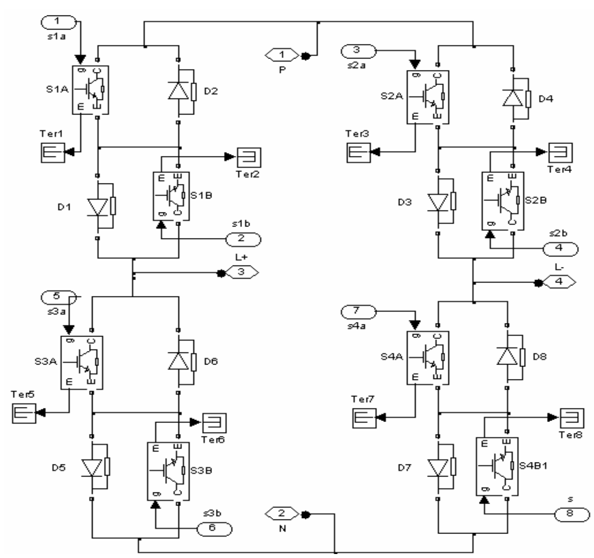

Figure-12(a). SPMC subsystem common emitter IGBT with diode pair.

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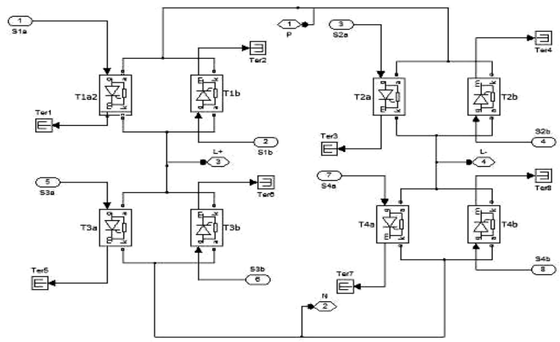

Figure-12 (b). SPMC subsystem with SCR pair.

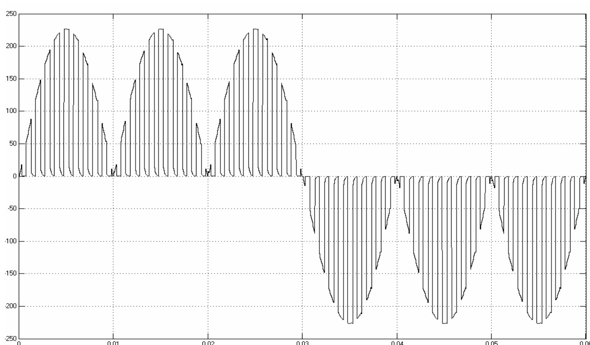

Figure-13. Output voltage with $m_a = 0.5$ (R load).

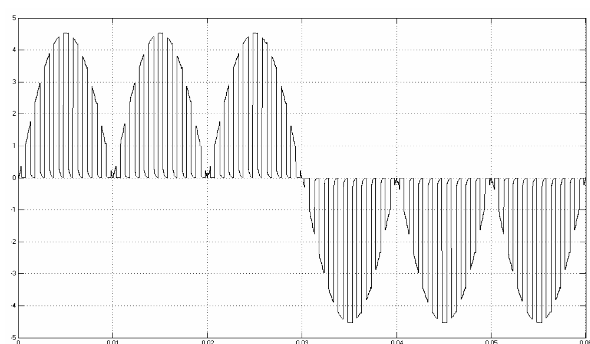

Figure-14. Output current with $m_a = 0.5$ (R load).

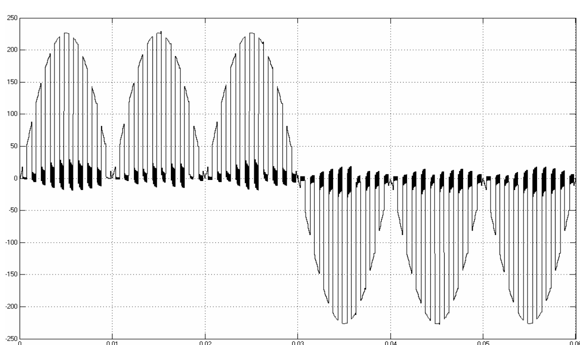

Figure-15. Output voltage with $m_a = 0.5$ (R-L load).

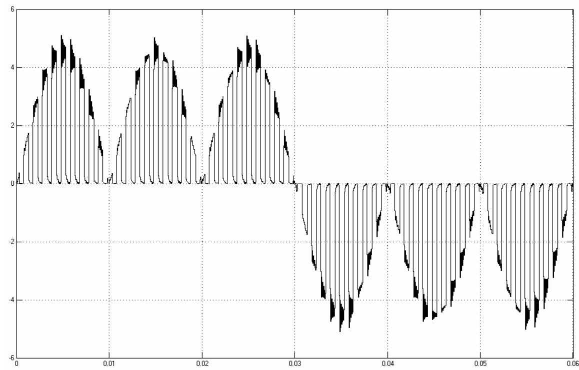

Figure-16. Output current with $m_a = 0.5$ (R-L load).

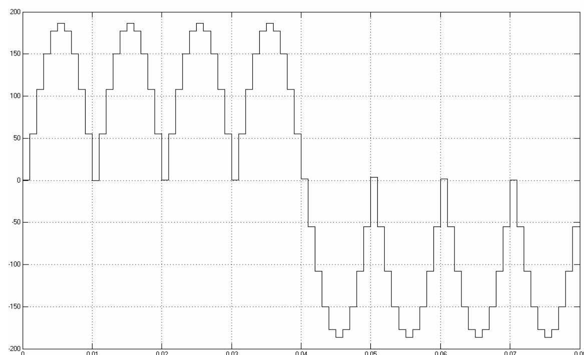

Figure-17. Output voltage with $m_a = 0.5$ (motor load).

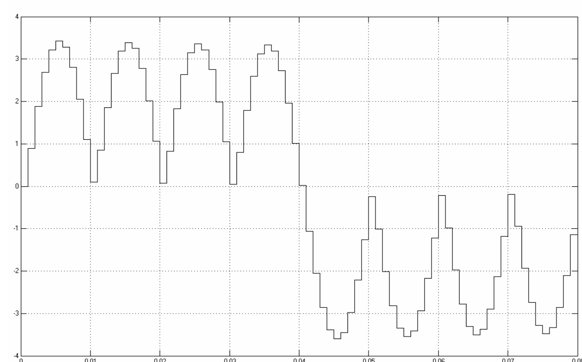

Figure-18. Output current with $m_a = 0.5$ (motor load).

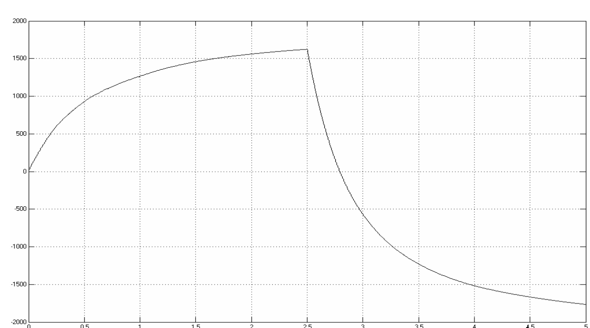

Figure-19. Speed of DC motor for $m_a = 0.5$.

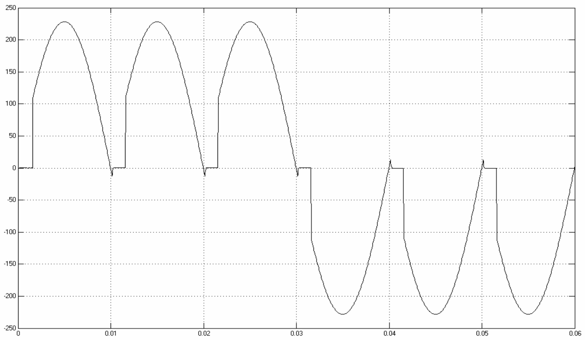

Figure-20. Output voltage with $f_a = 30^o$ (R load).

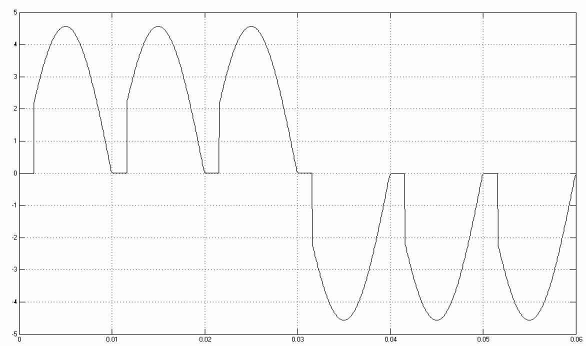

Figure-21. Output current with $f_a = 30^o$(R load).

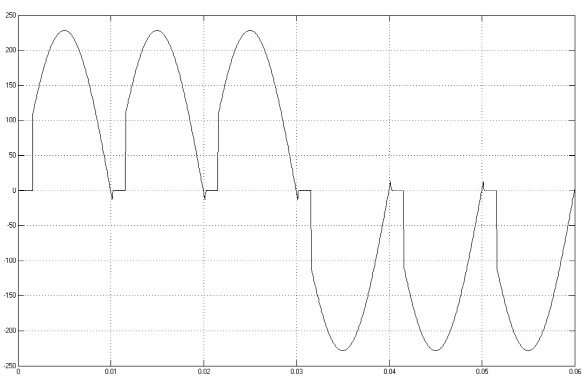

Figure-22. Output voltage with $f_a = 30^o$ (R-L load).

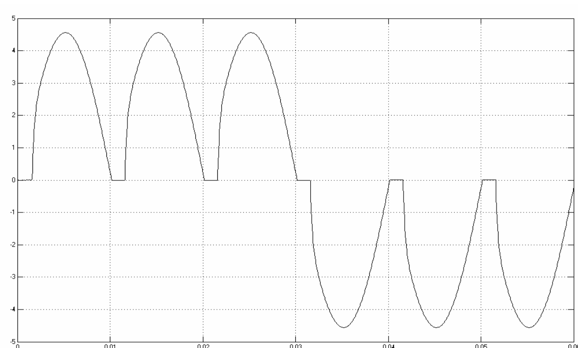

Figure-23. Output current with $f_a = 30^o$ (R-L load).

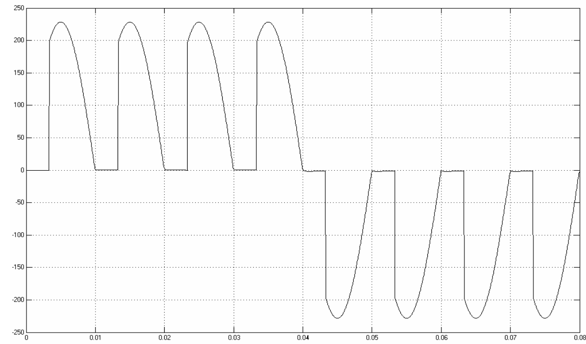

Figure-24. Output voltage with $f_a = 60^o$ (motor load).

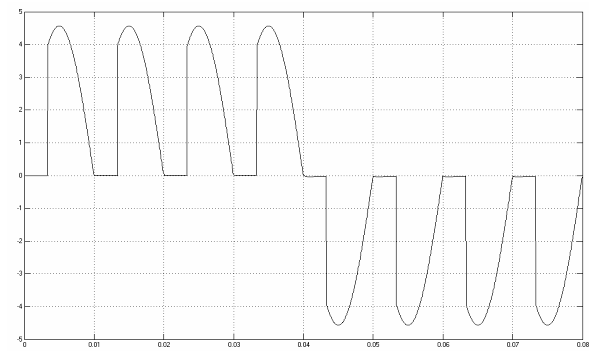

Figure-25. Output current with $f_a = 60^o$ (motor load).

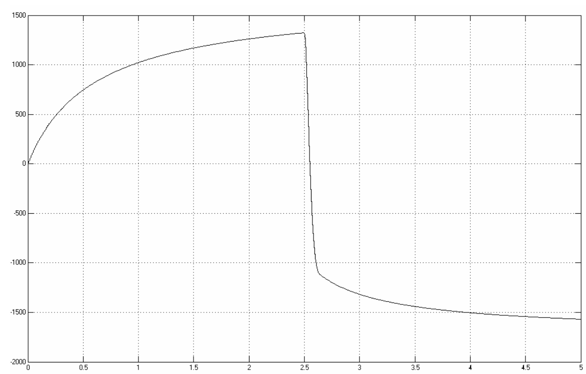

Figure-26. Speed of DC motor for $f_a = 60^0$.

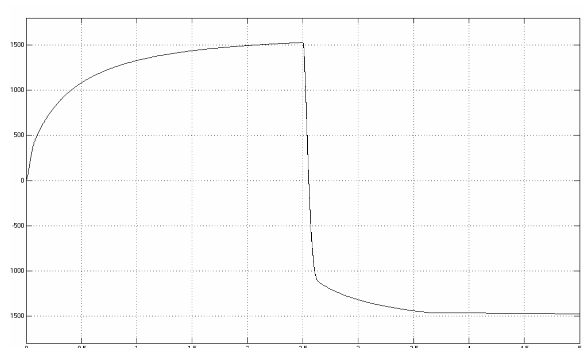

Figure-27. Speed of DC motor for $f_a = 30^0$.

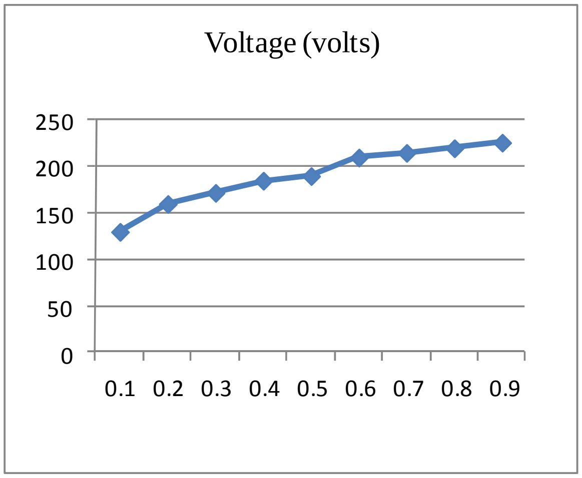

Figure-28. Output voltage versus modulation index.

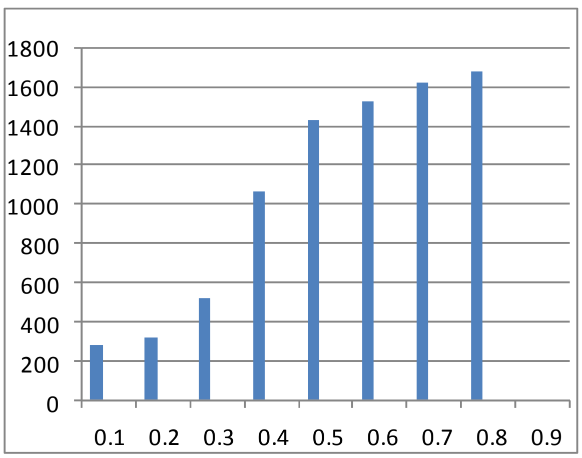

Figure-29. Speed (rpm) versus modulation index.

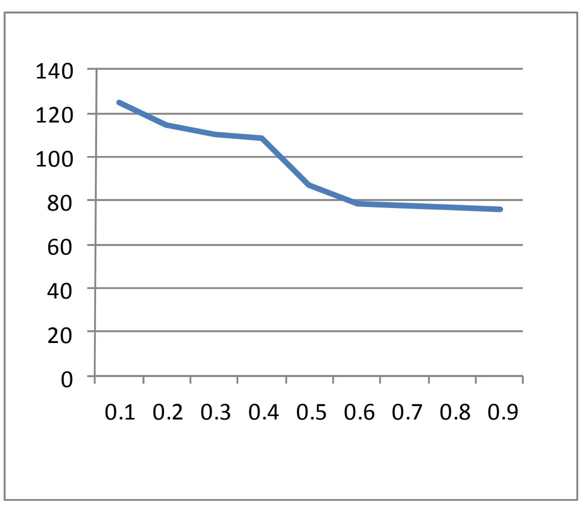

Figure-30. % THD versus modulation index.

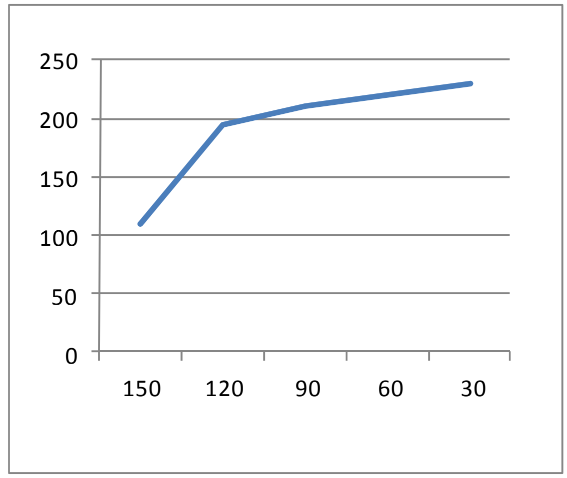

Figure-31. Output voltage versus firing angle (degrees).

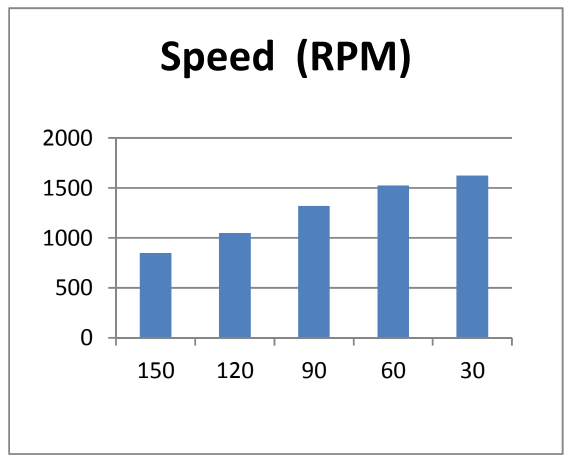

Figure-32. Speed (rpm) versus firing angle (degrees).

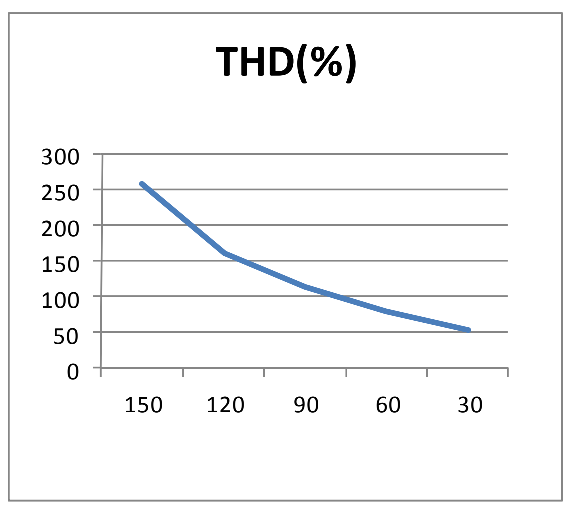

Figure-33. % THD versus firing angle (degrees).

8. CONCLUSIONS

Successful investigations on the operation of SPMC based dual converter feeding DC drive in two quadrant mode are presented. The gate pulse switching patterns are generated by MLS. The use of SPMC in the design of dual converter that has full controllability in both forward and reverses directions has been analyzed. The performances of DC drive with SPMC based rectifier and SCR based rectifier are compared. It is found that SPMC is a versatile topology.

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