Simulation of a DC Chopper Using Single Phase Matrix Converter Topology

Xu Sheng-hui
(Department of telecom Engineering, Wuhan Institute of Technology. Wuhan: 430074; China)

Abstract: Choppers are widely used for traction motor control in electric automobiles and other electric transportation system. In those applications, control of dc motor's speed is required where the supply is dc or an ac voltage that has been rectified. This paper presents work on development of four quadrant DC chopper based on the SPMC topology, an advanced topology that hypothetically could perform many different converter functions. Prior to hardware implementation a computer simulation model was developed using the Power System Block Set (PSB) within the MATLAB/Simulink (MLS) environment, to study the behaviors of the proposed converter. Successful results presented are mainly due to the use of resistive load to reduce complexities. Results from PSB simulation are compared with those obtained from PSpice to ascertain its validity. The output is being synthesized using Pulse Width Modulation (PWM) technique. It is shown that the same SPMC topology could be used as a DC chopper extending the versatility of the topology a desirable feature in the future as increases in costs for skilled manpower could be traded-off with versatile technology.

Keywords: Matrix Converter； Power System Block Set (PSB)； Pulse Width Modulation (PWM)； Single-Phase Matrix Converter (SPMC)；DC Chopper

0. INTRODUCTION

Choppers are widely used for traction motor control in electric automobiles and other electric transportation system. In those applications, control of do motor's speed is required where the supply is do or an ac voltage that has been rectified Other applications of do chopper also include high-current DC applications in industries [1] which have many operational benefits over conventional diode or thyristor rectifiers.

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 [2]. MC has the potential of affording an "all silicon" solution for AC-AC conversion, removing the need for reactive energy storage components used in conventional rectifier-inverter based system. Its topology was first proposed by Gyugyi [3] in 1976. Obviously all published studies dealt with mainly the three-phase circuit topologies [4-6].

The Single-phase matrix converter denoted as SPMC was first realized by Zuckerberger [7]. Other works includes those by Hossieni [8], Abdollah Khoei [9] . To date, the authors have only found those four published works on SPMC but none has proposed the use of the SPMC topology in DC chopper applications.

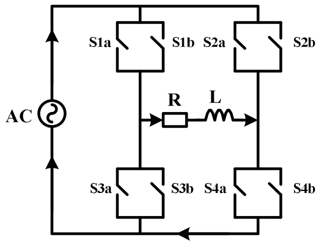


Figure 1: AC-AC single-phase matrix converter topology

In this work, DC chopper also known as dc-to-do converters were presented to operate as a variable do voltage from a fix do voltage using SPMC topology that has been used in direct AC-AC converter application. Main focus will be the operational do chopper functions in the first and third quadrant, nevertheless the operation of the second and fourth quadrant are also described. To ascertain its feasibility simulation models were developed using MATLABI Simulink and PSpice to study the behaviour of the proposed technique.

Successful results presented are mainly due to the use of resistive load without the introduction of inductances to reduce complexities. The DC Chopper is based on four-quadrant operation with the output being synthesized using Pulse Width Modulation (PWM) technique. The result of this work has indicated that the same SPMC topology [7-9] maybe used as a DC chopper. This versatility is a desirable feature in the future as increases in costs for skilled manpower maybe overcame by having a versatile technology.

1. SINGLE PHASE MATRIX CONVERTER

The SPMC requires 4 bi-directional switches as shown in Fig. 1; each capable of conducting current in both directions, blocking forward and reverse voltages. Using carefully designed switching sequences the following step-up and step-down frequency AC-AC conversion could be realized [9] as shown in fig. 2. It requires the use of bidirectional switches capable of blocking voltage and conducting current in both directions. Unfortunately there is no discrete semiconductor device currently that could fulfil the needs [8-9] and hence the use of common emitter anti-parallel IGBT, diode pair as shown in Fig. 3. The IGBT were used due to its popularity amongst researchers that could lead to high-power applications with reasonably fast switching frequency for fine control.

978-1-61284-459-6/11/$26.00 ©2011 IEEE

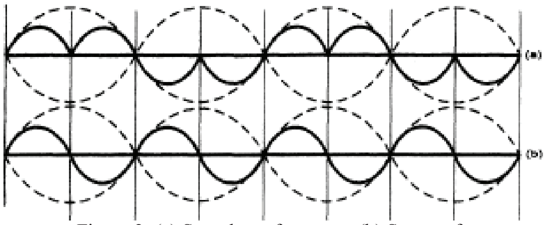


Figure 2: (a) Step-down frequency (b) Step-up frequency

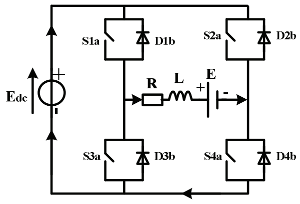


Figure 3: Conventional do chopper

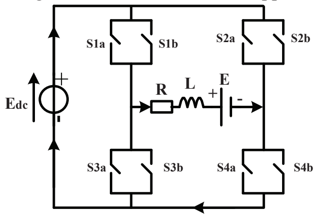


Figure 4: DC chopper using SPMC

2. DC CHOPPER BASED ON SPMC

Proposed DC chopper is as shown in fig.4. It has similar structure with those of the SPMC as shown in fig.1, the difference being the input do voltage. Practical realization of matrix converters requires the use of four-quadrant switch capable of bi-directional operation. In comparison with conventional do chopper of fig.3 it has 4 bi-directional switches as opposed to the use of 4 switch and 4 diodes in conventional do chopper. This arrangement was chosen because it allows within each switch independent control of the current in both direction. This back-to-back bi-directional arrangement of the matrix converted also has lower conduction losses than a diode bridge switch arrangement during commutation of the load current [7].

2.1 Pulse-Width Modulation (PWM)

The output of the do chopper maybe controlled using the (PWM), generated by comparing a triangle wave signal with an adjustable do 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 do to do conversion. This is as illustrated in fig.4.

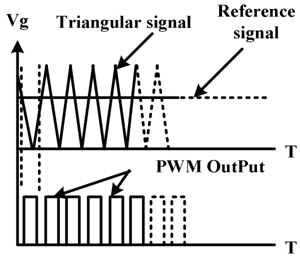


Figure 5: PWM waveform

2.2 Commutation Problem

The use of Pulse Width Modulation as in fig.5 as the switching algorithm in this converter, results with possible reversal current if inductive loads are used, during switch turn-off.

Theoretically the switching sequence in the SPMC must be instantaneous and simultaneous; unfortunately impossible for practical realization due to the turn-off IGBT characteristic, where the tailing-off of the collector current will create a short circuit with the next switch turn-on. This problem occurs when inductive loads are used. A change in current due to PWM switching will result in current and voltage spikes being generated resulting in the occurrence of a dual situation. First current spikes will be generated in the short-circuit path and secondly voltage spikes will be induced as a result of change in current direction across the inductance. Both will destroy the switches in use due to stress. A systematic switching sequence is required that allows for the energy flowing in the IGBT's to decay in a free-wheel manner.

2.3. Switching Strategies

The implementation of the SPMC as a do chopper requires different bi-directional switching arrangements depending on the desired operational requirements of the four quadrants defined. The magnitude of the output voltage of the converter is controlled by PWM variations in duty cycle. The switching sequences are designed to follow Table 1.

Figs.6 to 9 illustrates the four quadrant operation of do 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 Table1 .The dark arrow on the switch indicates that the switch is turned-on and behaves as the power switches performing the required converter operation.

1) 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, S1a and S4a 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 S1a, switches Sib and S4a are maintained as continuously ON during this cycle; S4a to complete the loop for current return and acts in conjunction with Sib to provide free-wheel operation whenever S1a is turned OFF.

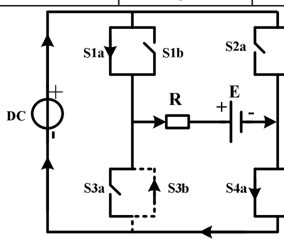
2) Second Quadrant (Q2)

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 S3a and S4b will operate while S1b will be continuously turned-on, the voltage E will drives current through the load and when both switch S3a and S4b are turn off, load dissipates energy through S1b to the supply.

TABLE 1: Switching pattern for four-quadrant dc-to-do matrix converter

Switches	First Quadrant	Second Quadrant	Third Quadrant	Fourth Quadrant
S1a	Modulate	Off	Off	Off

S1b	Off	Continuously On	Off	Off
S2a	Off	Off	Modulate	Off
S2b	Off	Off	Off	Continuously On
S3a	Off	Switching	Continuously On	Off
S3b	Continuously On	Off	Off	Continuously On
S4a	Continuously On	Off	Off	Switching
S4b	Off	Continuously On	Continuously On	Off



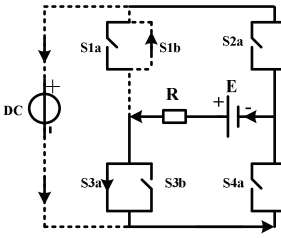


Figure 6: First Quadrant Figure 7: Second quadrant

3) 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, S2a and S3a 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 S2a, switches S3a and S4b are maintained as continuously ON during this cycle; S3a to complete the loop for current return and acts in conjunction with S4b to provide free-wheel operation whenever S2a is turned OFF.

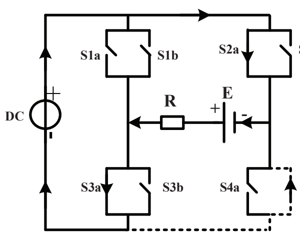


Figure 8: Third Quadrant

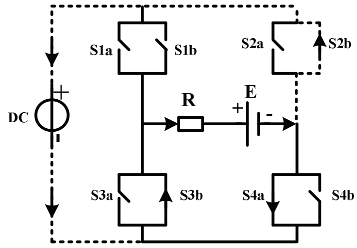


Figure 9: Fourth Quadrant

4) Fourth quadrant (Q4)

In the fourth quadrant, the load voltage is negative but the load current is positive as shown in fig.8. The loads current flows out of the load. To achieve this condition, Switch S3a and S4b will operate while S1b will be continuously turned-on, the voltage E will drives current through the load and when both switch S3a and S4b are turn off, load dissipates energy through S1b to the supply.

3. SIMULATION IMPLEMENTATION

In this simulation implementation, Power System Block Set (PSB) in MLS and PSpice are used to model and simulate the circuit. The DC Chopper was supplied by 30V DC voltage source; the load takes the form of a pure resistive 50Ω with battery E representing a back emf of a do motor. Fig. 10 and 11 show the MLS model circuit used to implement the simulation, Parameters used are as shown in table 2.

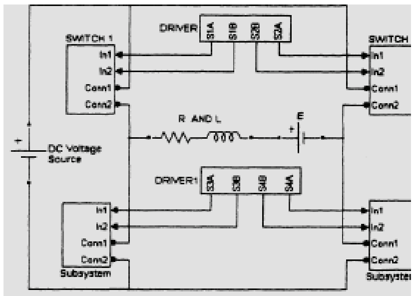


Figure 10: Top level main model of SPMC in MLS

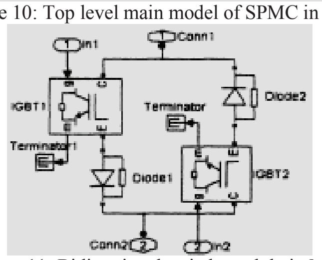


Figure 11: Bidirectional switch module in MLS

TABLE 2: Parameter for simulation model in MATLAB and Pspice

Input Source（DC）	30V
Sample Modulation Index （mi）	0.75
Resistance	R=50 Ω
Inductance	L=0.004H

3.1 RL Load (with no-commutation)

Inductance is introduced to represent windings in machines. Without commutation results are as in fig.12 to 13, with spikes generated tabulated in Table 3. Severe voltage spikes are noticeable. For an input of 30V, the voltage spike is in the region of +176V to -196V.

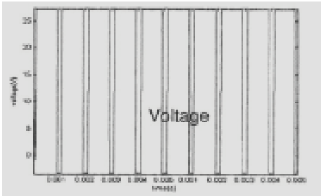


Figure 12: Output voltage for Q1 PSB without commutation

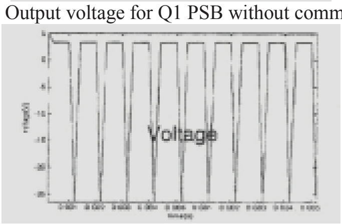


Figure 13: Output voltage for Q3 PSB without commutation

4. CONCLUSION

The SPMC topology has been presented capable of being operated as do chopper to operate in the four quadrants similar to the conventional do chopper. Simulation models in MATLAB/Simulink and PSpice are used to study the behaviour of the proposed technique and have shown good agreement with those obtained experimentally. This versatility is a desirable feature in the future as increases in costs for skilled manpower maybe overcame by having a versatile technology. The commutation strategy used in this work has to a certain extent reduced the spikes that has been resulted but still requires further investigations in an effort to solve the problems, a common phenomenon in matrix converter topologies. Further investigations are however in order to eliminate the switching transients caused by PWM particularly when applications involved the use of inductances, in an effort to use the SPMC topology as a do chopper.

Authors and Affiliations

Author: Xu Sheng-hui(1966-) received B.S.and M.S. degrees,Wuhan,China.He is currently an Assistant Professor and the director of the training center, Department of Electronic Information Engineering, Wuhan Polytechnic.His main study fields is automatic control. Email:xsh0566@sina.com （ 027-87767776 13098870566）

Address: NO. 463, GuanShan Road, Wuhan.

Postcode: 430074

REFERENCES

[1] Vince Scaini & Tosn MA, "High-current DC choppers in the Metal Industry", IEEE Industry applications Magazine, Apri1 2002, pp 26-33

[2] Wei wei, Hu wei. The design of a cut wave DC/DC power supply [J]. Experimental Technology and Management, 2007.24(10):37-39

[3] Wei wei. MATLAB Teaching and Application [M]. Beijing: Tsinghua University Press, 2009.

[4] Oyama, J., Higuchi, T., Yamada, E., Koga, T., and Lipo, T., "New Control Strategies for Matrix Converter," IEEE Power Electron. Spec. Conf. Rec., 1989, pp. 360-367.

[5] Sobczyk, T., "Numerical Study of Control Strategies for Frequency Conversion with a Matrix Converter," Proceedings of Conference on Power Electronics and Motion Control, Warsaw, Poland, 1994, pp. 497-502.

[6] Cho, J.G., and Cho, G.H, Soft-switched Matrix Converter for High Frequency direct AC-to-AC Power Conversion. Int. J. Electron., 1992, 72, (4), pp. 669-680.

[7] Wei wei,Hu wei,Wei Lan-jie. Study of a much function switch power supply [J]. Electrotechnical Application.2007，26(10):48-50

[8] Hosseini, S.H.; Babaei, E, A new generalized direct matrix converter. Industrial Electronics, 2001. Proc. ISLE 2001. Vol(2).2001, pp.1071-1076

[9] Zhao Lian-bin. Modem Power Electronics Technology Base [M]. Beijing: Tsinghua University Press, 1995.