The Performance of SPMC Operating as AC-DC Controlled Rectifier Using Matlab/Simulink

Mohammad Khairil Bin Abdullah
Faculty of Electrical Engineering
Universiti Teknologi MARA Malaysia
40450 Shah Alam, Selangor, Malaysia
e-mail: mkhair_05@yahoo.com

Abstract— **This paper presents the application of single phase matrix converter (SPMC) as an AC-DC controlled rectifier with the effect of passive filter. For basic operation, multiple PWM techniques was used as a switching technique to synthesize the output voltage and current. Besides, commutation strategy was developed to avoid overlapping during turn ON and turn OFF state of the IGBTs when inductive loads are used. Filtering requirements for current-source rectifiers are usually satisfied through the use of Passive Filter which is low-pass LC input filters. Design of LC filters involves the positioning of the resonant frequency to meet the harmonic attenuation requirements.**

Keywords- Matrix Converter (MC); Matlab/Simulink (MLS); Pulse Width Modulation (PWM); Single Phase Matrix Converter (SPMC)r; Passive Filter; Insulated Gate Bipolar Transistor

I. INTRODUCTION

The matrix converter (MC) offers possible "all silicon" solution for AC-AC conversion, removing the need for reactive energy storage components used in conventional converter system. 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]. Its topology was first described by Gyugyi in 1976 [2]. MC in the three-phase variant is widely researched whilst the Single-Phase Matrix Converter (SPMC) has very little attention whilst offering very wide application. SPMC was first realised by Zuckerberger [3].

In this work the SPMC topology was presented to operate as a controlled rectifier by suitable switching schemes, where IGBTs are used for the main power switching devices. The multiple PWM was chosen due to their suitability in application for AC-DC converter as a switching technique to synthesize the output voltage and current. The harmonics in the output voltage of power electronic converters can be reduced using Pulse-Width Modulation (PWM) switching techniques [11]. Safe commutation strategy was developed to avoid overlapping during turn ON and turn OFF state of the IGBTs since inductive loads are used.

A sinusoidal component of a periodic wave or quantity having a frequency that is an integral multiple of the fundamental frequency. Thus, reduction of harmonics is becoming important topic among electric power engineers in these days. The lower component harmonics have large current magnitudes refer to their harmonic spectrum. The harmonics generated will be divided into three types that is positive sequences harmonic components such as 7th , 13th, 19th and negative sequence harmonic components such as 5th, 11th, 17th that is excessive in phase line which increase the THD of the system. While zero sequences harmonics current that is triplen harmonics such as 3, 9, 15 will flows through the neutral wire and may cause overheating on that wire [8]. Simple method for minimizing the harmonics supply current distortion associated with SPMC as a rectifier for LC output filter is presented by using Passive Filter.

II. SPMC

SPMC requires 4 bi-directional switches as shown in Fig. 1; each capable of conducting current in both directions, blocking forward and reverse voltages [4]. 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 fulfill the needs and hence the use of common emitter anti-parallel IGBT, diode pair as shown in Fig. 2. 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.

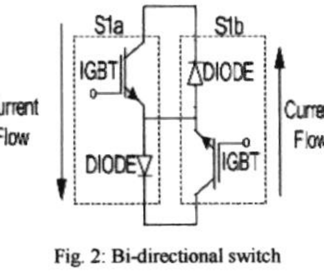

Fig. 1: AC-AC single-phase matrix converter topology

Fig. 2: Bi-directional switch

III. BASIC CONTROLLED RECTIFIER

The classical rectifier normally using a bridge-diode in implementation without affording any control function. The simplicity makes it universal for rectification of low-power application and some common high-power applications but are major contributors to power factor and current distortion problems. Sensitive equipments are less tolerable to nuisances caused by harmonics penetration into the supply system. As using nonlinear loads such as bridge diode rectifier with capacitor filter, there are associated problems since this rectifiers suffer from poor input power factor, heating effects, device malfunction and high content of low order harmonics in the supply current which can yield a number of problems for other electrical apparatus in the vicinity of the rectifier. Therefore the demand for high quality power supply has shown an upward increase in recent years. This trend reflects in the increase use of provision of unity supply power factor [8].

IV. SWITCHING TECHNIQUE OF SPMC

SPMC consists of four set bi-directional switches to control the output voltage, where one set of bi-directional switch is built by a set of two IGBTs, two diodes, and it is arranged in anti-parallel as previously described [5,6,7]. This SPMC which has four switching states is illustrated by Fig. 3 to 6.

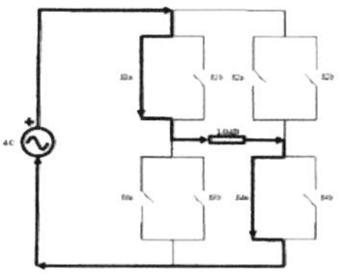

Fig. 3: State 1 AC Input (positive cycle)

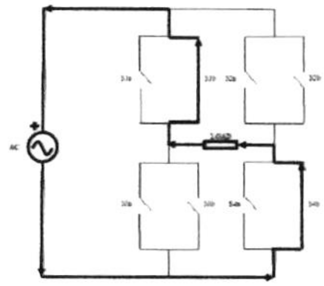

Fig. 4: State 2 Ac Input (negative cycle)

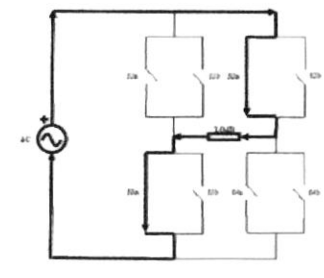

Fig. 5: State 3 AC Input (positive cycle)

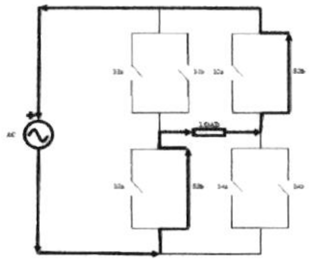

Fig. 6: State 4 AC Input (negative cycle)

V. SPMC OPERATING AS RECTIFIER

For implementing SPMC as a controlled rectifier, only State 1 and 4 described in the previous section are used, making State 2 and State 3 redundant [6]. Fig. 7 and Fig. 8 illustrate operation that includes safe commutation arrangements as indicated by the highlight-line and will be discussed in subsequent section.

Switching pattern commutation strategy in Fig. 9 and switching states in Table 1. During state1, the switch S4a and S3b are maintained ON while the PWM sequence will be sent to S1a only. Meaning that, between two PWM sequences, the inductive load current will flow through S4a and S3b until decay. During state3, the switch S1a and S2b are maintained ON in whole state 3 and the PWM sequences will be sent to S3b. Then the inductive load current will flow through S2b and S1a for the same part for freewheeling.

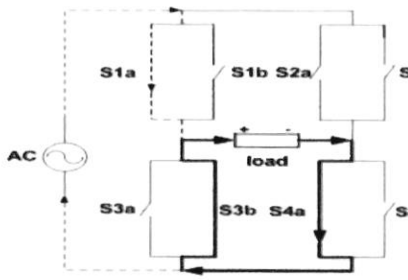

Fig. 7: Positive cycle with commutation (state 1)

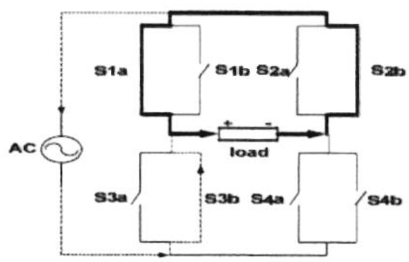

Fig. 8: Negative cycle with commutation (state 3)

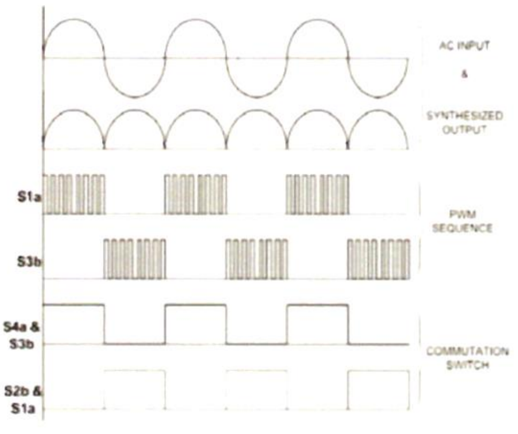

Fig. 9: Switching Pattern Commutation Strategy

STATE	PWM Switch	Commutation switch
1	S1a	S4a and S3b
3	S3b	S2b and S1a

Table 1: Switching State

VI. COMMUTATION TECHNIQUE OF SPMC

MC is very simple in structure and has powerful controllability but commutation problem and complex control has kept it from being utilized in industry. Theoretically the switching sequence in the SPMC must be instantaneous and simultaneous. Unfortunately impossible for practical realization due to the IGBT characteristic, where there is a short circuit or overlapping occurs between the switch turn-off with the next switch turn-on. This will be illustrated by consider Fig. 10. This problem occurs when inductive loads are used. So that, a systematic switching sequence is required that allows for the energy flowing in the IGBTs to decay [4].

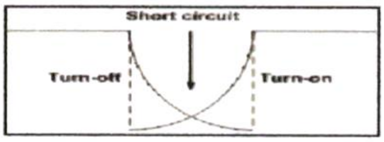

Fig. 10: Short circuit configuration in IGBT

For the conventional controlled rectifier, free-wheeling diode is used for this purpose which normally implemented in the form of free-wheeling diode in rectifier systems arranged in anti-parallel with power switching devices. But, in SPMC this does not exist, hence the need to develop a switching sequence to allow for forced free-wheeling action. This is used to protect the converter from being damaged as a result of voltage and current spikes as described. In this study, we will focus our attention to switching spikes and assume that there is no-change in the direction of current so as to minimize complexities

VII. SPMC WITH PASSIVE FILTER

Passive filter is one of the earlier methods used to address harmonic mitigation issues have been always considered as a good alternative for current harmonics compensation. Low pass LC filter is designed for the second-order passive filter, which contains two reactive components that are inductor and capacitor. Increasing frequency leads to increasing impedance [9]. The frequency for the LC filter can be calculated as:

$$F_C = \frac{1}{2\pi\sqrt{LC}} \quad \text{. . . . Equation (1)}$$

where

L_C = cut off frequency
L = inductance
C = capacitance

Due to these two reactive components, most of the frequency can block and reduce the number of harmonic frequency that goes through the system. As a result, it can reduce the current harmonics for phase and neutral conductor of the input side of SPMC.

To get the purely DC Conventionally, rectifier uses LC filter at the DC side of the rectifier where the capacitor holds the output voltage at the constant level and inductor smooth the current from the rectifier will create a non sinusoidal current supply hence generated current harmonics which are injected back to the AC system. As a result, contributes to high total harmonic distortion (THD). Filtering requirements for current-source rectifiers are usually satisfied through the use of low pass LC input filter as in Fig. 11. So far, there has been no systematic and user friendly approach in choosing the filter components.

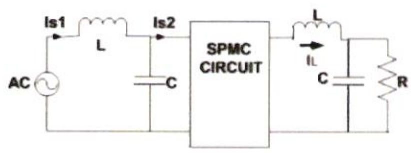

Fig. 11: LC input filter

VIII. RESULT AND EXPLANATION

The simulation using MLS are shown in Fig. 12. Table 12 and Fig. 13 shows the Total Harmonics Distortion (%) level versus modulation index for 1 kHz switching frequency and the result shows that the THD (%) will be decreased by an increase in modulation index value. The input current and supply voltage is as shown in Fig. 14. With pure resistive load no spikes are apparent (Fig. 15). Upon the introductive load, damaging spikes was observed (Fig. 16). Implementation of the communication strategy as proposed has resulted in spikes being eliminated (Fig. 17). In Fig. 18 the terminal load voltage is able to be maintained at an average value of 46V dc.

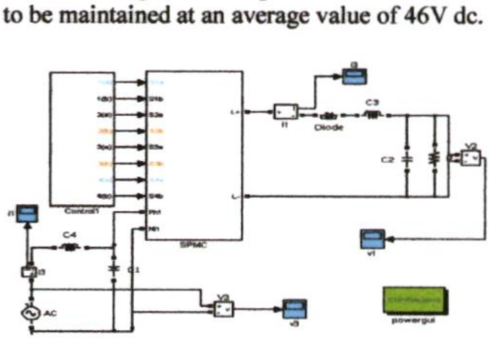

Fig. 12: Simulation circuit using MLS

Modulation Index	THD %
0.1	300.07
0.2	220.57
0.3	175.26
0.4	143.61
0.5	121.68
0.6	102.54
0.7	87.68
0.8	73.25
0.9	61.51
1.0	4.66

Table 2: The percent reduction in THD with modulation index

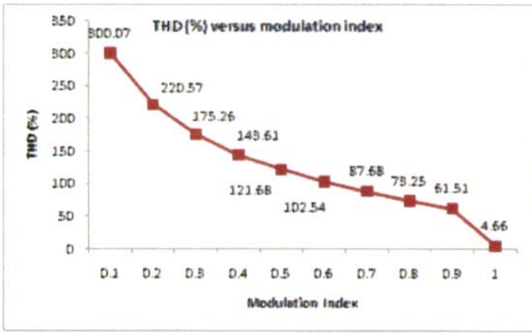

Fig.13: THD (%) versus modulation index

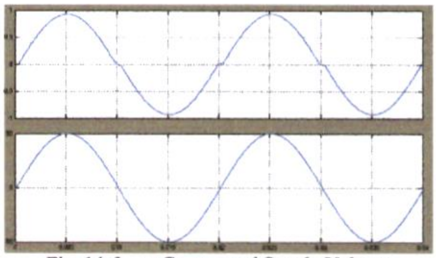

Fig. 14: Input Current and Supply Voltage

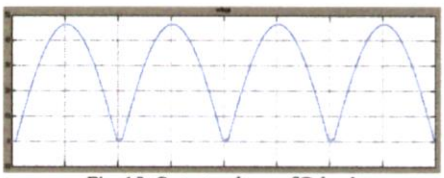

Fig. 15: Output voltage of R load

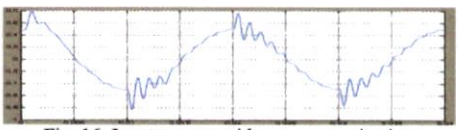

Fig. 16: Input current without communication

Fig. 17: Input current with communication

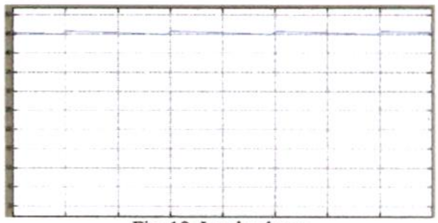

Fig. 18: Load voltage

IX. DISCUSSION

There are few observation has to be done in order to complete this project. The structure of this project was carefully planned to get success output of the project. Theoretically the switching sequence in the SPMC must be instantaneous and simultaneous. Unfortunately impossible for practical realization due to the IGBT characteristic, where there is a short circuit or overlapping occurs between the switch turn-off with the next switch turn-on. For the conventional controlled rectifier, free-wheeling diode is used for this purpose which normally implemented in the form of free-wheeling diode in rectifier systems arranged in anti-parallel with power switching devices. Another problem apart from converting AC input supply to a DC type, investigations are also carried out by applying a passive filter at the AC side. It is shown that this passive filter improves high input power factor and able to reduce input current total harmonic distortion (THD), which can yield a number of problems for other electrical apparatus in the vicinity of the rectifier. In these studies it has been observed that the supply current has been improved from a THD 300.07% to a THD level of below 4%. We can state that the higher the modulation index, the THD is better. Safe commutation also proposed to solve the inherent commutation problem that lead to switching spikes.

X. CONCLUSIONS

Performances of SPMC operating as rectifier with passive filter have been presented. The SPMC topology as a controlled rectifier by using suitable switching schemes, where IGBTs are used for the main power switching device. Simulation models in MLS is used to study the behavior of the proposed technique. The communication strategy used in this work has to a certain extent reduced the spikes that have been resulted. Supply current distortions have been eliminated and DC output voltage can also be kept constant in the present a load variation.

XI. FUTURE DEVELOPMENT

Even though passive filters have always been considered as a good alternative for current source harmonics mitigation, there are still many disadvantages exist from this application. The most critical aspect of passive filters are related to be fact that they cannot modify their compensation characteristic following the dynamic changes of non linear load and difficult to meet the THD following standard IEEE-std 519 which is less than 5%. Hence, to solve this problem, Active Filter can be uses. It can be eliminate both of the AC and DC side of the rectifier effectively [10].

REFERENCES

[1] Venturini M., "A New Sine Wave in Sine Wave Out, ConversionTechnique Which Eliminates Reactive Elements," ProceedingsPowercon 7, pp.E3_1-E3_15, 1980.

[2] Gyugyi,L and Pelly,B.R, "Static Power Chargers, Theory, Performance and Application," John Wiley & Son Inc, 1976

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

[4] Firdaus, S., Hamzah, M.K.," Modelling and simulation of a single-phase AC-AC matrix converter using SPWM,", Student Conference on Research and Development 16-17 July 2002, SCOReD2002., pp286-289.

[5] Firdaus, S., Hamzah, M.K.," Modelling and simulation of asingle-phase AC-AC matrix converter using SPWM,", StudentConference on Research and Development 16-17 July 2002,SCOReD2002., pp286-289

[6] Siti Zaliha Mohammad Noor, Mustafar Kamal Hamzah &Ahmad Farid Abidin, "Modelling and Simulation of a DCChopper Using Single Phase Matrix Converter Topology" IEEE Chopper Using Singe Sixth International Conference PEDS 2005, Kuala Lumpur,Malaysia

[7] Baharom R.,A.S.A. Hasim, M.K.Hamzah and A.F Omar "ANew Single-Phase Controlled Rectifier Using Single-PhaseMatrix Converter Topology". Proceeding for IEEE First International Power and Energy Conference, 2006.

[8] R. Blundell, L. Kupka, S. Spiteri, AC-DC converter with unity power factor and minimum harmonic content of line current: design considerations, IEE Proc.-Electr.Power Appl., Vol. 145, No.6, November 1998.

[9] Najwa mahamad, C.M. Hadzer "Application of LC Filter in Harmonic Reduction" Power Research Group, School of Electrical and Electronic Engineering , USM

[10] Darwin Rivas, Luis Moran,Juan W. Dixon, Jose R.Espinoza, Member IEEE " Improving Passive Filter Compensation Performance With Active Technique"

[11] D. Quek and S. Yuvarajan, "A novel PWM scheme for harmonic reduction in power converters," Proc. of International Conference on Power Electronics and Drive systems, Singapore, February 1995.