Modelling & Simulation of a new Single-phase to Single-phase Cycloconverter based on Single-phase Matrix Converter Topology with Sinusoidal Pulse Width Modulation Using MATLAB/Simulink

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***Abstract*—Single-phase Cycloconverters are used for AC-AC power conversion particular for speed control of AC drives. In this work the Single-phase matrix converter (SPMC) topology is used for cycloconverter operation are proposed. IGBTs are used for the power switches. The well-known sinusoidal pulse width modulation (SPWM) scheme is used in this instance. This paper presents work on modelling and simulation of cycloconverter using MATLAB/Simulink incorporating the SimPowerSystem blockset. Simulations are compared with the well-known Pspice simulations to ascertain the accuracy of modelling. Experimental verifications were also carried out to validate the simulation model and the converter.**

Keywords*–Power Electronics, Single-Phase Matrix Converter (SPMC), Cycloconverter, Sinusoidal Pulse Width Modulation (SPWM), MATLab Simulation & Computer Modelling

I. INTRODUCTION

In a cycloconverter, the ac power at one frequency is converted directly to another frequency generally lower than the input supply frequency without any intermediate dc stage. In the 1970's, various aspects of the cycloconverter theory and practice were discussed [1-3]. In the late 1980's (1986) implementations on cycloconverter, experienced growth in usage due to the development of microprocessor based control systems [4-6]. Thyristor controlled cycloconverter today, has found its way in higher power applications such as in electric traction, rolling mills, variable frequency speed control for AC machines, constant frequency power supply and controllable reactive power supply for an AC system.

Amongst previous development of the cycloconverter includes; work on improvements of harmonic spectrum in the output voltage with new control strategies [7], new topology [8] and study of the cycloconverter behaviour [9].

The matrix converter (MC) offers possible "all silicon" solution for AC-AC conversion, removing the need for reactive energy storage components used in conventional rectifier-inverter based system [10]. Gyugyi [3] first described the topology in 1976. Obviously all published studies dealt with mainly the three-phase circuit topologies [11-13]. The Single-phase matrix converter variant on the same philosophy denoted as SPMC was first realised by Zuckerberger [14]. Other works, such as those of Hossieni [15] and Saiful [16] does not include experimental verification. Previous works on SPMC had focussed on step-up frequency operation with no reported work on step-down frequency operation.

In this work, it proposed that the SPMC as used by Saiful is investigated for use in step-down frequency operation of which this paper will describe in part. The development of a computer simulation model on SPMC for cycloconverter operation using MATLAB/Simulink (MLS) software package will be discussed. Comparisons are initially made with the well-known and widely used Pspice to ascertain the validity of the model. This is then followed by simple experimental verification on a test-rig developed and constructed in the laboratory. Amongst the major difference to conventional cyclo-converter topology, which mainly used thyristors, the SPMC requires the use of IGBT in its power switches. In this work, implementation is simplified by the use of the well-known SPWM technique with resistive load. Sample simulations and experimental results are presented in this paper. Further simulations were also carried out with simple RL load, with a brief description of problems encountered in the absence of suitable commutation strategies that result with voltage spikes that needs to be avoided. Further investigations are required in an effort to solve the problems, a common phenomenon in matrix converter topologies.

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II. THE CYCLOCONVERTER

Cycloconverter are a historical class of power converters based on SCRs. They are used to generate AC output (single-phase or three-phase) from a single-phase or three-phase input [17]. A typical cycloconverter consists of one or more pairs of back-to-back connected controlled rectifiers as shown in Fig. 1. Detailed treatment on the operation of conventional cycloconverter could be obtained from reference [9] but will be briefly described for completeness. As can be observed, the conventional cycloconverter uses two separate converters called the P-converter and the N-converter; each performing similar to an H-bridge inverter.

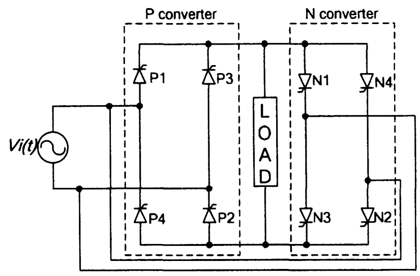


Figure 1. Schematic of a conventional single-phase bridge cycloconverter

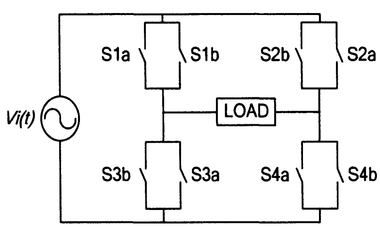


Figure 2. SPMC circuit configuration

III. THE SPMC AS CYCLOCONVERTER

In comparison the SPMC requires 4 bi-directional switches as illustrated in Fig. 2 for its cycloconverter implementation. 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 [18, 19] and hence the use of common emitter anti-parallel IGBT, diode pair as shown in Fig. 3. Diodes are in place to provide reverse blocking capability to the switch module. The IGBT were used due its high switching capabilities and high current carrying capacities desirable amongst researchers for high-power applications.

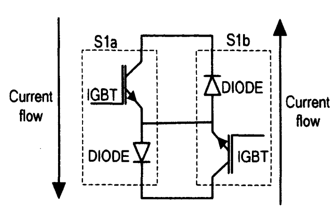


Figure 3. Bi-directional switch module (common emitter)

IV. SINUSOIDAL PULSE WIDTH MODULATION

The Sinusoidal Pulse Width Modulation (SPWM) is a well known wave shaping technique in power electronics as illustrated in Fig. 5. For realisation, a high frequency triangular carrier signal, V_c, is compared with a sinusoidal reference signal, V_{ref}, of the desired frequency. The crossover points are used to determine the switching instants.

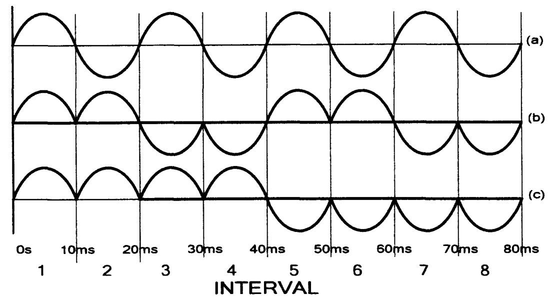


Figure 4. (a) Input 50 Hz (b) Output 25 Hz (c) Output 12 ½ Hz

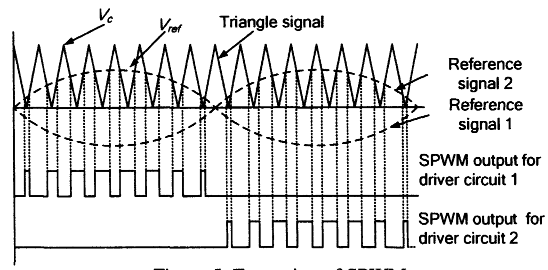


Figure 5: Formation of SPWM

The magnitude ratio of the reference signal (V_{ref}) to that of the triangular signal (V_c) is known as the modulation index (m_i). The magnitude of fundamental component of output voltage is proportional to m_i. The amplitude V_c of the triangular signal is generally kept constant. By varying the modulation index, the output voltage could be controlled.

TABLE 1. SEQUENCE OF SWITCHING CONTROL

Input Frequency	Target Output Frequency	Time Interval	State	Switch "modulated"
50 Hz	25 Hz	1	1	S1a and S4a
		2	4	S2a and S3a
		3	3	S2b and S3b
		4	2	S1b and S4b
	12 ½ Hz	1	1	S1a and S4a
		2	4	S2a and S3a
		3	1	S1a and S4a
		4	4	S2a and S3a
		5	3	S2b and S3b
		6	2	S1b and S4b
		7	3	S2b and S3b
		8	2	S1b and S4b

V. SWITCHING STRATEGIES

The implementation of the SPMC as a cycloconverter requires different bi-directional switching arrangements depending on the desired output frequency. The output voltage of the converter is controlled by SPWM, but the frequency of the converter is changed by controlling the duration of operation of the switch. In this work the input frequency of power supply used is set at 50 Hz and the desired output frequency synthesized at the 25 Hz and 12 ½ Hz as represented in Fig. 4. The switching sequences are dependent on the time interval and the state of the driver circuit following table 1 below (for one cycle).

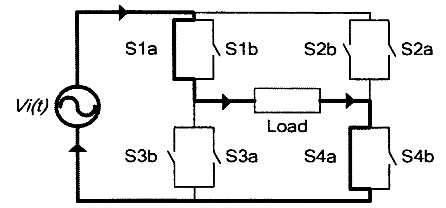


Figure 6. State 1 (positive cycle)

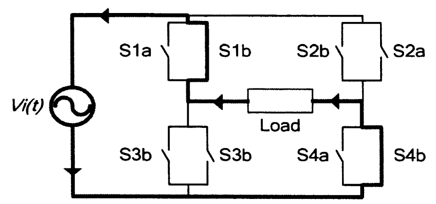


Figure 7. State 2 (Negative Cycle)

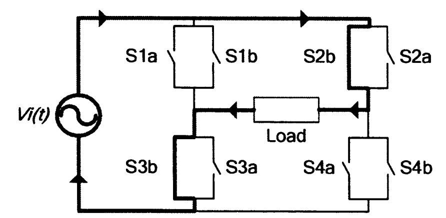


Figure 8. State 3 (Positive Cycle)

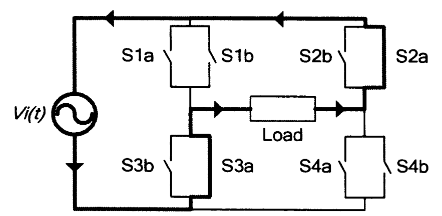


Figure 9. State 4 (Negative Cycle)

The switching angles, of the 4 bi-directional switches S_{ij} (i = 1,2,3,4 and j = a,b) where 'a' and 'b' represent as driver one and driver two respectively will be considered by the following rules below,

- At any time't', only two switches S_{ij} (i = 1, 4 and j = a) will be in 'ON' state and conduct the current flow during positive cycle of input source. (state 1)
- At any time't' only two switches S_{ij} (i = 1, 4 and j = b) will be in 'ON' state and conduct the current flow during negative cycle of input source. (state 2)
- At any time't' only two switches S_{ij} (i = 2, 3 and j = b) will be in 'ON' state and conduct the current flow during positive cycle of input source. (state 3)
- At any time't' only two switches S_{ij} (i = 2, 3 and j = a) will be in 'ON' state and conduct the current flow during negative cycle of input source. (state 4)

Certain rules are applied as illustrated in Figs. 6 to 9.

VI. MAIN SIMULATION MODEL

Fig. 10 and Fig. 11 is the developed MLS and Pspice model respectively for SPMC that performs the operation of a cycloconverter. Fig. 12 shown the bi-directional switch module in MLS.

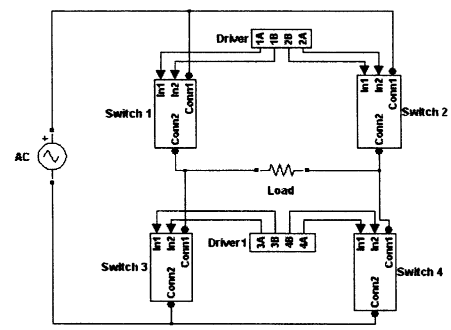


Figure 10. Top level main model of SPMC in MLS

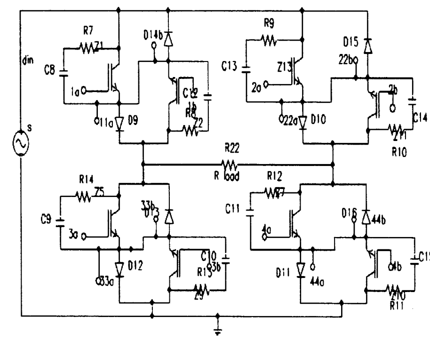


Figure 11. Main model of SPMC in Pspice.

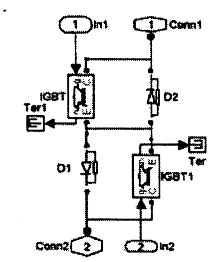
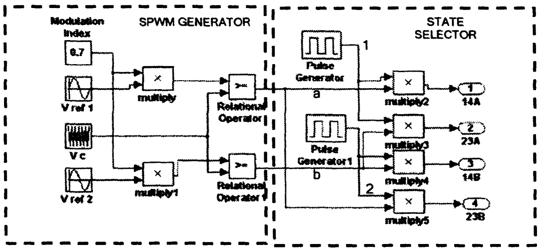


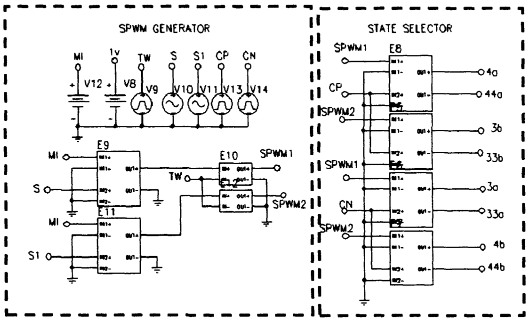
Figure 12. Bi-directional switch module in MLS

Driver circuits were designed to generate the SPWM pattern that is controlled using the switching states as in table 1. The driver circuit algorithm are designed by using MLS and Pspice model as shown in Fig.13, comprising SPWM generator portion and state selector portion.

From Fig.13 (a), two "sine wave" blocks are used to generate two sinusoidal references signal 'V_{ref1}' and 'V_{ref2}'. Output from the "sine wave" block is multiplied using a "multiply" block with the output from the constant block that represents the modulation index, thus magnitude could be varied by changing this "constant" value. The "repeating sequence" block are used to generate the triangular carrier signal 'V_c'. To produce the SPWM the "relational operation" block are used as a comparator that triggers an output switching function between "0" and "1' that represents the PWM pulse train.



(a)



(b)

Figure 13. Actual diagram of driver circuit (a) using MLS (b) using Pspice

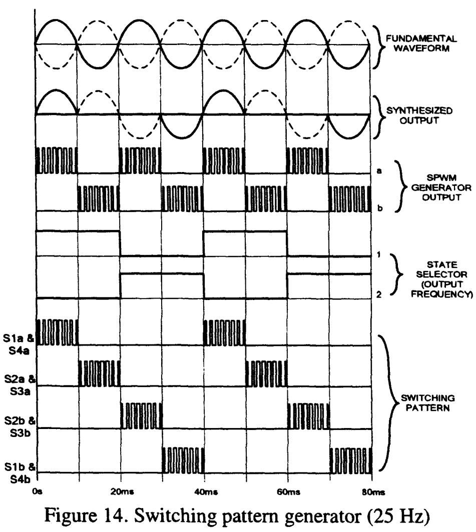


Figure 14. Switching pattern generator (25 Hz)

The state selector portion implements the operation of required switching state of table 1. Here, the square wave pulse represents the desired output frequency that are generated by the "pulse generator" block. The final switching pattern for the cycloconverter is produced by multiplying the output from SPWM generator with the state selector using the "multiply" block. Each output from the "pulse generator" is multiplied with both outputs from the SPWM and are as illustrated in Fig. 14.

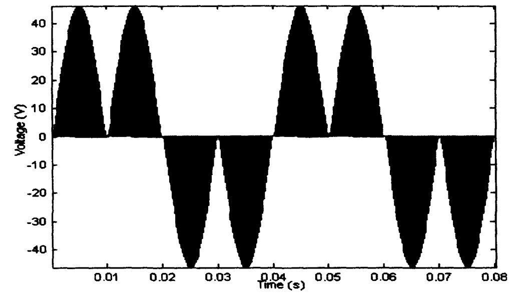
VII. RESULT

A. SIMULATION

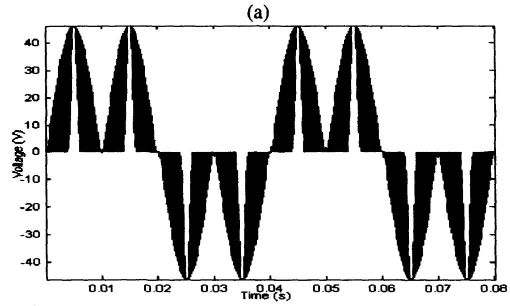
Simulation results are presented in the following Fig. 15 and 16 for MATLAB and Pspice respectively. Parameters used are as shown in table 2.

TABLE 2. PARAMETERS

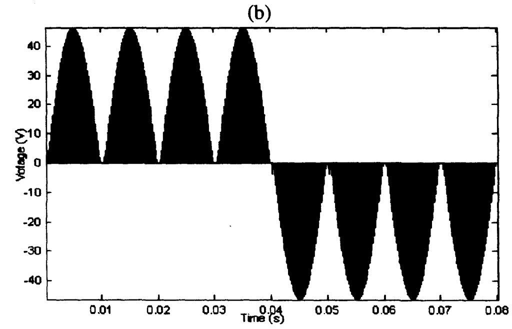
Input Source (AC)	50 V_{rms}
Reference Frequency signal (f_r)	50 Hz
Carrier Signal (f_c)	5 KHz
Sample Modulation Index (m_i)	0.7 and 1.0
Load	R = 50 Ω



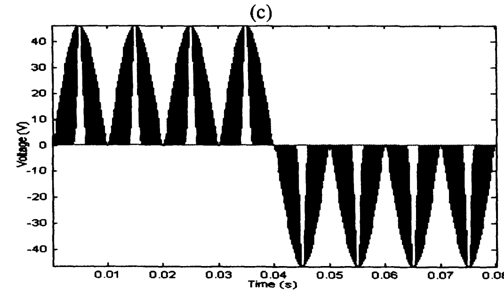
(a)



(b)



(c)



(d)

Figure 15. simulation result (MLS) (a) at 25 Hz and m_i=0.7, (b) at 25 Hz and m_i=1.0, (c) at 12.5 Hz and m_i=0.7, (d) at 12.5 Hz and m_i=1.0

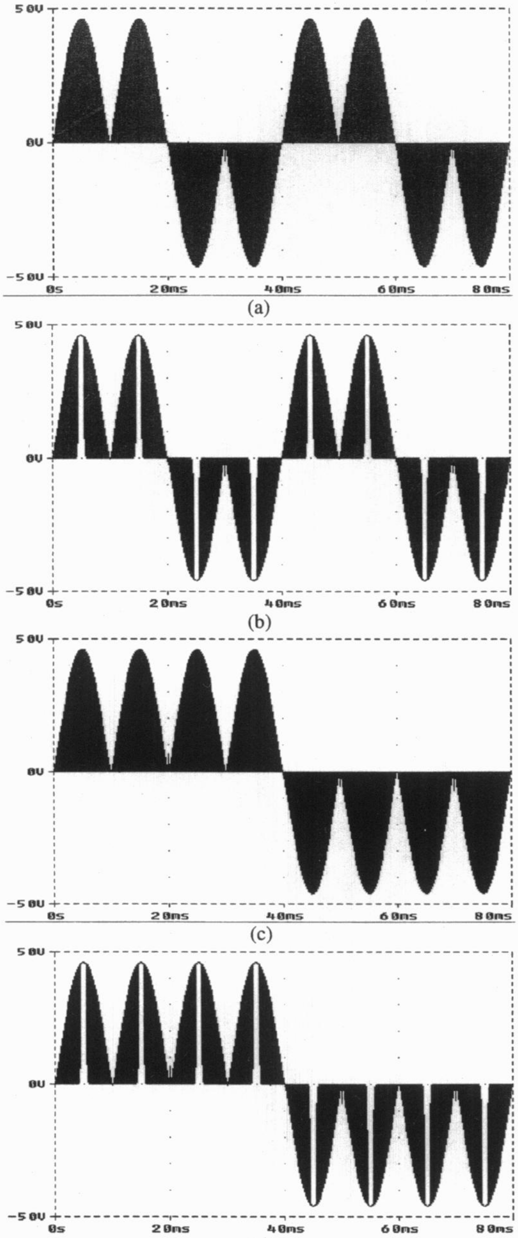


Figure 16. simulation result (Pspice) (a) at 25 Hz and m_i=0.7, (b) at 25 Hz and m_i=1.0, (c) at 12.5 Hz and m_i=0.7, (d) at 12.5 Hz and m_i=1.0

The simulation model could be used to study the behaviour of the SPMC as a cycloconverter under a variety of the operating conditions, including different reference frequency and variety of load. In this paper we have focussed into simulation of purely resistive load due to the absence of commutation strategy. However, simulation was also carried out with R-L load at f_c = 25Hz and are as given in Fig. 17. This is to observe the spikes being produced under those circumstances.

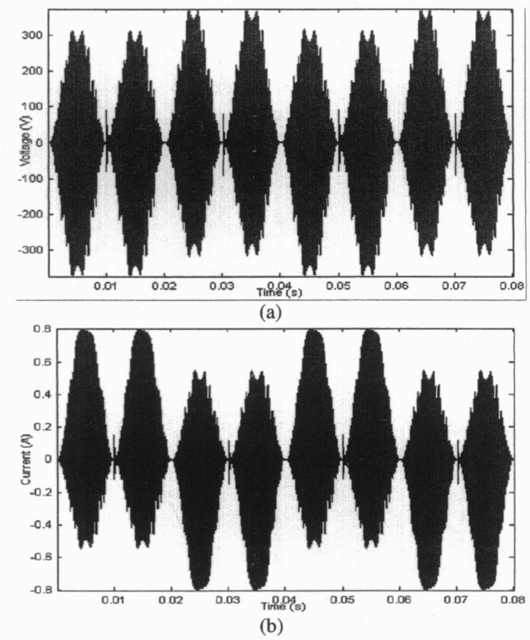
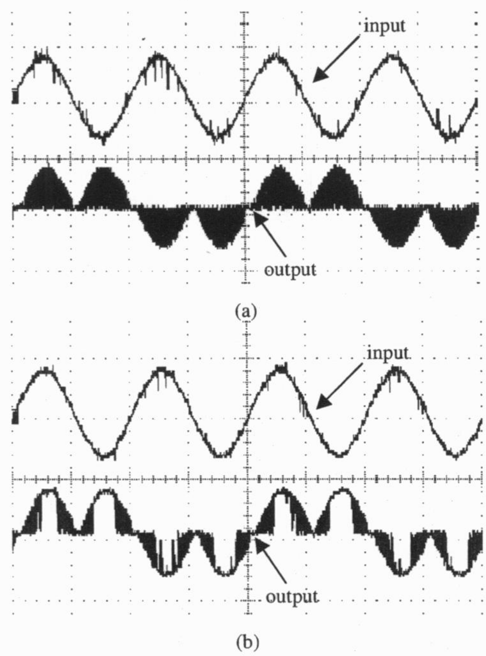


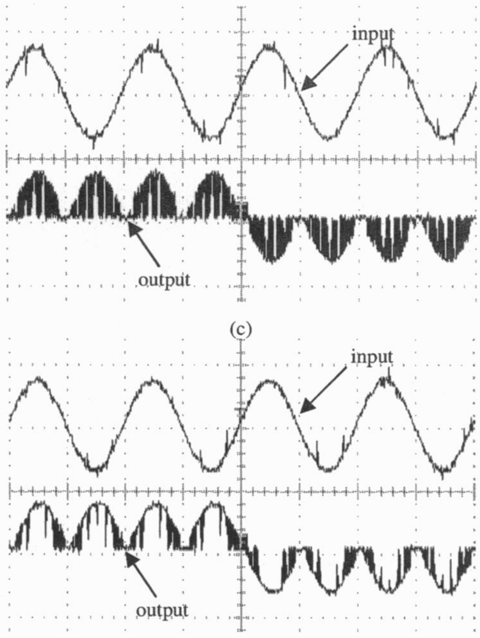
Figure 17. Simulation result of SPMC with R-L load at f_c= 50Hz (MLS), (a) output voltage (b) output current

We could observe that the output voltage and current waveforms are indeed, distorted. Undesirable spikes seem to appear with a reasonable degree of magnitude that requires elimination. This probably could be solved using novel commutation strategies that could be investigated in the future

B. Experimental Verification

The behaviour of this model has been verified experimentally in the laboratory environment as shown in Fig. 18. Notice that the behaviour does produce good agreement with those simulated using MLS.





(c)

(d)

Figure 18. Experimental result (a) at 25 Hz and m_i=0.7, (b) at 25 Hz and m_i=1.0, (c) at 12.5 Hz and m_i=0.7, (d) at 12.5 Hz and m_i=1.0, scale Y:100V/div, X: 10ms/div

VIII. CONCLUSION

The computer simulation model on SPMC for cycloconverter operation using MATLAB/Simulink (MLS) software package had been presented. It includes the implementation of SPWM to synthesize the AC output supply for a given AC input. Comparisons of this models with the well-known Pspice has shown good agreement. This is also verified by simple experimental work on a test-rig developed and constructed in the laboratory.

Further simulations were also carried out with simple RL load. Undesirable spikes seems to appear with a reasonable degree of magnitude that requires elimination. This probably could be solved using novel commutation strategies that could be investigated in the future.

REFERENCES

[1] Maamoun, A., "Development of cycloconverters," Canadian Conference on Electrical and Computer Engineering, 2003. IEEE CCECE 2003., Vol.1, 4-7 May 2003, pp. 521 - 524

[2] Pelly, B.R., "Thyristor phase-controlled converters and cycloconverter," New York, U.S.A., John Wiley & Son Inc, 1971.

[3] Gyugyi, L., and Pelly,B.R, "Static Power frequency Chargers," New York, U.S.A., John Wiley & Son Inc, 1976.

[4] Miyazawa, S., Nakamura, F., Yamada, N., "A novel strategy for microcomputer-based control of a single-phase output cycloconverter," IEEE Transactions on Industrial Electronics, Vol. 36 (4), Nov. 1989, pp. 560 – 567.

[5] Zein El Din, A.S.; Aubry, J.F.; Mahmoud, S.A., "32 bits high performance single chip microcontroller MC68332 for the control of cycloconverter," Fifth European Conference on Power Electronics and Applications, 1993, Vol.4, 13-16 Sep 1993, pp.53 – 58.

[6] Arsov, G.L., "Improvements in microcomputer-based digital control of cycloconverters," IEEE Transactions on Industry Applications, Vol. 30 (3), May-June 1994, pp. 585 – 588.

[7] Karamat, A., Thomson, T., Mehta, P., "A novel strategy for control of cycloconverters," 22nd Annual IEEE Power Electronics Specialists Conference, 1991. PESC '91 Record., 24-27 June 1991, pp. 819 – 824.

[8] Choudhury, M.A., Uddin, M.B., Bhuyia, A.R., Rahman, M.A., "New topology and analysis of a single phase delta modulated cycloconverter," Proceedings of the 1996 International Conference on Power Electronics, Drives and Energy Systems for Industrial Growth, 8-11 Jan. 1996, Vol. 2, pp.819 – 825

[9] Hill, W.A., Ho, E.Y.Y., Nuezil, I.J., "Dynamic behavior of cycloconverter system," IEEE Transactions on Industry Applications, Vol. 27(4), July-Aug. 1991, pp.750 – 755

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

[11] 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.

[12] 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.

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

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

[15] Hosseini, S.H., and Babaei, E, "A new generalized direct matrix converter," International Symposium on Industrial Electronics, 2001. Vol(2) , 2001, pp.1071-1076.

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

[17] Neacsu, D.O., "IGBT-based "Cycloconverters" built of conventional current source inverter modules," International Symposium on Signals, Circuits and Systems," 2003. SCS 2003, Vol. 1, 10-11 July 2003, pp. 217 – 220.

[18] Wheeler, P.W., Clare, J.C., Empringham, L., Bland, M., Kerris, K.G., "Matrix converters," IEEE Industry Applications Magazine, Vol. 10 (1), Jan-Feb2004, pp. 59 – 65.

[19] Wheeler, P.W., Rodriguez, J., Clare, J.C., Empringham, L., Weinstein, A., "Matrix converters: a technology review," IEEE Transactions on Industrial Electronics, Vol. 49 (2), April 2002, pp. 276 – 28