Single Phase Matrix Converter for Inverter Operation Controlled Using Peripheral Interface Controller (PIC)

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Abstract **–This paper is concerned on PIC implementation of design for control the Single Phase Matrix Converter (SPMC) operates as inverter. The SPWM technique was used to synthesize the output. Safe commutation strategy was implemented to avoid voltage spikes due to inductive load. The Insulated Gate Bipolar Transistor act as a power switching devices in the SPMC implementation.**

Keywords **– Peripheral Interphase Controller (PIC); Inverter; Safe commutation; Single Phase Matrix Converter (SPMC); Sinusoidal Pulse Width Modulation (SPWM)**

I. INTRODUCTION

Inverter converts a DC input into an AC output statically with output waveforms ideally sinusoidal. Single-phase voltage source inverters are widely used for example in standby power supplies, variable speed AC motor drive and shunt active power filter applications for energy transformation [1,2], where bidirectional operation is required. In such applications full control is limited to unidirectional operation.

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 a controllable input current displacement factor [3]. It 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 systems.

The topology was first proposed by Gyugyi [4] in 1976. Previous published studies mainly dealt with three-phase circuit topologies [5]. The Single-phase matrix converter (SPMC) was first realized by Zuckerberger [6]. It has been shown that the SPMC could be used to operate as a direct AC-AC single-phase converter [7], DC chopper [8], rectifier [9] & inverter [10]. MC in the three-phase variant is widely researched whilst the Single-Phase Matrix Converter (SPMC) has had very little attention whilst offering the possibility of a very wide application.

This paper will discuss the design and development of a pulse-width modulation (PWM) generator suitable for Single-Phase Matrix Converter (SPMC) operating as an inverter. It is based on the Peripheral Interphase Controller (PIC) with IGBTs as the power switching device. The output voltage is synthesized using Sinusoidal Pulse Width Modulation (SPWM). The proposed design enables the modulation index and the switching frequency to be changed. Results are provided to demonstrate successful.

II. SINGLE PHASE MATRIX CONVERTER (SPMC)

The single phase matrix converter operation use four bi-directional switches that capable to block reverse voltage and conducting current in both directions as shown in figure 1 [11]. The diodes provide reverse blocking capabilities to switch module. The IGBT has the capabilities of high switching capabilities and also high current carrying capabilities that are suitable for high power application.

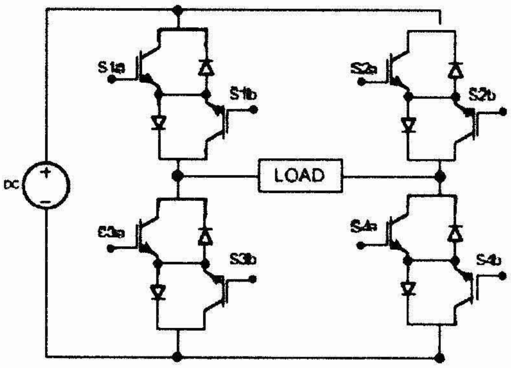


Fig 1: SPMC Inverter

III. INVERTER OPERATION

The input of the inverter is DC, then the operation of the inverter operation positive half cycle, switch S_{1a} would be the PWM switch while switch S_{3b} and S_{4a} will be ON state for commutation current to circulate without change in direction during turn OFF. During negative half cycle, S_{3a} will be the PWM switch while switch S_{1b} and S_{2a} will be ON state. The propose of using this technique is to create a safe commutation technique. It is impossible for the switching during turn ON or OFF in real application to be instantaneous and simultaneous to avoid spikes. So this technique is applied. The LC filter is use at the output of this converter. The standard SPWM operation principles can be illustrated with Fig 3 and 4. The bold line flow of current in the diagram represent the safe commutation switch during each particular state that is continuously turn on as in table 1.

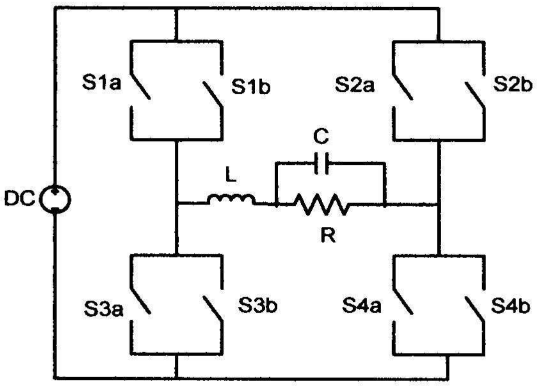


Fig 2: SPMC with LC filter

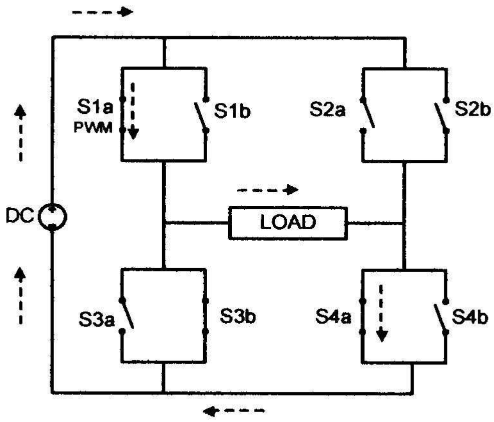


Fig 3: Positive cycle

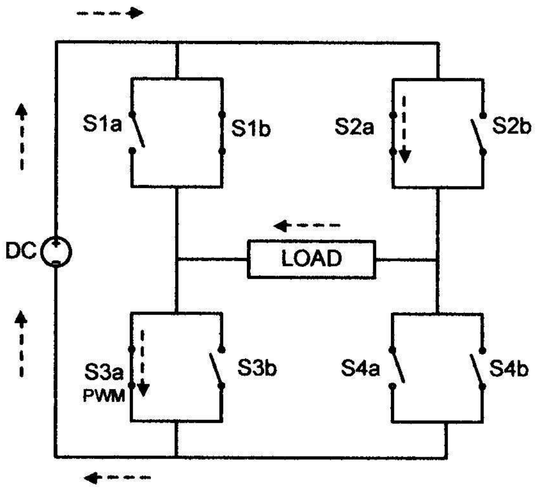


Fig 4: Negative cycle

TABLE I
SWITCHING STRATEGIES

Switches	Positive cycle	Negative cycle
S1a	PWM	OFF
S1b	OFF	ON
S2a	OFF	ON
S2b	OFF	OFF
S3a	OFF	PWM
S3b	ON	OFF
S4a	ON	OFF
S4b	OFF	OFF

IV. MODELLING AND SIMULATION

Matlab/Simulink software was used for the simulation purpose. The circuit was constructed using this simulation software to get the simulation result in order to compare with the experimental result as shown in figure 5. Operating frequency used is 50Hz while the switching frequency varied for 3k, 6k and 9 kHz result. The modulation index was also varied to get various form of result. The circuit consists of eight IGBT and the voltage source is set at 20V. The low pass filter is used at the output to mitigate the harmonic. The parameter of the component in the circuit is shown below:

a) Voltage = 20V
b) Resistor = 50 Ω
c) Capacitor = 10μF
d) Inductor = 4mH
e) Frequency = 50Hz

Voltage and current measurement is placed at the load to measure the output and obtain the output waveform. In the simulation the PWM waveform is generated using simple circuit as shown in figure 6 to replace the PIC.

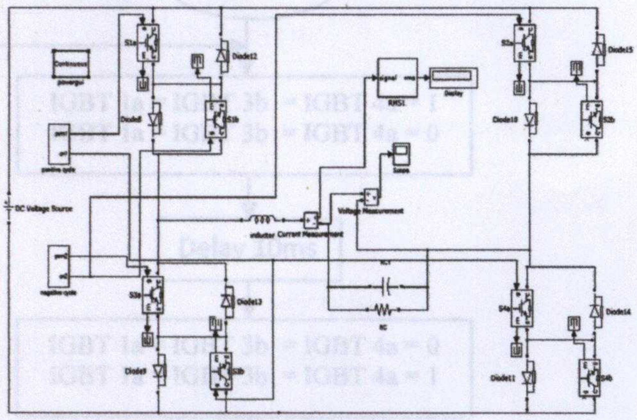


Fig 5: Simulation model

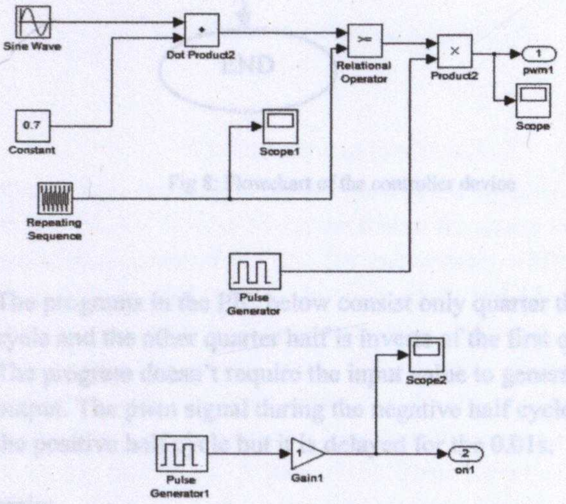


Fig 6: PWM generation model

V. HARDWARE IMPLEMENTATION

A. Hardware Setup

The block diagram for implementation is as shown in Fig.6 with the laboratory test-rig as shown in Figure 7 with switching strategy that includes safe commutation strategy and the use of Sinusoidal Pulse Width Modulation (SPWM). Switching combinations are compiled as shown in Table 1 with details of full switching implementation.

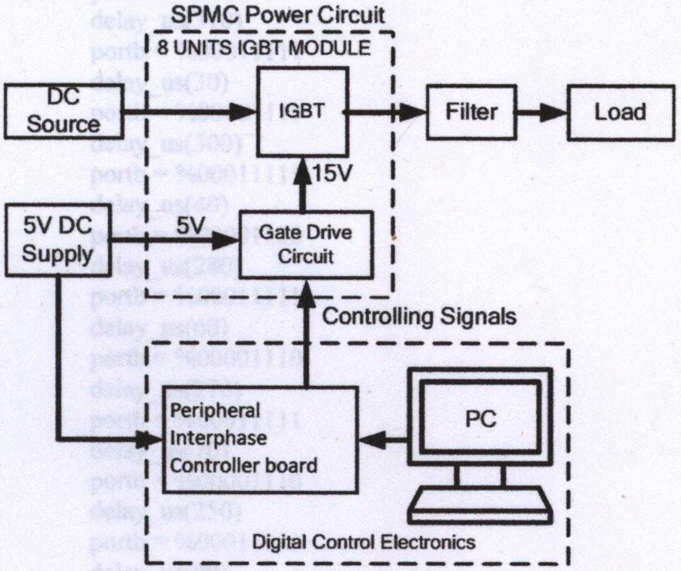


Fig 6: Experimental set-up

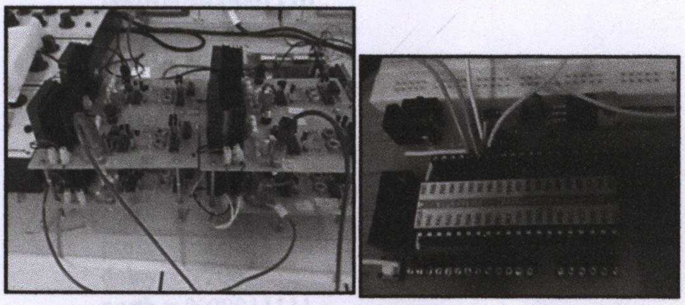


Fig 7: Experimental Test-Rig

B. PIC Implementation

The flow chart of the pic program for the controller device is shown in figure 8. For each of the switching frequency and modulation index varied, a new program has to download into the pic using MPLAB software and the pic downloader as shown in figure 9. The developed PWM is based on the value from the simulation using MATLAB software.

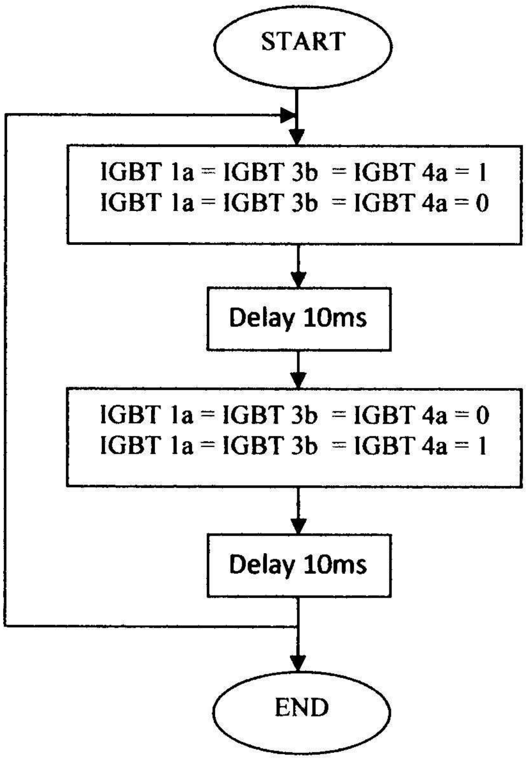


Fig 8: Flowchart of the controller device

The programs in the PIC below consist only quarter the half cycle and the other quarter half is inverts of the first quarter half. The program doesn't require the input value to generate the output. The pwm signal during the negative half cycle is same as the positive half cycle but it is delayed for the 0.01s.

```
main:

'  Main program

 ADCON1 = 0x07        ' Set PORTA as DIO
 TRISA = 0xFF         ' Set PORTA as digital input
 TRISB = 0x00         ' Set PORTA as output
 TRISC = 0x00         ' Set PORTC as output

 portb = 0x00
while (TRUE)

               portb = %00001110
               delay_us(170)
               portb = %00011111
               delay_us(10)
               portb = %00001110
               delay_us(310)
               portb = %00011111
               delay_us(30)
               portb = %00001110
               delay_us(300)
               portb = %00011111
               delay_us(40)
               portb = %00001110
               delay_us(280)
               portb = %00011111
               delay_us(60)
               portb = %00001110
               delay_us(270)
               portb = %00011111
               delay_us(70)
               portb = %00001110
               delay_us(250)
               portb = %00011111
               delay_us(90)
               portb = %00001110
               delay_us(240)
               portb = %00011111
               delay_us(100)
               portb = %00001110
               delay_us(230)
               portb = %00011111
               delay_us(110)
               portb = %00001110
               delay_us(210)
               portb = %00011111
               delay_us(130)
               portb = %00001110
               delay_us(200)
               portb = %00011111
               delay_us(140)
               portb = %00001110
               delay_us(190)
               portb = %00011111
               delay_us(150)
```

```
portb = %00001110
delay_us(180)
portb = %00011111
delay_us(150)
portb = %00001110
delay_us(180)
portb = %00011111
delay_us(160)
portb = %00001110
delay_us(170)
portb = %00011111
delay_us(160)
portb = %00001110
delay_us(170)
portb = %00011111
delay_us(170)
portb = %00001110
delay_us(160)

                    '1/4 half cycle positive cycle
```

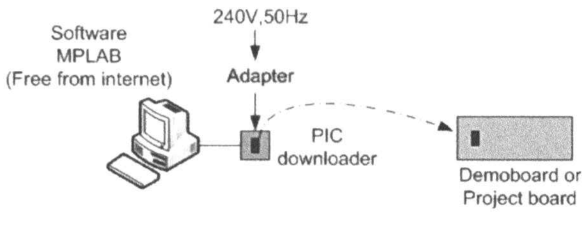


Fig 9: Sequence to download a PIC program

VI. RESULT AND DISCUSSION

The voltage and current result obtain in the simulation is shown in fig. 10, 11, 13 and 14 for switching frequency of 3kHz and modulation index of 0.3 and 0.9 respectively while the output from experimental result is shown in fig 12 and 15. The result is quite the same for both simulation and experiment. The higher the modulation index used the smooth waveform being generated with less spike. From the simulation the rms output voltage and current increased linearly with the modulation index as in fig 16 and 17. A plot of the Total Harmonic Distortion (THD) of voltage and current is as shown in Fig.18 and Fig.19 it shows that the higher modulation index with the lower switching frequencies give the best THD value of voltage with THD 6.43%.

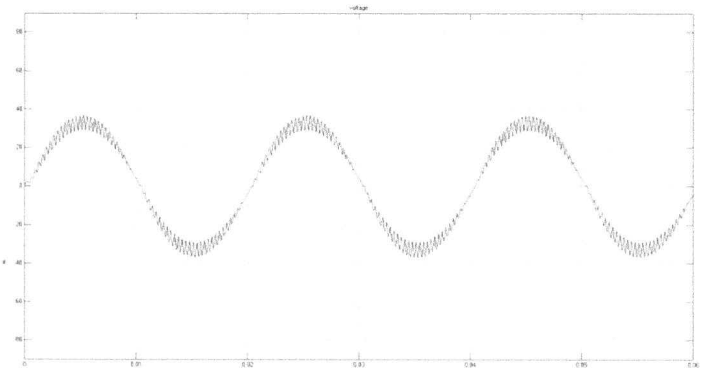


Fig 10: Voltage 3 kHz with modulation index 0.3s from simulation output.

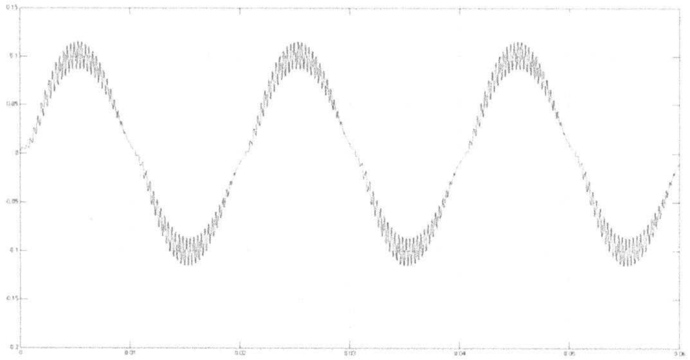


Fig 11: Current 3 kHz with modulation index 0.3 from simulation output.

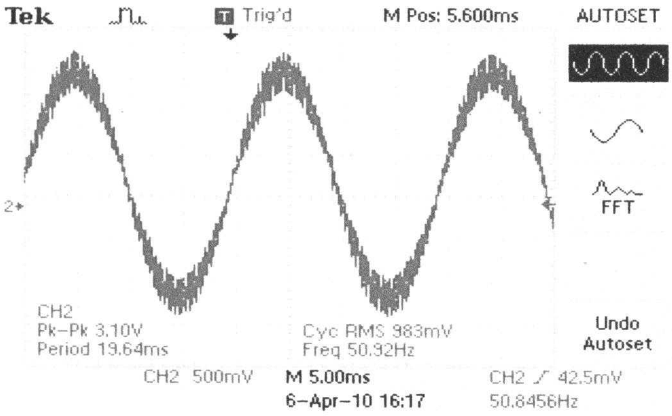


Fig 12: Voltage 3 kHz with modulation index 0.3 from experimental output.

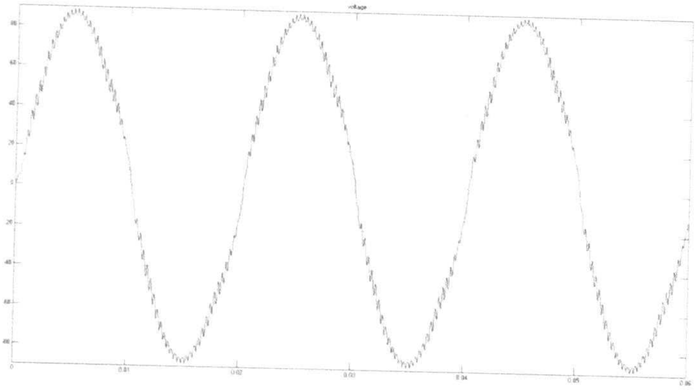


Fig 13: Voltage 3 kHz with modulation index 0.9 from simulation output.

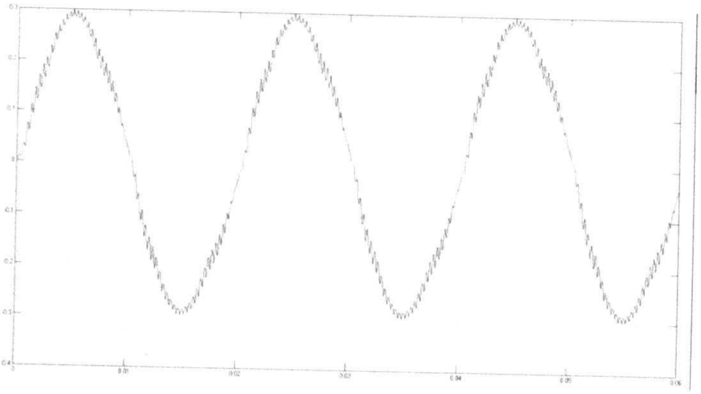
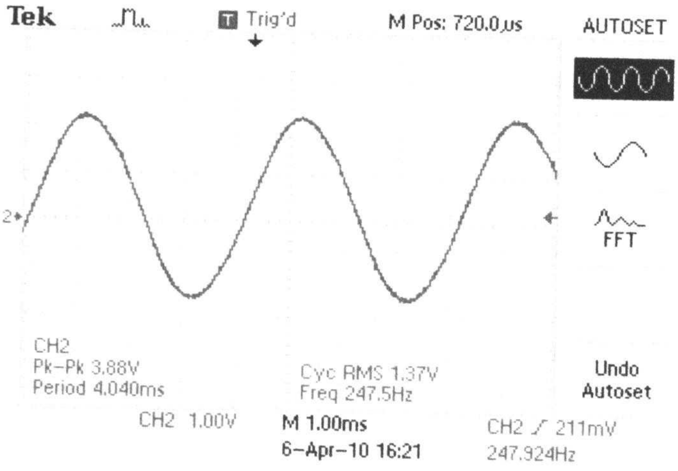


Fig 14: Current 3 kHz with modulation index 0.9 from simulation output.



M Pos: 720.0μs

CH2
Pk–Pk 3.88V
Period 4.040ms

Cyc RMS 1.37V
Freq 247.5Hz

CH2 1.00V
M 1.00ms
6–Apr–10 16:21
CH2 ⁄ 211mV
247.924Hz

Fig 15: Voltage 3 kHz with modulation index 0.9 from experimental output.

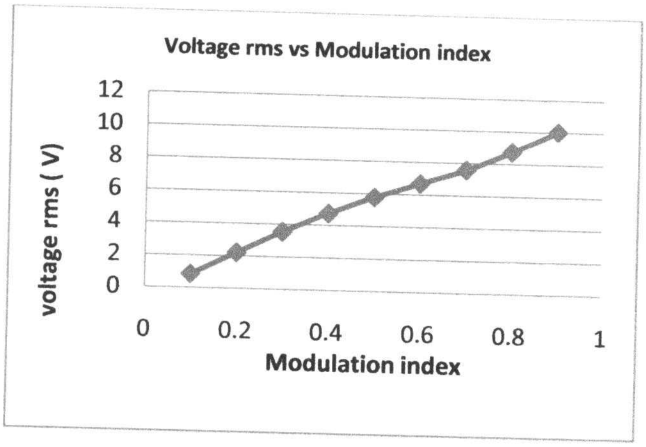


Fig 16: Simulation voltage rms vs modulation index for 3 kHz switching frequency

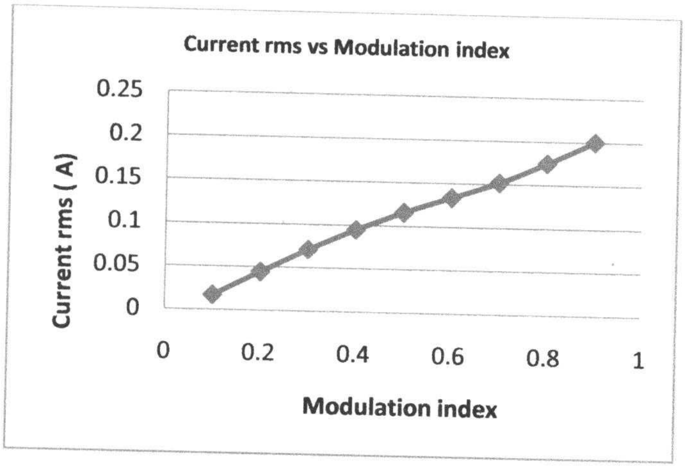


Fig 17: Simulation current rms vs modulation index for 3 kHz switching frequency

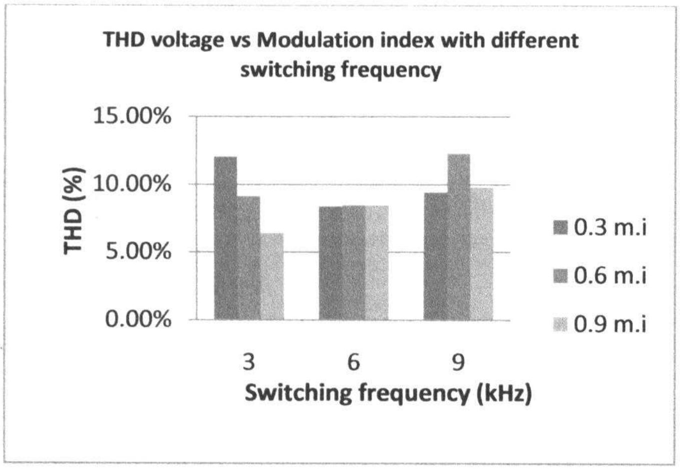


Fig 18: Variation of THD of output voltage versus modulation index, ma with different switching frequency for SPMC supplied by Vdc=20V loaded with resistive, R load 50 ohm with LC filter, L = 4mH and C= 10uF

VII. CONCLUSION

A safe commutation technique in SPMC is proposed with simple implementation. This commutation technique allows energy to flow during dead-time to avoid current spikes of non-ideal switch and at the same time establishing a current path for dissipation of energy stored in inductive load to avoid voltage spikes. An overview of various commutation technique of matrix converter by other researcher has also been briefly described.

A computer simulation model was then successfully developed using MATLAB Simulink (MLS) to investigate the behaviour of the proposed SPMC. Two different tools are used to ascertain its results, one to counter-confirm each other. This is then verified experimentally on a test-rig constructed in the laboratory.

The hardware implementation of the SPMC is described including overall system configuration, designation of digital control SPWM by using PIC and the power circuit. Voltage spikes due to inductive load has been successfully eliminated using the proposed safe-commutation strategies. It has also been shown MLS and experimental is an effective computer simulation model to predict the behaviour of SPMC. Tests have been carried out to show the effectiveness and flexibility of the proposed method.

RECOMMENDATION

i) Extend the operation of the SPMC as inverter with successful practical realization using IGBT as power switch complete with its associated safe-commutation technique.

ii) Develop the Sinusoidal Pulse Width Modulation (SPWM) used for control of the power switching devices in the SPMC to operate as an inverter complete with basic passive filter design.

iii) Improvement of PIC programming to control the power switching device with proper and reliable design.

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