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A novel matrix converter based single phase to three phase converter

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Abstract: *This paper presents a new approach for single phase AC to three phase AC power conversion using a Matrix Converter (MC). The MC chosen in this work is capable of providing a variable three phase output voltage from a fixed single phase input using single stage phase conversion principle. The implementation requires the use of solid state bidirectional switching cells. The performance of the phase converter is evaluated using MATLAB/SIMULINK for different loads. The complete description about the modes of operation of chosen phase converter is provided in this paper. Simulation results for three phase resistive, inductive and motor load fed by above phase converter are presented. The results validate the conversion strategy developed.*

Keywords. *Matrix Converter (MC), Single Phase To Three Phase Converter (SPTPC), Harmonics, Voltage transformation.*

1. Introduction

Use of balanced three phase AC mains allows for the most efficient and economical use of electrical power. In many instances the cost of providing three phase service to remote rural areas is prohibitive due to the higher installation cost of three phase extension. Therefore SPTPC is an excellent choice for situations where three phase power is not available. Proposed converter has a wide range of applications in which a three phase load is to be fed from available single phase source. Such applications include variety of forming equipments, fans, pumps, air conditioners etc. Another important application for SPTPC is in electric traction where three phase drive can be operated from single phase mains feeder. Consequently for feeding three phase loads from single phase source, single phase to three phase converter can be used and SPTPC's cost can be made a fraction of cost of providing three phase service. For this reason several phase conversion systems [1-4] have been developed and are widely in use.

Presently available phase converters can be broadly classified into three categories:

a) Rotary type converters wherein three phase alternator is coupled with single

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phase motor

b) Phase converters with passive components such as capacitors and inductors

c) Static converters wherein single phase AC is converted to DC and then to three phase AC using three phase inverter.

Categories (a) and (b) employ bulky magnetic components of considerable size and weight. Category (c) employs double stage conversion using static switches whereas strategy proposed in this work employs single stage direct conversion of single phase input to three phase output.

2. Phase Conversion Using MC

The single phase to three phase static converter proposed in this paper employing only three bidirectional switching cells for phase transformation possesses the following merits:

a) It allows for voltage control which helps in smooth starting of induction motor load (phase conversion with AC chopping technique).

b) It also helps in frequency control in turn employing constant V/F control.

c) The converter input current is nearly sinusoidal with approximate sinusoidal output current.

The basic phase converter configuration is shown in Fig.1(a).It can be operated in two modes:

a) 180^0 conduction mode

b) 120^0 conduction mode.

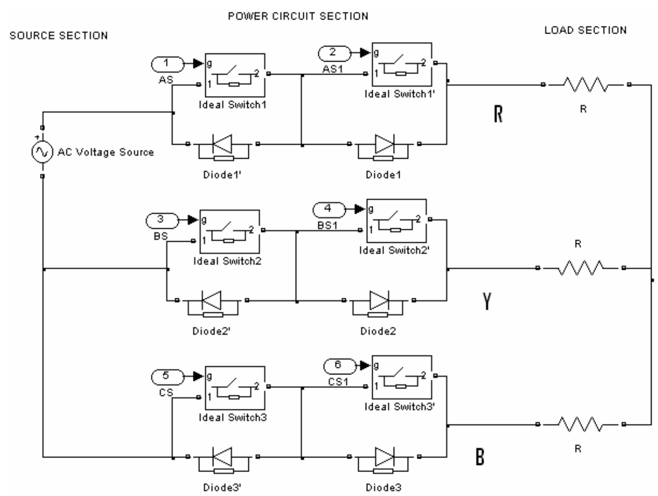

Fig.1 (a). Configuration of proposed single phase to three phase static power conversion system with resistive load

An attempt is made in this work to model and simulate MC based single phase to three phase static converter since literature survey does not report much work on this scheme of phase conversion.

To simply the simulation process, matrix converter, load, measurement block and gating pulse circuit are modeled as a subsystems in MATLAB/SIMULINK as shown in Fig.1(b)

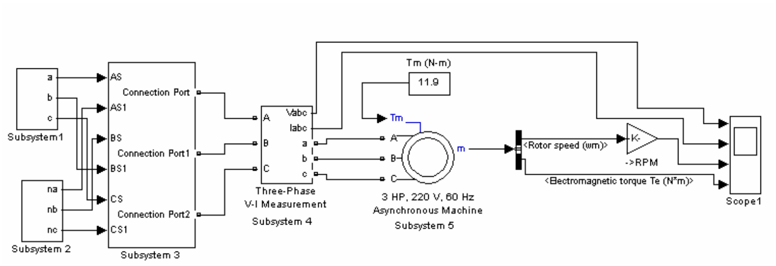

Fig.1 (b). SIMULINK model of MC with motor load

3. Analysis of matrix converter as phase converter

MC chosen in this work converts a single phase AC input voltage of amplitude V_i at supply frequency ω_i directly to three phase AC output voltage at either required amplitude V_o or frequency ω_o. It uses high frequency self commutated switching devices which are capable of conducting in both directions. The converter as the name indicates is a matrix of switching devices that permit the conversion of any input to any output and can be represented as,

[3*1]= [3*1] [1*1]
Z = X * Y

where

Y- Input voltage matrix
X- Switching matrix
Z- Output voltage matrix

The operation of the proposed converter is based on the principle that multiplication of [1*1] sinusoidal quantity (input voltage matrix) by a compatible set of [3*1] (converter switch matrix) yields a third set of [3*1] sinusoidal quantities (output voltage matrix). Therefore the analytical equation for converter output voltages [V_O (ω_O t)] and input current (I_i(ω $_i$t)] can be obtained from following equations:

$$[V_0(\omega_0 t)] = [F_d(\omega_s t)] * [V_i(\omega_i t)]$$

$$\begin{bmatrix} V_{0,1} \\ V_{0,2} \\ V_{0,3} \end{bmatrix} = A \begin{bmatrix} f_{1,1} \\ f_{2,1} \\ f_{3,1} \end{bmatrix} * V_i[\cos(\omega_i t)] = A \begin{bmatrix} \cos(\omega_s t) \\ \cos(\omega_s t - 120^\circ) \\ \cos(\omega_s t - 240^\circ) \end{bmatrix} * V_i[\cos(\omega_i t)]$$

$$[I_i(\omega_i t)] = [F_d(\omega_s t)]^T * [I_0(\omega_0 t)] = A[f_{1,1} \quad f_{2,1} \quad f_{3,1}] * \begin{bmatrix} I_{o,1} \\ I_{o,2} \\ I_{o,3} \end{bmatrix}$$

$$= A[\cos(\omega_s t)\cos(\omega_s t - 120)\cos(\omega_s t - 240)] * I_o \begin{bmatrix} \cos(\omega_0 t) \\ \cos(\omega_0 t - 120^o) \\ \cos(\omega_0 t - 240^o) \end{bmatrix}$$

$$= \frac{3AI_o}{2}[\cos(\omega_s - \omega_0)t] = \frac{3AI_o}{2}[\cos(\omega_i t)]$$

where $\omega_s = \omega_0 + \omega_i = 2\omega_i = 2\omega_0$

The respective switch on/off control strategy and the resulting output phase voltages both for 180^0 conduction mode and 120^0 conduction mode are shown in Figs.2(a) and (b), 3(a) and (b) and 4(a) and (b).

The essential information regarding the transfer characteristics of the proposed single stage SPTPMC can be obtained by simulation using MATLAB/SIMULINK model developed for different types of load both for 180^0 and 120^0 conduction modes.

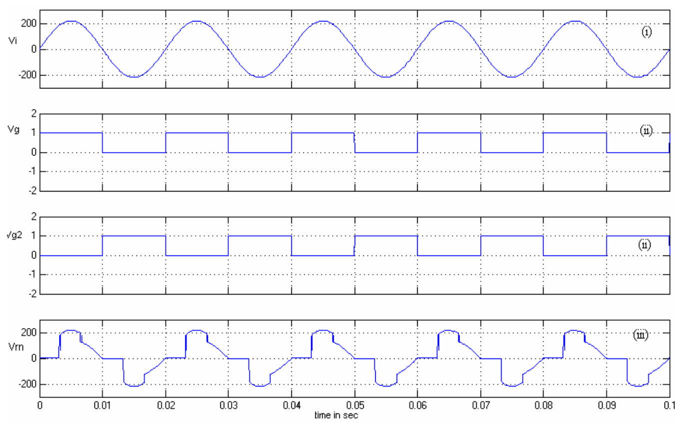

Fig.2 (a). Waveforms describing operation of single phase to three phase converter for 180 degree mode (i) Single phase input voltage (ii) Converter switching function $f_{1,1}$ (iii) Resultant output phase voltage V_{RN}

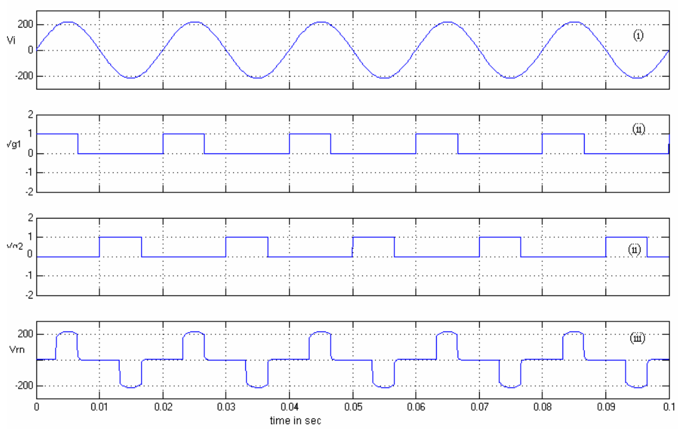

Fig.2 (b). Waveforms describing operation of single phase to three phase converter for 120 degree mode (i) Single phase input voltage (ii) Converter switching function $f_{1,1}$ (iii) Resultant output phase voltage V_{RN}

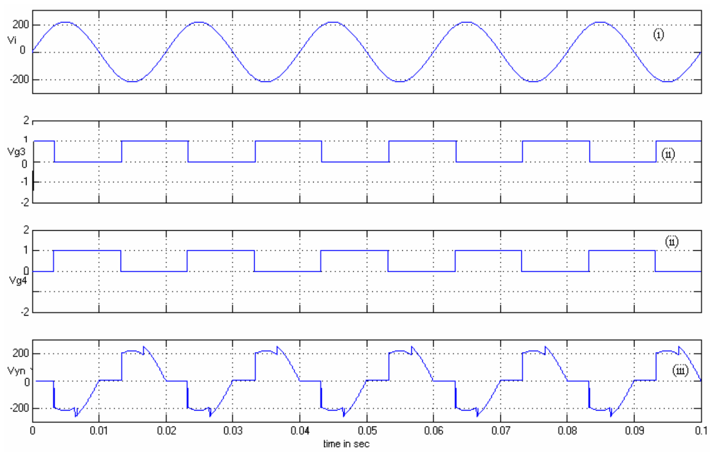

Fig.3 (a). Waveforms describing operation of single phase to three phase converter for 180 degree (i) Single phase input voltage (ii)Converter switching function $f_{2,1}$ (iii)Resultant output phase voltage V_{YN}

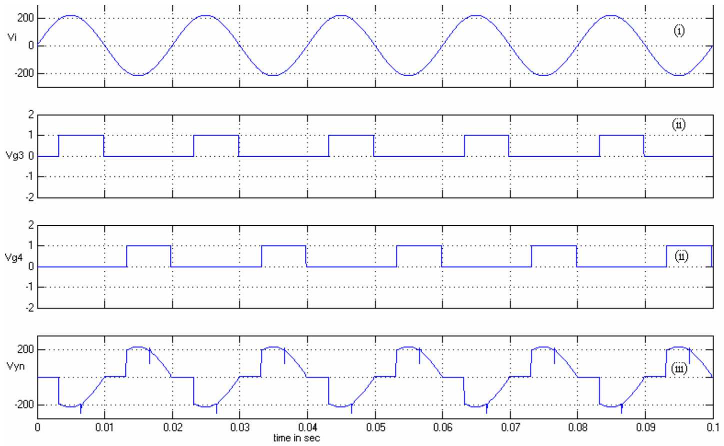

Fig.3 (b). Waveforms describing operation of single phase to three phase converter for 120 degree mode (i) Single phase input voltage (ii)Converter switching function $f_{2,1}$ (iii) Resultant output phase voltage V_{YN}

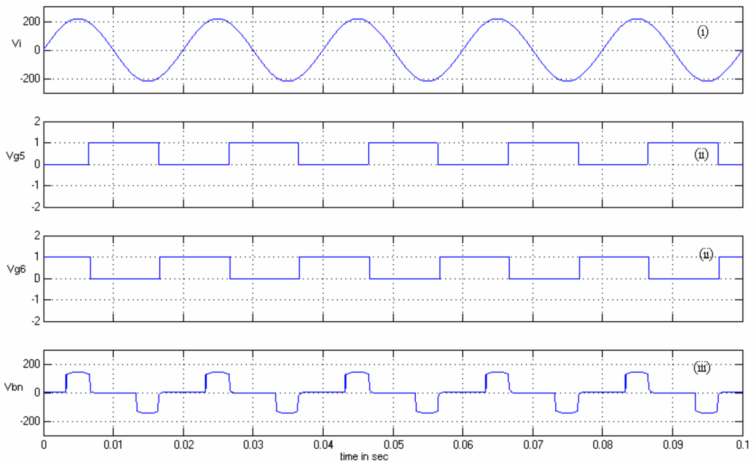

Fig.4 (a). Waveforms describing operation of single phase to three phase converter for 180 degree mode (i) Single phase input voltage (ii)Converter switching function $f_{3,1}$ (iii) Resultant output phase voltage V_{BN}

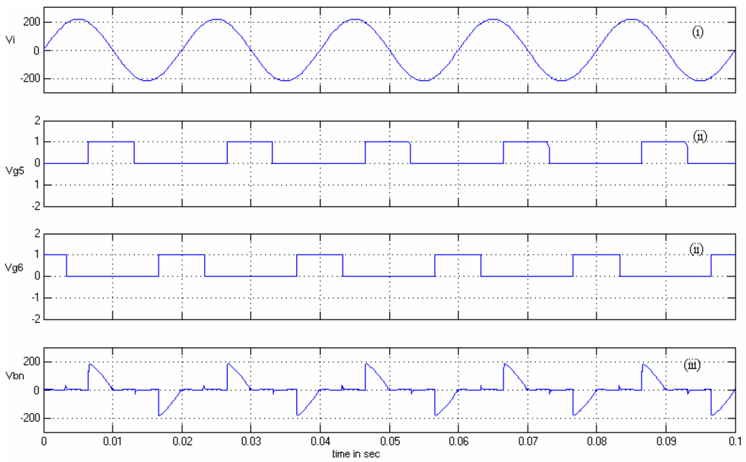

Fig. 4 (b). Waveforms describing operation of single phase to three phase converter for 120 degree mode (i) Single phase input voltage (ii) Converter switching function $f_{3,1}$ (iii) Resultant output phase voltage V_{BN}

4. Gating Logic

It is essential to generate six gating signals for three bidirectional switching cells corresponding to three phase output of the SPTPC i.e two gating signals for each bidirectional switch cell. These gating signals can be pulses of either 180^0 duration or 120^0 duration resulting in two modes of operation. The six gating pulses for each mode of operation are shown in Fig.5(a) and (b). These gating pulses are produced by simple logic circuit elements. These gating pulses can be applied directly to the gates of appropriate bidirectional switching cell through opto isolators. Simulation has been carried out with different types of loads using MATLAB/SIMULINK model. Voltage control, if required can be achieved by introducing notches either in the beginning or middle or end of these pulses. This results in reduction of pulse duration. The gating signal waveforms for six switches of SPTPC operating in 180^0 and 120^0 conduction modes can be suitably generated through logic circuits for reduced pulse duration also.

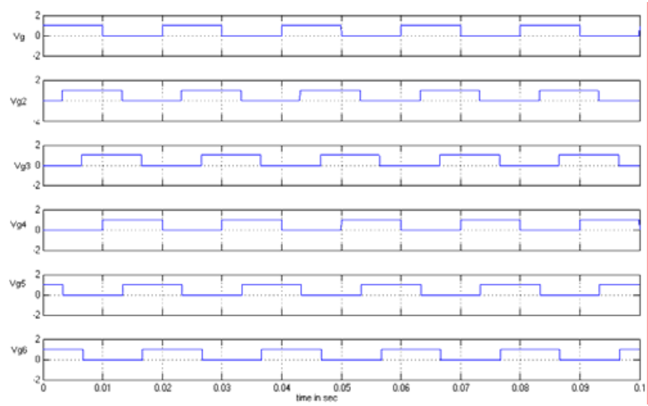

Fig. 5 (a). Gating pulses for 180° conduction mode of operation

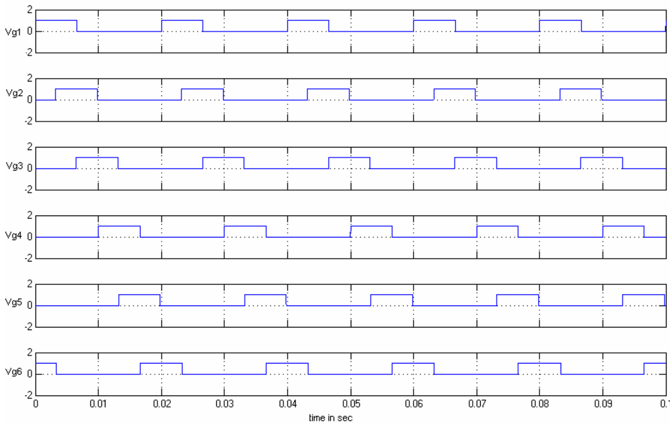

Fig. 5 (b). Gating pulses for 120° conduction mode of operation

5. Simulation Results

To demonstrate the feasibility of the proposed converter, the results are obtained through simulation for different types of loads. The output voltage and current waveforms and frequency spectrum of output voltage of R phase for resistive load are presented in Figs.6 and 7 respectively for 180 ^{0}and 120^0 mode of operation. Similarly the results obtained by simulation for inductive load is presented in Figs. 8 and 9.

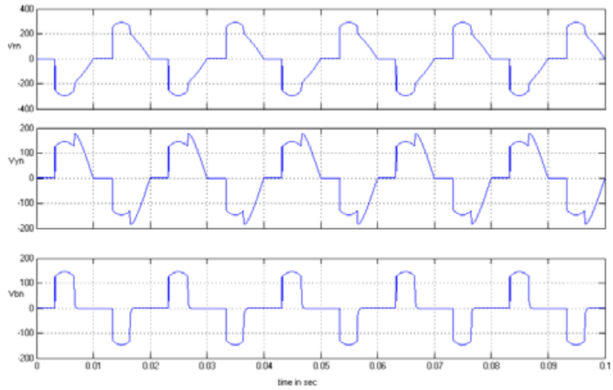

Fig.6 (a). Voltage waveform for all three phases of SPTPC feeding R load (R=100 Ω) without filter under 180° conduction mode

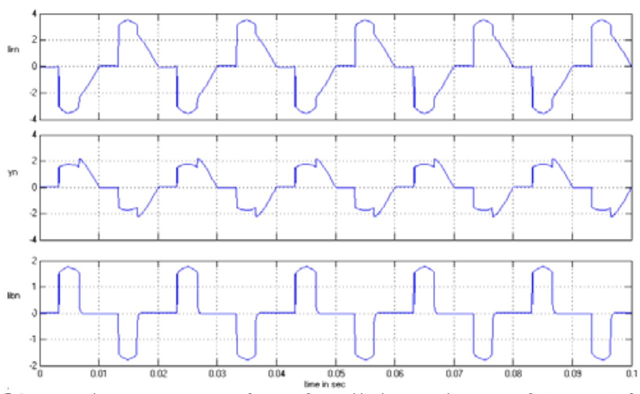

Fig.6(b). Load current waveform for all three phases of SPTPC feeding load without filter under 180° conduction mode

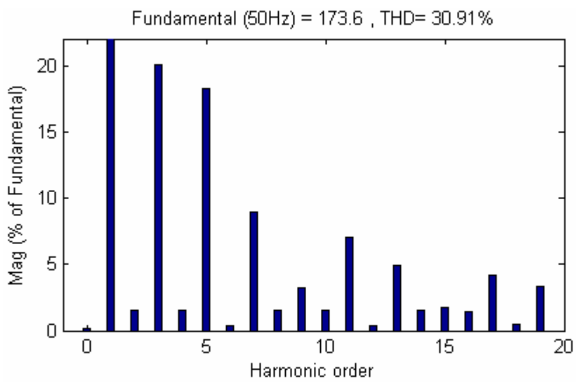

Fig.6 (c). Frequency spectrum of load voltage of R phase for 180^0 mode (R load)

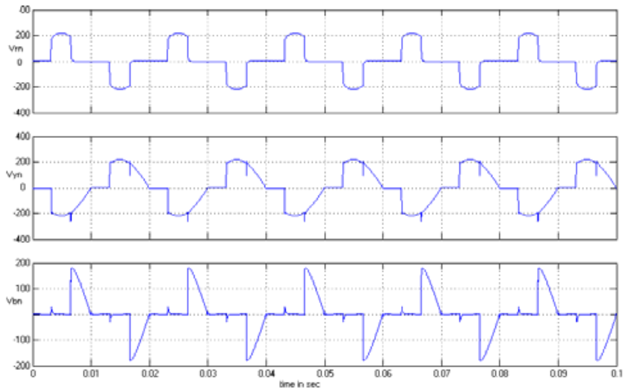

Fig.7 (a). Voltage waveform for all three phases of SPTPC feeding resistive load (R=100 Ω) without filter 120° conduction mode

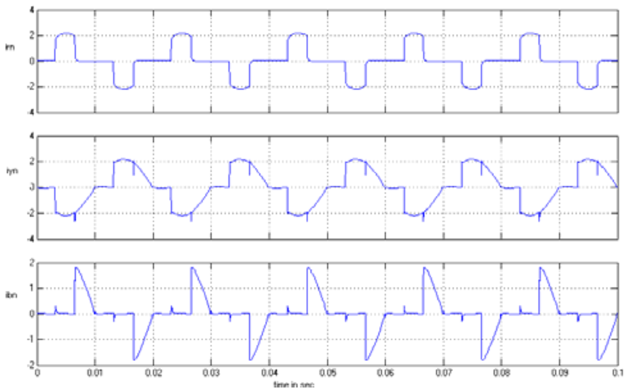

Fig. 7(b). Load current waveform for all three phases of SPTPC feeding resistive load without filter under 120° conduction mode

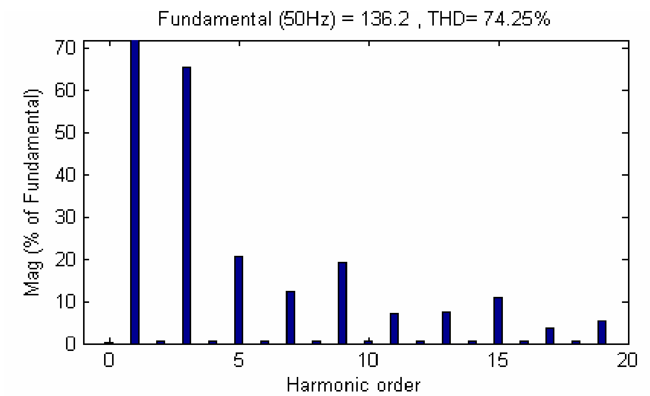

Fig.7 (c). Frequency spectrum of load voltage of R phase for 120^0 mode (R load)

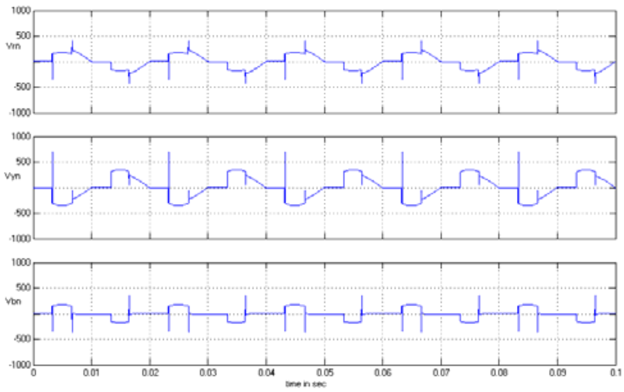

Fig.8 (a). Voltage waveform for all three phases of SPTPC feeding inductive load (R=100 Ω, L=1mH) without filter under 180° conduction mode

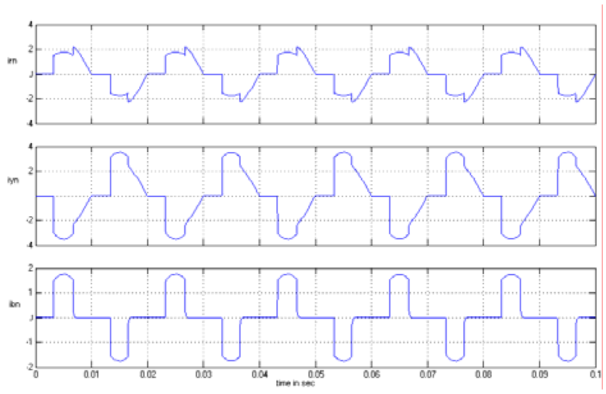

Fig.8 (b). Load current waveform for all three phases of SPTPC feeding inductive load (R=100 Ω , L=1mH) without filter under 180° conduction mode

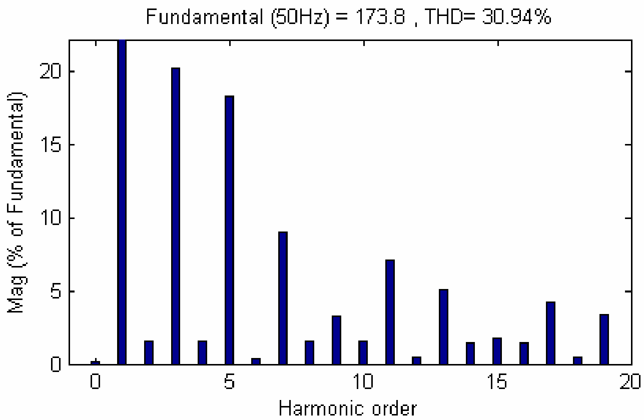

Fig.8 (c). Frequency spectrum of load voltage of R phase for 180^0 mode (Inductive load)

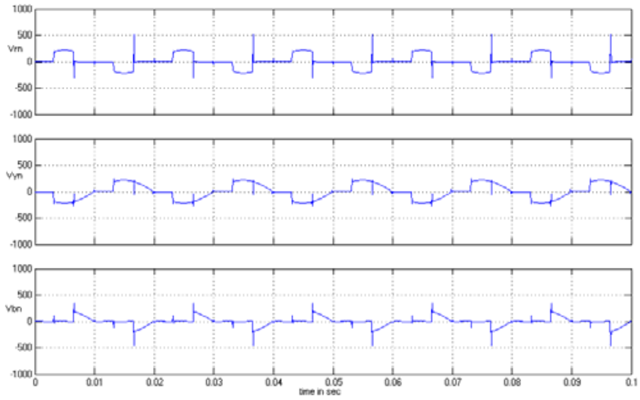

Fig.9 (a) . Voltage waveform for all three phases of SPTPC feeding inductive load (R=100 Ω, L=1mH) load without filter under 120° conduction mode

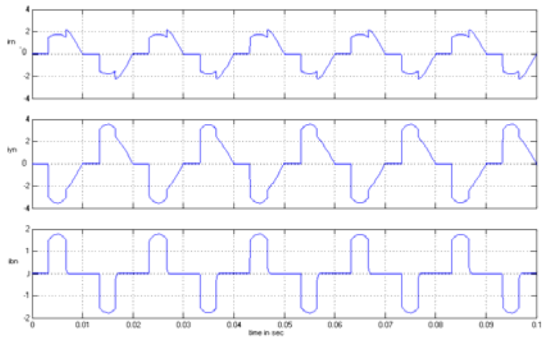

Fig. 9 (b). Load current waveform for all three phases of SPTPC feeding inductive load under 120° conduction mode

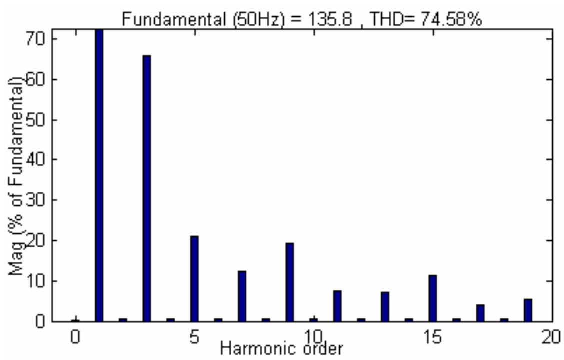

Fig.9 (c). Frequency spectrum of load voltage of R phase for 120^0 mode (inductive load)

Simulation is also carried out with three phase induction motor load with the following parameters:

Stator winding

$R1 = 1.115\Omega$; $L1 = 0.005974H$

Rotor winding

$R2 = 1.083\ \Omega$; $L2 = 0.005974H$

Magnetizing inductance L_m=0.2037H

Inertia constant = 0.02 J/kgm^2

Damping constant = 0.005752Nms ;

No. of poles = 4

Using these parameters and SIMULINK model of three phase induction motor, simulation is carried out .The phase voltages, currents, speed and spectrum of load voltage of R phase of motor are obtained for 180^0 mode of operation as shown in Figs.10 (a)-(d).

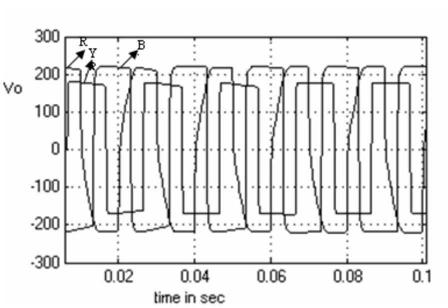

Fig.10 (a). Voltage waveform for all three phases of SPTPC feeding motor load without filter under 180° conduction mode

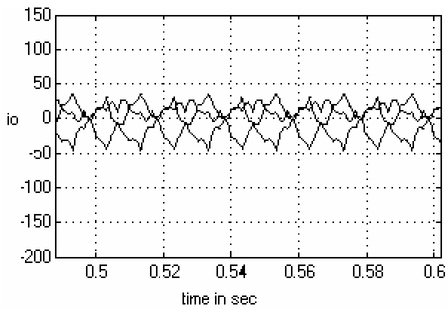

Fig.10 (b). Load current waveform for all three phases of SPTPC feeding motor load without filter under 180° conduction mode

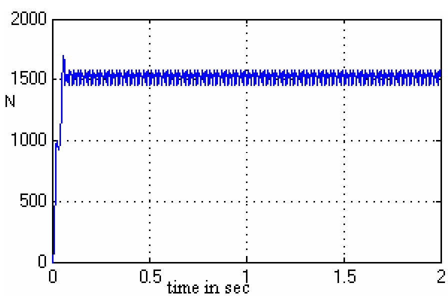

Fig. 10(c). Speed of motor for 180^0 mode

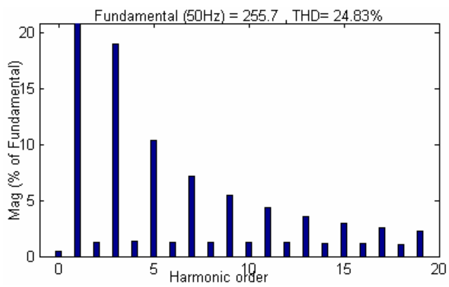

Fig.10 (d). Frequency spectrum of load voltage of R phase for 180^0 mode (motor load)

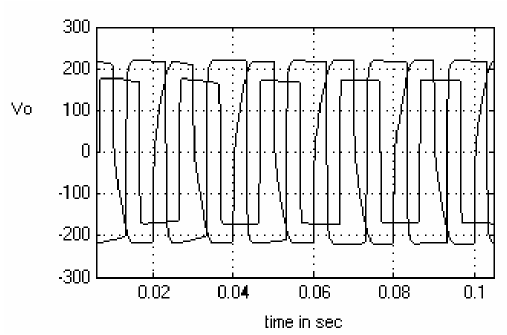

Fig.11 (a). Voltage waveform for all three phases of SPTPC feeding motor load without filter under 120°conduction mode

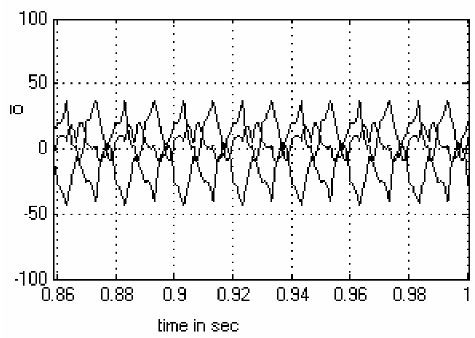

Fig.11 (b). Load current waveform for all three phases of SPTPC feeding motor load without filter under 120° conduction mode

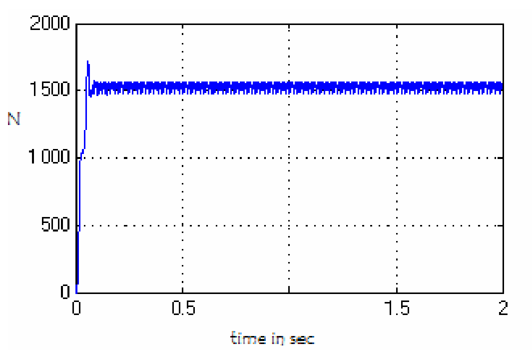

Fig.11 (c). Speed of motor for 120^0 mode

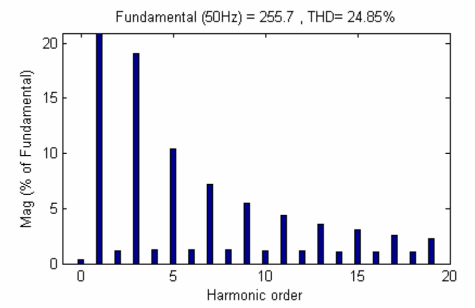

Fig.11 (d). Frequency spectrum of load voltage of R phase with motor load for 120^0 mode

The corresponding simulated output voltage, output current waveform, speed and spectrum of load voltage of R phase for motor load are shown in Figs.11(a)-(d) for 120^0 mode of operation. The recommended mode of operation is 180^0 in the view of lower THD.

6. Conclusion

Analysis of phase conversion technique for providing three phase power from existing single phase mains has been presented in this paper incorporating 1800 and 1200 conduction modes. The proposed converter provides almost balanced three phase output which can be confirmed from simulation results developed. The simple control logic circuits developed make the proposed converter highly attractive for real time applications.

The simulation results obtained using MATLAB/SIMULINK models prove the validity of two modes of operation which can also be implemented in real time. Simulation results show that the THD is lesser with 1800 mode of operation both for R and R-L loads but with motor load the frequency spectrum is found to be same for both the modes.

7. References

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