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DIRECT AC TO AC CONVERTER WITH VARIABLE FREQUENCY SINUSOIDAL CURRENTS FOR APPLICATION TO GRID CONNECTED WIND GENERATORS

***TC Subramanyam, #TC Srinivasarao**
**Electrical & Electronics Engineering Dept., Bharat Institute of Engineering &Technology (BIET), Mangalpally, Ibrahimpatnam,RR district, Hyderabad,AP,INDIA 501 510*
#Electrical & Electronics Engineering Dept.,Vardhaman College of Engineering,Kacharam(v),Shamshabad,Hyderabad,AP,INDIA

ABSTRACT

AC to AC Matrix Converter having a nine switch topology with hysteresis controller is analyzed in this paper using MATLAB/SIMULINK package. A Matrix Converter with 18 IGBTs and 18 diodes achieves the desired variable voltage, variable frequency performance using a two stage circuit. In the first stage three phase normal frequency voltage is converted to single phase high frequency voltage. In second stage three phase variable amplitude variable frequency voltage is generated. Hysteresis controller is implemented to obtain sinusoidal output current.In this paper output frequency realized is 50 Hz. It is possible to set the output to any other frequencyalso.
Index Terms— *Matrix Converter, Hystersis Controller, SPWM, IGBTs*

INTRODUCTION

The oil crisis in the early 70's and the steadily increasing environmental concern have initiated a major interest for the exploitation of renewable sources of energy for the generation of electrical power. Most promising among them appear to be the wind package is used and, at a second level, the solar energy. The main characteristic of these sources, compared with the conventional ones, is that the primary energy flow is stochastic in nature and thus uncontrolled and continuously fluctuating, which is particularly true for the wind. Therefore, special schemes and control procedures have to be developed and implemented for the regulation of the produced electrical power and the maximization of the capture of the available energy. With the recent developments in the power electronics, low-cost, high-reliability and efficiency converters are available for wind turbine applications. The utilization of advanced power conversion schemes and sophisticated controllers presents an increasing interest, since it improves the energy production and the quality of operation of theplants.

Direct AC to AC power conversion without the use of intermediate energy storage [1] is achieved by a Matrix Converter (MC) for connection to grid with input as wind turbine generator shown in fig 1. The absence of energy storage devices makes the Matrix Converters to be compact and permits them to be readily integrated into drive systems as opposed to traditional ac to ac converters which are usually bulky. The static AC to AC Matrix Converters use a four out put leg topology in order to eliminate the need for DC link capacitors. Recently there has been considerable interest in the Matrix Converter technology due to the potential benefits it offers especially in applications where size, weight, and long-term reliability are important factors . Since there is no need for stored energy in the Matrix Converter the potential drop at high power densities is absent as is the case with many existing solutions. This Converter is also inherently bidirectional,soitcanregenerateenergybacktotheutility[2].InspiteofalltherewardsofusingMCina motor drive system, it has major disadvantage is that the output voltage of a MC is limited to 86% of the input.

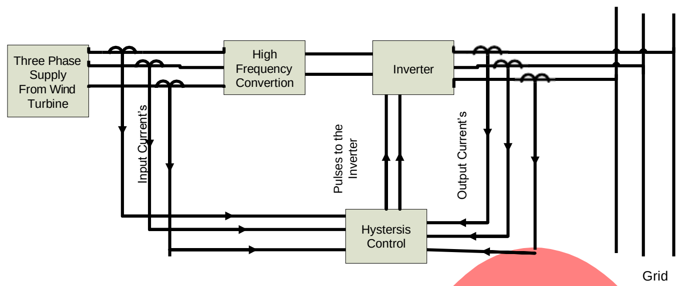


Fig 1 Block Diagram of Matrix Converter with Hysteresis Controller

This paper investigates the performance of the direct AC to AC converter in high frequency applications. The role of high frequency link is analyzed since this type of link provides galvanic isolation and also acts as a power conditioner in some of the typical applications. Detailed simulation has been carried out with hysteresis controller to achieve sinusoidal output current.

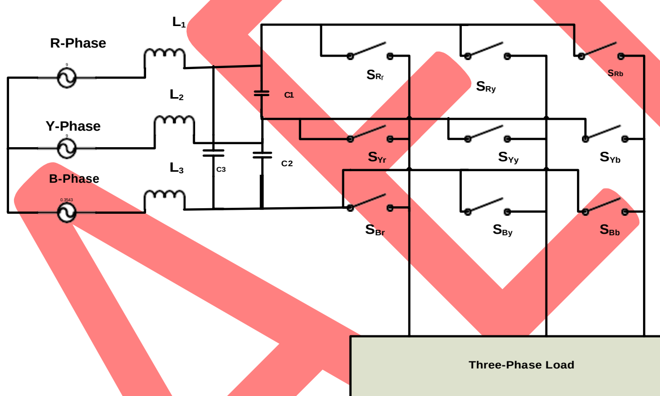


Fig. 2 Matrix Converter Overview

MATRIX CONVERTER

Fig 2 shows a schematic diagram of a three phase to three-phase Matrix Converter (MC), for which inputs and outputs are v_a, v_b, v_c and i_A,i_B,i_C respectively. The switching relationship between the input and output is givenby:

$$S_{Kj} = \begin{cases} 1, \ switch S_{Kj} closed \\ 0, \ switch S_{Kj} open \end{cases} \quad (1)$$

Where K= {A,B,C}, j={a,b,c}, and

$$S_{Ka}+S_{Kb}+S_{Kc}=1 \quad (2)$$

The relationship between input and output instantaneous phase voltages is *given by*:

(3)

$$\begin{bmatrix} V_R \\ V_Y \\ V_B \end{bmatrix} = \begin{bmatrix} S_{Rr} & S_{Ry} & S_{Rb} \\ S_{Yr} & S_{Yy} & S_{Yb} \\ S_{Br} & S_{By} & S_{Bb} \end{bmatrix} \begin{bmatrix} v_r \\ v_y \\ v_b \end{bmatrix} \qquad (3)$$

Where V_R,V_Y,V_B (vr,vy,vb) are the output (input) voltage.Basedon above equation (3), line to line voltages and phase currents at the output (input) terminals are givenby

$$\begin{bmatrix} V_{RY} \\ V_{YB} \\ V_{BR} \end{bmatrix} = \begin{bmatrix} S_{Rr}-S_{Yr} & S_{Ry}-S_{Yy} & S_{Rb}-S_{Yb} \\ S_{Yr}-S_{Br} & S_{Yy}-S_{By} & S_{Yb}-S_{Bb} \\ S_{Br}-S_{Rr} & S_{By}-S_{Ry} & S_{Bb}-S_{Rb} \end{bmatrix} \begin{bmatrix} v_r \\ v_y \\ v_b \end{bmatrix} \qquad (4)$$

$$\begin{bmatrix} i_r \\ i_y \\ i_b \end{bmatrix} = \begin{bmatrix} S_{Rr} & S_{Yr} & S_{Br} \\ S_{Ry} & S_{Yy} & S_{By} \\ S_{Rb} & S_{Yb} & S_{Bb} \end{bmatrix} \begin{bmatrix} I_R \\ I_Y \\ I_B \end{bmatrix} \qquad (5)$$

Where V_{RY},V_{YB},V_{BR} (I_R,I_Y,I_B) are the output instantaneous voltage (currents), and i_r,i_y,i_b are the instantaneous phase currents.

THE PROPOSED CONVERTER AND ITS CONTROL

In this paper, high frequency converter topology is proposed.
It consists of the following two power conversion stages.

i). Primary converter:- In this stage fixed frequency utility three phase supply to high frequency single phase conversion isdeveloped.

ii). Secondary converter:- In this stage high frequency single phase to three phase variable voltage-variable frequency converter stage isdeveloped.

Usingprimaryconverterandsecondaryconverters,threephasenormalfrequencyandnormalvoltagecanbe converted into three phase variable voltage variable frequency by using 18 IGBTs and 18 diodes as shown infig3.IneachbidirectionalswitchtwoIGBT's&twodiodesareconnectedinantiparalleldirection.
Primary converter consists of sixbidirectional
switches and secondary converter consists of ten unidirectional switches

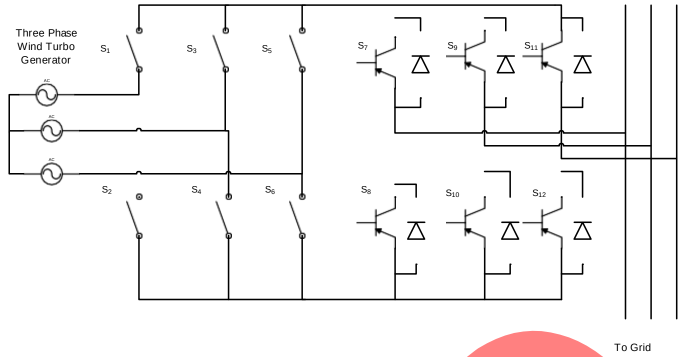


Fig 3 Matrix Converter-Variable Voltage & Frequency

In the secondary converter , switches S_7 to S_{10} are made used for full bridge rectification and S_{11} to S_{16} are used for DC to three phase AC conversion.

ANALYSIS OF PRIMARY CONVERTER

This primary converter is used to convert normal utility three phase supply voltage which is having fixed frequency to high frequency single phase pulses. This can be achieved by chopping the input voltage in a predetermined manner. The control method is based on the detection of maximum conducting phases for generation of modulation signal. Consider the following balanced set of 3 phase input voltages as shown in the formulae given below.

$$V_r=V_m\sin(2\pi f_{in}t) \qquad (6)$$

$$V_y=V_m\sin(2\pi f_{in}t-2\pi/3) \qquad (7)$$

$$V_b=V_m\sin(2\pi f_{in}t+2\pi/3) \qquad (8)$$

Where V_m is the maximum value of input phase voltage and
f_{in} is the supply frequency of source.

Initially study the three phase waveforms for one complete cycle (or) 360^0 and then it can be divided into the six equal parts as shown in the figure 7.

In these six sectors, in each sector one phase can be taken as reference and in the remaining other two phases one phase is increasing from 0^0 to 60^0, the second phase is decreasing from 60^0 to 0^0 .For example, let us consider Y phase as a reference phase, then from R phase and B phase's positive & negative cycles can be obtained as given in(9).

$$V_y=V_r+V_b \qquad (9)$$

For sector I, for constructing the positive pulses across the transformer switch S_{yn} is turned on for a period $T_{sw}/2$, while S_{rn}& S_{bn} are modulated while all other switches are remain off position. The duty ratio for the switches is calculated as given below.

$$D_r = \frac{|v_r|}{\max(|v_r|,|v_y|,|v_b|)} \quad (10) \qquad D_y = \frac{|v_y|}{\max(|v_r|,|v_y|,|v_b|)} \quad (11)$$

$$D_b = \frac{|v_b|}{\max(|v_r|,|v_y|,|v_b|)} \quad (12)$$ &output DC voltage is equated as $V_{dc}=(D_b(V_y-V_b)+D_r(V_y-V_r))$ (13)

Negative part of the high frequency wave is generated by forcing S_{yn} to off condition and S_{yp} to turn on for a next period of T_{sw} / 2. The switches S_{bn} and S_{rn} are modulated for this period T_{sw} / 2.Hence this converter can be considered as a forced commutated cycloconverter and its implementation is possible due to availability of semiconductors as IGBTS, MCTS etc. Similarly the whole sequence of generation of high frequency pulses and conduction of bidirectional switches can be tabulated [8-12] as given in table 1.

Table 1 switching sequence for high frequency conversion

S.No	Reference Phase	Positive Cycle	Negative Cycle
1	Negative Y Phase	S_3,S_6	S_4,S_1
2	Positive R Phase	S_1,S_4	S_2,S_5
3	Negative B Phase	S_5,S_2	S_6,S_3
4	Positive Y Phase	S_4,S_1	S_3,S_6
5	Negative R Phase	S_2,S_5	S_1,S_4
6	Positive B Phase	S_6,S_3	S_5,S_2

In the first sector I, for positive half cycle switches S3 & S6 conducts, all other four switches are in off condition and power flows from S3 to S6 as shown in fig 4. In this case the duty cycle can be taken as 50% of the total time period .In the

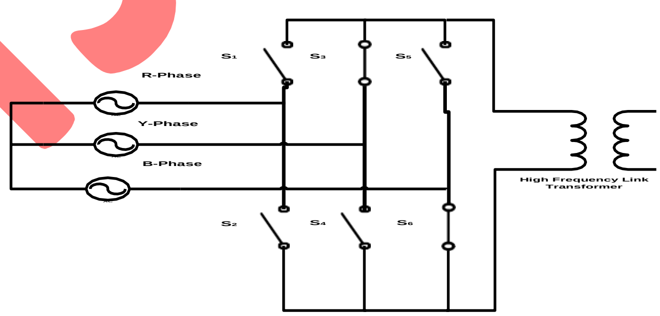


Fig 4 High Frequency Positive Conducting Cycle - Sector I

negative half cycle for the sector 1, switches S4 & S1 conduct, all other switches are in off condition as shown in fig 5. In this case also the duty cycle will be the remaining 50% of the total time period

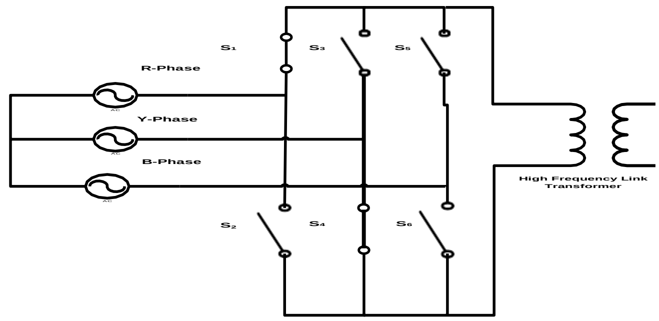


Fig. 5 High Frequency Negative Conducting Cycle- Sector I

ANALYSIS OF SECONDARY CONVERTER

The main purpose of this converter is to provide variable voltage, variable frequency from the single phase high frequency. In this secondary converter 6 unidirectional switches S7 to S12 are used for the inversion.

Here SPWM is used to convert Pulsating DC to AC, in each case three switches can be operating at a time one from positive and two from negative or vice versa as mentioned in the table 2.

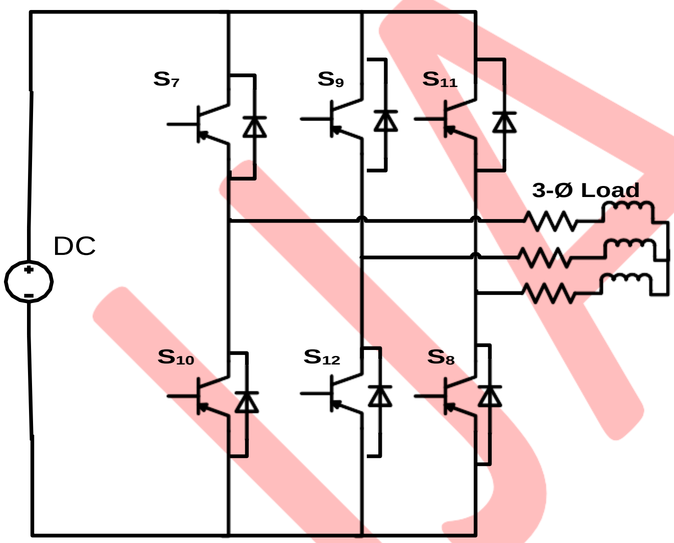


Fig 6 Circuit Diagram of Inversion

Table 2 Inverter Switching States

Switch Condition	State No	V_{ab}	V_{bc}	V_{ca}
S_7,S_{11} and S_{12} are on and S_{10},S_8 and S_9 are off	1	Vi	0	-Vi
S_8,S_9 and S_7 are on and S_{11},S_{12} and $S_{10}$are off	2	0	Vi	-Vi
S_9,S_7 and S_8 are on	3	-Vi	Vi	0

and S_{12},S_{10} and S_{11} are off				
S_{10},S_8 and S_9 are on and S_{15},S_{11} and S_{16} are off	4	-Vi	0	Vi
S_{12},S_{10} and S_{11} are on and S_9,S_7 and S_8 are off	5	0	-Vi	Vi
S_{12},S_{10} and S_{11} are on and S_9,S_7 and S_8 are off	6	Vi	-Vi	0
S_7,S_9 and S_{11} are on and S_8,S_{10} and $S_{12}$are off	7	0	0	0
S_8,S_{10} and S_{12} are on and S_7,S_9 and S_{11} are off	8	0	0	0

Out of eight switching states only six switching states are useful for getting required output , the other two switching states 7and 8 are not useful for inversion because in 7^{th} switching state as shown in the table 2 only upper case switches are conducting and in 8^{th} switching state only lower case switches are conducting so that it does not provide closed path in fig 6.

SIMULATION RESULTS

In this Matrix Converter SPWM technique with Hysteresis Controller is used. In this Hysteresis Controller, the output current wave is compared with the input current sine wave and then it is compared with upper and lower hysteresis bands to obtain required pluses to the inverter and hence to achieve sinusoidal current waveform. The performance of this Matrix Converter has been demonstrated by simulations using Mat lab /Simulink. The wave forms of high frequency voltage, input current & output current waveforms are shown in the fig 8, fig 9,fig 10respectively

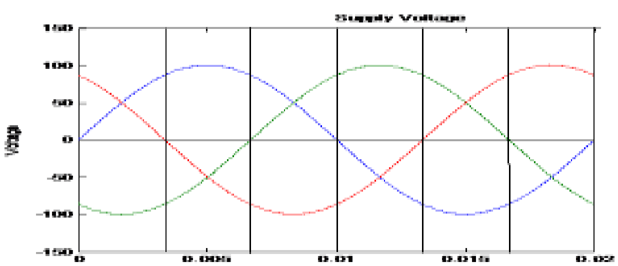
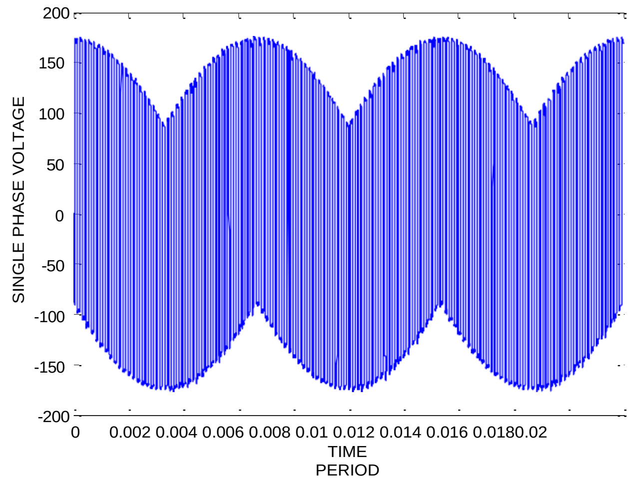


Fig 7Three Phase Input Supply voltage Wave Form



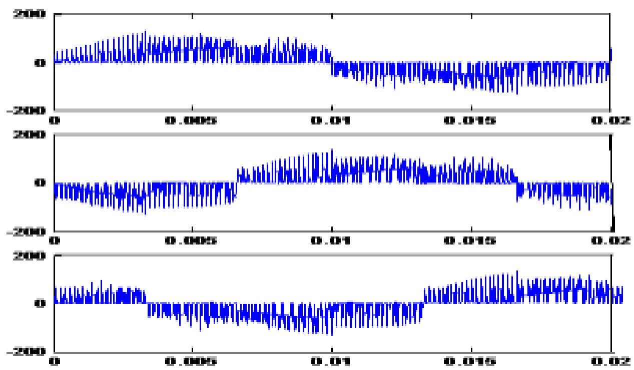


Fig 9 Input Current Wave forms

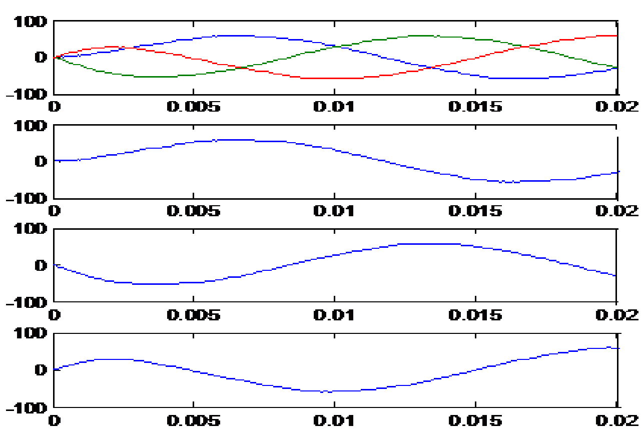


Fig 10 Output Current Waveforms

CONCLUSION

Direct AC to AC Converter with Variable Frequency Sinusoidal input/output currents is achieved. This scheme of AC/AC converter is well suited in case of a windmill prime mover connected to an alternator. Wind mill speed is continuously changes depend on the wind speed and the volume of wind displaced by wind mill. Through this scheme as inter face wind mill power can fed to power system grid. Grid Connected Wind Generators is achieved without dc stage (no storage elements) with HysteresisController.

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