Digitally Controlled Switch Mode Power Supply Based on Matrix Converter

S. Anu

First year, M.E. Power Electronics and Drives Department of Electrical & Electronics Engineering
Maria College of Engineering and Technology,Marthandam, Kanyakumari District, Tamil Nadu, India
E-mail: anu.pmks@gmail.co

Abstract - **In this paper, a switch mode power supply based on matrix converter is proposed for telecommunication applications. The conventional high power switch mode power supply consists of an AC/DC conversion with boost converter followed by a DC/DC converter to produce dc voltage. These rectifiers draw significant harmonic current from the utility, resulting in poor input power factor with high total harmonic distortion (THD). The proposed AC-AC system is an effective replacement of the conventional system which employs two-step power conversion. In the proposed approach, the matrix converter directly converts the low frequency (50 Hz, three phases) input to a high frequency (10 kHz, single phase) ac output without a dc-link. The output of the matrix converter is then processed via a high frequency isolation transformer to produce dc voltage. Control of the system ensures that output voltage is regulated and input currents are of high quality. The matrix converter forms an attractive topology of power converter for high power applications where factors such as absence of electrolytic capacitors, potentiality of increasing power density, reducing size and weight, good input power quality are fundamental. The proposed method is verified using Simulink toolbox of MATLAB 7.2 version.**

Keywords: **Matrix converter, Three-phase switch mode rectifier, Total harmonic distortion (THD)**

I. INTRODUCTION

With the ever increasing appetite for energy consumption, there has been an increase in the need for power electronic converters and, in particular, switch-mode power supplies (SMPS) /switching converters. The matrix converter is a force commutated converter; also it is simple in structure and has powerful controllability. The introduction of power transistors for implementing the bidirectional switches made the matrix converter topology more attractive. The power circuit of matrix converter is represented as the matrix of bidirectional power switches and hence introduced the name as the matrix converter. In case of TV set, Telecommunication system and on almost every occasion when electrical energy is converted to mechanical energy, the need for power electronic converters forms the necessary one. In Telecommunication system applications require several rectifiers in parallel to obtain higher current dc output at 48 V_{dc}. Commercially available Telecommunication systems employ ac/dc conversion stage with a boost converter, followed by a high frequency dc/dc converter to produce 48 V_{dc} (Fig. 2). This type of rectifier draws significant fifth and seventh order harmonic currents resulting in nearly 40% total harmonic distortion (THD). In addition, the rectifier dc-link capacitor stage is bulky, contributes to weight and volume. Furthermore, the presence of multiple power conversion stages contributes to lower efficiency.

In response to these concerns, this paper proposes a unity power factor switch mode power supply based on matrix converter for high power Telecommunication system applications (Fig.2). Matrix converter topology employs six bidirectional switches to convert low frequency (50 Hz) three-phase input directly to a high frequency (10 kHz) single-phase output [1]. The output is then processed via a high frequency isolation transformer and rectified to 48 V_{dc}. Control of the matrix converter stage ensures that the output voltage is regulated against load changes as well as input supply variations while maintaining sinusoidal input current shape at near unity power factor.

Advantages of the proposed topology are

* No dc-link capacitor required;

* Capable of operation over a wide input voltage range;

* Lower Total Harmonic Distortion in the line current;

* Proper switching modulation results in small input filter;

* Unity input power factor over the wide load range

* Higher efficiency with the increased power density;

* Enable parallel operation of several stages, implementation of complex closed loop control function.

II. CONVENTIONAL SWITCH MODE POWER SUPPLY

The power AC-DC-AC converter for conventional switch mode power supply can be separated into two units: One is AC-DC unit, that is a diode bridge rectifier with a boost converter and the other is DC-AC unit that is an MOSFET inverter with a dc voltage link as shown in fig.1. The DC link in any AC-DC-AC converter is normally equipped with an electrolytic capacitor, which provides decoupling between the rectifier and the inverter, so that the two converters can be driven independently. However, the DC link capacitor is a large, heavy, and expensive component.

The dc-link capacitor forms a critical component, especially in high-power (or) high-voltage source applications. Since it is large and expensive, it has limited lifetime, in addition to this it is temperature sensitive and the control of the system becomes complex. The source-side inductor becomes burden to the system.
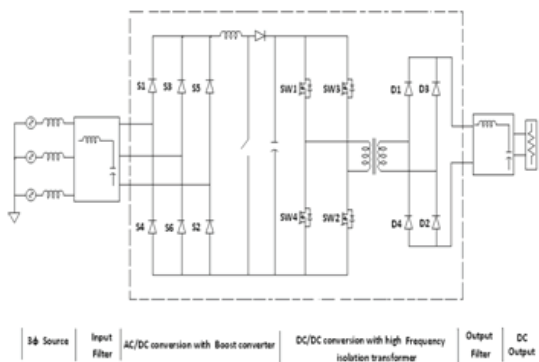

Fig.1 Conventional Telecommunication Switch Mode Power Supply

The quality of the system get affected since this type of rectifier draws significant fifth and seventh order harmonic currents resulting in nearly 40% total harmonic distortion (THD). It becomes a significant problem at increased power levels because the harmonic distortion is injected to the mains and cause power losses. In addition, the rectifier dc-link capacitor stage is bulky, contributes to weight and volume causing security issues. Furthermore, the presence of multiple power conversion stages contributes to lower efficiency; their size is usually 20%–40% of the system size, if the switching frequency of several kilohertz is assumed. This drawback has been removed in the proposed method.

III. MATRIX CONVERTER

The introduction of power transistors for implementing the bidirectional switches made the matrix converter topology more attractive. A Matrix Converter consists of bi-directional switches, which are required to be commutated in the right way and sequence, in order to minimize losses and produce the desired output with a high quality input and output waveforms. Matrix Converter provided the possibility of generating alternating currents of variable frequency directly from a fixed frequency AC supply, the positive rectifier supplying the positive half cycles of current and the negative rectifier providing the negative half cycles of current. This system was called cycloconverter at its early stage and this proved to be so appropriate that nowadays it is still used in some high power applications because of high power requirements and the Matrix Converter technology is still not available widely [4], [5]. Moreover, most of the industrial applications require frequencies in the range of 50Hz - 60Hz, which is easily obtained by the cycloconverter. For a three-phase to three-phase cycloconverter, 36 thyristors are required. This makes the cycloconverter systems large and complicated which tends to be used in applications where high power is required.

Matrix Converters were first mentioned in the early 1980's by Alesina and Venturini. The AC-AC Matrix Converter is optimal in terms of minimum switch number and minimum filtering requirements [2]. A three-phase AC-AC Matrix Converter consists of bidirectional voltage-blocking, current-conducting Switches. These switches are arranged in a matrix format and by using this arrangement any input phase can be

connected to any output phase at any time. Matrix Converters could become a more attractive alternative to the back-to-back converter applications where sinusoidal input currents and true bi-directional power flow are required. The matrix converter can operate in a regenerative mode without the need of braking resistor or special converter. The regenerative energy is fed back to the source without any extra equipment so that the drive operates efficiently in all four quadrants reliably for a long time.

Benefits of the Matrix Converter technology is the possibility of greater power density due to the absence of a DC link. The filter size is also optimized, by having a sufficiently high switching frequency of semiconductor devices. This means, a compromise between filter size and semiconductor losses must be found. Factors such as the absence of electrolytic capacitors, the advantage for increasing power density, reducing size, reducing weight and obtaining good input power quality are fundamental to power supply applications

IV. Proposed Switch Mode Power Supply

The block diagram of the proposed method is shown in fig.2. The three phase ac supply is used for providing supply to power circuit. The control circuit is used for providing the gating signal and to provide excellent isolation through the optocoupler circuit. The output from the power circuit is given to the load. The schematic diagram of the proposed unity power factor switch mode power supply based on matrix converter is shown in Fig.4. The AC-DC-AC converter in the conventional switch mode power supply is replaced by the matrix converter in the proposed topology. The matrix converter topology employs six bidirectional switches which directly converts the low frequency (50 Hz, three phases) input to a high frequency (10 kHz, single phase) ac output as shown in fig.3 without a dc-link. The output of the matrix converter is then processed via a high frequency isolation transformer to produce dc voltage.

The three phase input voltage V_i is given by

$$V_i = \begin{bmatrix} V_{an} \\ V_{bn} \\ V_{cn} \end{bmatrix} = \begin{bmatrix} V_m sin(\omega_i t) \\ V_m sin(\omega_i t - 120) \\ V_m sin(\omega_i t + 120) \end{bmatrix} \longrightarrow \quad (1)$$

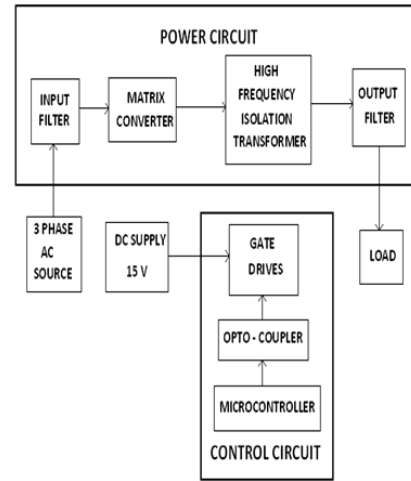Where V_m is the amplitude of input voltage and ω_i is input angular frequency

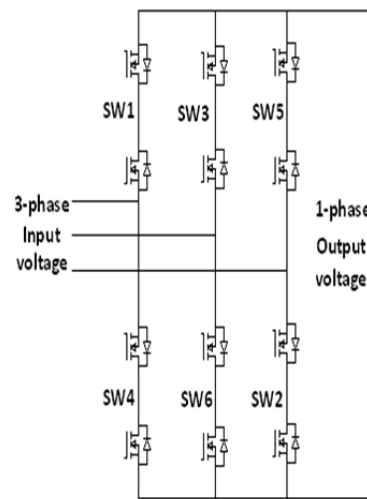Fig.2 Block Diagram for the proposed method
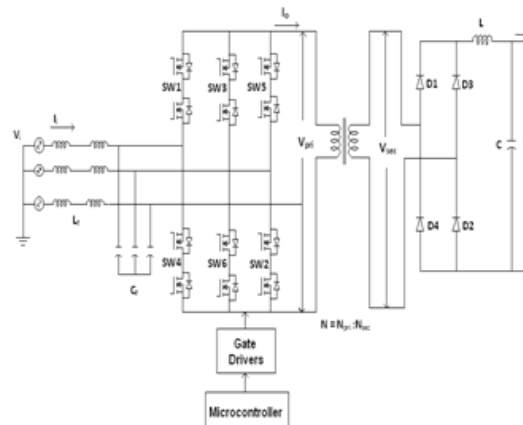

Fig.3 Three phase to one phase matrix converter

Fig.4 Schematic diagram for the proposed method

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The bidirectional switches are capable of blocking voltages and conduct current in both the direction. The output is then processed via a high frequency isolation transformer and rectified to 48 V_{dc}. Control of the matrix converter stage ensures that the output voltage is regulated against load changes as well as input supply variations.

Matrix converter is a direct ac/ac converter operated without a dc-link. It has the advantage of bidirectional power flow, controllable input power factor, high reliability, and compact design. High operating frequency of the system allows the size and weight of the transformer to be reduced. The switch mode rectifier integrates the technology with superior power, protection, and control features in a compact, cost-efficient power-conversion system [3]. The main advantage of this method is greater efficiency because the switching transistor dissipates little power in the saturated state and in off state; compared to the semiconducting state (active region). Other advantages include smaller size and lighter weight (from the elimination of low frequency transformers which have more weight) and lower heat generation obtained from the higher efficiency. Disadvantages include greater complexity, generation of high amplitude, high frequency that the low-pass filter must block to avoid EMI, ripple voltage at the switching frequency and higher harmonic frequencies.

V. Filter Design

The Filter circuit plays the major role in matrix converter to remove the harmonic components generated in the input and output side of the converter circuit.

a) *Input Filter*

The input filter is used to attenuate the harmonics injected to the three phase power supply (mains) shown in fig.5. These harmonics are generated by the modulator of matrix converter. These harmonics provoke distortion of the waveform in the input current; also the distortion is injected to the grid and cause problems to other electronic equipments. In order to reduce or attenuate the current harmonics in the supply an LC low pass filter has to be included. The input filter protects the converter and its load from transients that appear in the input voltage, thereby improving the system stability. In addition to this the LC filter attenuates the current harmonics produced by the switching frequency in the power converter, and smoothen the current waveform drawn from the power source.
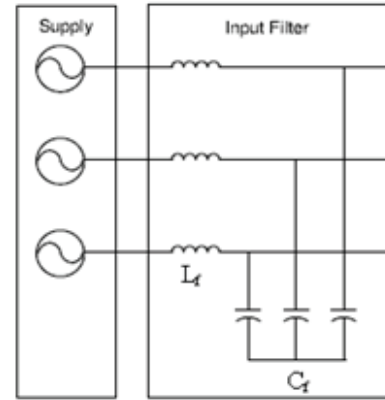

Fig.5 Input Filter

The input frequency is the mains frequency, has a value of 50 Hz. The input filter must attenuate low order harmonics, in which multiples of 50 Hz values of the components in the input filter must be as small as possible. The value of the input filter capacitance is chosen by,

$$C_f = \frac{2 * P}{3 * V_m^{\,2} * \omega_i} \tag{2}$$

Where P is the power rating, V_m is the peak of input voltage and ω_i is angular input frequency. L_f and C_f forms the input filter inductance and capacitance. The value of filter inductor is chosen by,

$$L_f = \frac{1}{\left(2\pi f_c\right)^2 * C_f} \tag{3}$$

Where f_c is the cut-off frequency and is chosen to be lower than the switching frequency. The input current, which is sinusoidal, shows that the filter has removed most of the higher frequency components from the waveform (Fig 10, 11, 12). The requirements of input filter are,

a) To have the cut-off frequency lower than the switching frequency of the converter.

b) To minimize its reactive power at the grid frequency.

c) To minimize the volume and weight of the capacitors and chokes.

d) To minimize the filter inductance voltage drop at rated current in order to avoid a reduction in the voltage transfer ratio.
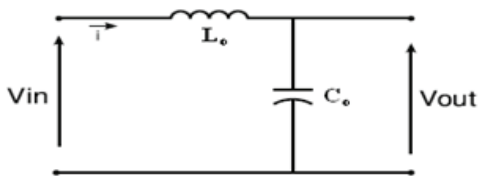
b) *Output Filter*

Fig.6 Output Filter

The power converter requires a LC filter at the output side to reduce the harmonics as shown in fig.6. A power converter with higher switching frequency will result in smaller LC filter size. For the design of the LC low-pass filter, the cut-off frequency is considered to be able to eliminate the lower order harmonics of the output voltage waveform. For higher switching frequencies, components with lower capacitance and inductance are needed. This is done by attenuating or eliminating the harmonic content and the ripple that appear in the output generated by the pulsating modulation of voltage waveform. When the value of the capacitor is increased the power rating of the matrix converter is increased as well. This is due to the increment of the filter reactive power.

VI. SIMULATION RESULTS

The gating signals are given in such a manner that only two devices conduct at a time. By giving the suitable time delay, the devices are made to conduct. Fig.7. shows about the simulation model of the proposed method.
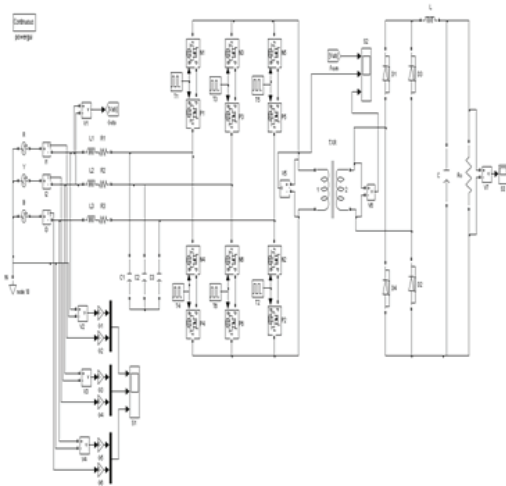

Fig.7 Simulation model of the proposed method

In this section, simulation results of the proposed approach have been discussed. Fig.8 shows the gating signal. Fig.9 shows the input voltage V_{ab}, matrix converter output voltage V_{pri} and transformer secondary voltage V_{sec}. Fig 10, 11, 12 illustrates the performance of the proposed converter from utility perspective. It is clear from these results that input current is of high quality and is in phase with the input line to neutral voltage so that unity power factor has been obtained. Fig.13. shows the output dc voltage (48 V).
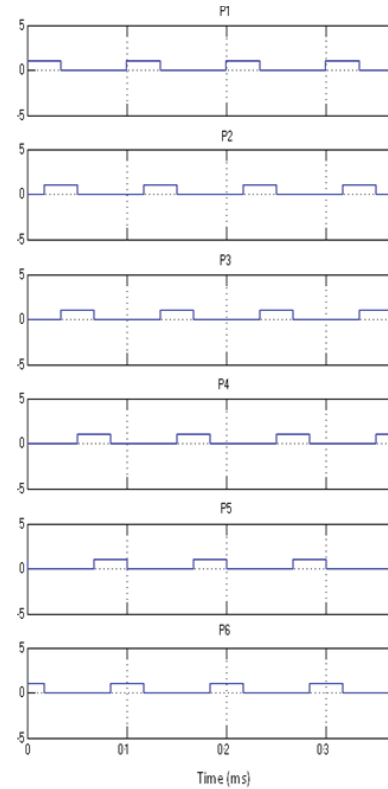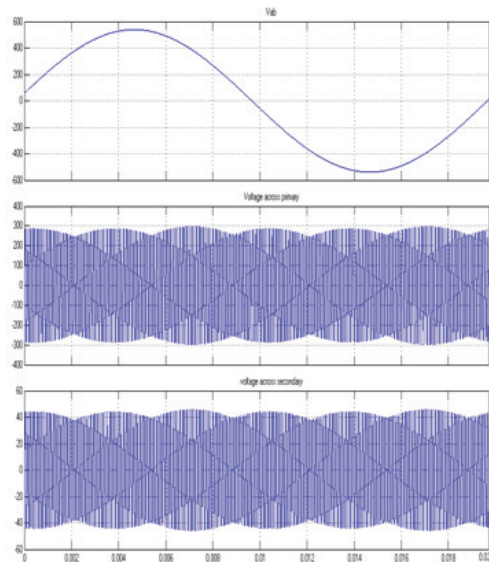

Fig.8 Gating signal

Fig.9 Input voltage V_{ab}, matrix converter output voltage V_{pri} and transformer secondary voltage V_{sec}
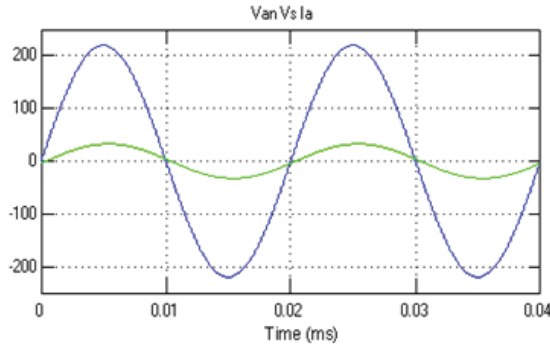
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Van Vs Ia

Fig.10 Input voltage V_{an} and input current I_a

Vbn Vs Ib
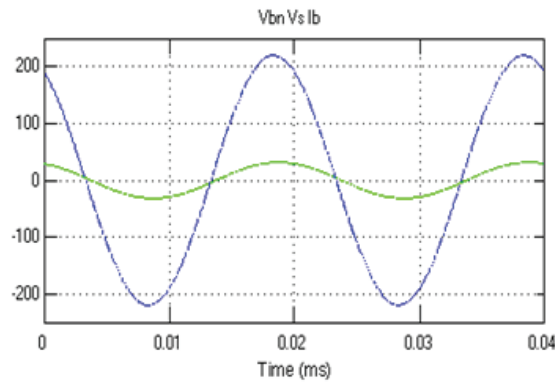
Fig.11 Input voltage V_{bn} and input current I_b
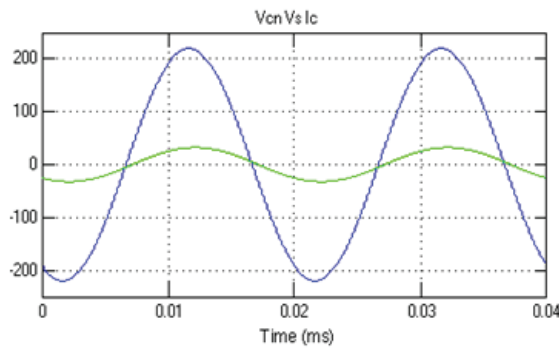
Vcn Vs Ic

Fig.12 Input voltage V_{cn} and input current I_c
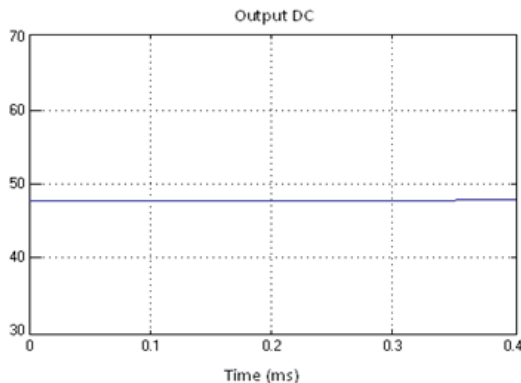
Output DC

Fig: 13 Output dc voltage (48 V)

VII. CONCLUSION

In this paper, a unity power factor switch mode power supply based on matrix converter for Telecommunication applications has been shown. Simulation results show that the matrix converter based switch mode power supply converter has following performance features:

- The proposed topology has advantages like low total harmonic distortion, higher efficiency, and increased power density.

- No DC link capacitors are needed, which means that large energy storage elements are avoided.

- Input current is of high quality and is in phase with the input supply voltage; hence unity power factor has been achieved.

REFERENCES

[1] Patrick. W. Wheeler, Member, IEEE, Jose Rodriguez, Senior Member, IEEE, Jon C. Clare, Member, IEEE, Lee Empringham, Member, IEEE and Alejandro Weinstein, "Matrix Converters: A Technology Review *IEEE Transaction in Industrial Electronics,* Vol. 49, No. 2, April 2002

[2] Tyco Electronics, "Galaxy Switching mode Rectifier 595 Series", *Tech. Rep.,*Feb.2003.

[3] C. L. Neft and C. D. Schauder, "Theory and Design of 30 - hp matrix converter," *IEEE Trans. Industrial Appl.,* vol. 28, No.3, pp. 546 – 551, May/June 1992.

[4] M. Kang, P. N. Enjeti, and I. J. Pitel, "Analysis, Design of electronic transformers for electric Power distribution system," *IEEE Transaction Power Electronics*, vol. 14, no. 6, pp.1133 – 1141, Nov 1999.

[5] Bimal K. Bose, "Modern Power Electronics and AC Drives", *Prentice - Hall, Inc, New Jersey,* USA, 2002.

[6] Rashid M.H., "Power Electronics Circuits, Devices and Applications", Pierson Prentice Hall,India, New Delhi, 2004.