A DC Power supply Based on Matrix Converter with Reduced Number of Switches

Farshid Behrangi, Ali Dastfan
Faculty of Electrical Engineering and Robotics
Shahrood University of Technology, Iran

Abstract: - High Power telecommunication power supply systems consist of a three-phase switch mode rectifier followed by a DC/DC converter to supply loads at -48 VDC. These rectifiers draw significant harmonic currents from the utility, resulting in poor input power factor with high total harmonic distortion (THD). In this paper, a DC power supply based on matrix converter with reduced number of switches is proposed for telecommunication applications. In the proposed approach, three switches convert the low frequency (50Hz, three-phase) input to a DC link. A single-phase bridge inverter converts the DC-link to a high frequency (25 KHz, one-phase) AC output. The output of the matrix converter is then processed via a high frequency isolation transformer and rectified to-48VDC.In the proposed topology only a simple voltage control loop ensures that the output voltage is regulated against load changes as well as input supply variations. The input currents are of a high quality and devoid of low frequency harmonics under varying load conditions, inherently. Therefore, the current control loop is not used to correct the input currents. So, its control circuit is not complicated. Simulation results verify the feasibility of the proposed converter.

Key-Words: - AC-DC power conversion, matrix converter, harmonic distortion

1 Introduction

In previous works on DC power supply based on matrix converter, the power stage includes six bidirectional switches (12 switches).
In [1], the operation of the matrix converter is expressed mathematically in a matrix formation, where the matrix converter switching function is the product of rectifier mode switching function by inverter mode switching function. The low frequency (50Hz, three-phase) input is directly converted to high frequency (10/20 KHz, one-phase) output by applying the matrix converter switching function to power stage.
In the rectifier mode by using a proper switching algorithm, input currents will have a high quality and also a low total harmonic distortion (THD).
In [2], a symmetrical pure AC profile is generated at the primary side of the high frequency isolation transformer by applying specific pulses to power switches that these pulses consider the restrictions of the matrix converter. These restrictions are discussed in [3].
In this matrix converter, the implementation of control techniques like space vector modulation (SVM) [4] permits to sinusoidal shape the input line current waveforms.
In ([5],[6]),the matrix converter directly converts the low frequency (50Hz,three-phase) input to a DC- link with applying a low frequency modulation function is called direct control method. Hence, high frequency isolation transformer is not used in this approach. The low frequency modulation function permits to obtain high quality input currents.
In the mentioned methods in above, high frequency current components in the input currents of converter can be eliminated via a small damped input filter. There are two main drawbacks in these approaches:

1. A large number of switches lead to the complexity and high cost of the converter.
2. Two separated control loops are needed, the current control loop is used to correct the input currents and the voltage control loop is used to adjust the output voltage.

In this paper, with reduction of the number of switches from twelve switches to seven switches, the cost of converter is reduced. In addition, the bidirectional switches constructions which have complex commutation and protection problems are not used. [7]
Advantages of the proposed topology are:

- The number of switches is reduced.
- No DC-link capacitor required
- Low total harmonic distortion (THD) in line current.
- Reduction of volume and weight due to the high frequency operation.
- Its control circuit is not complicated.

The paper presents a detailed analysis of the modulation scheme, and simulation results are provided to verify its feasibility.

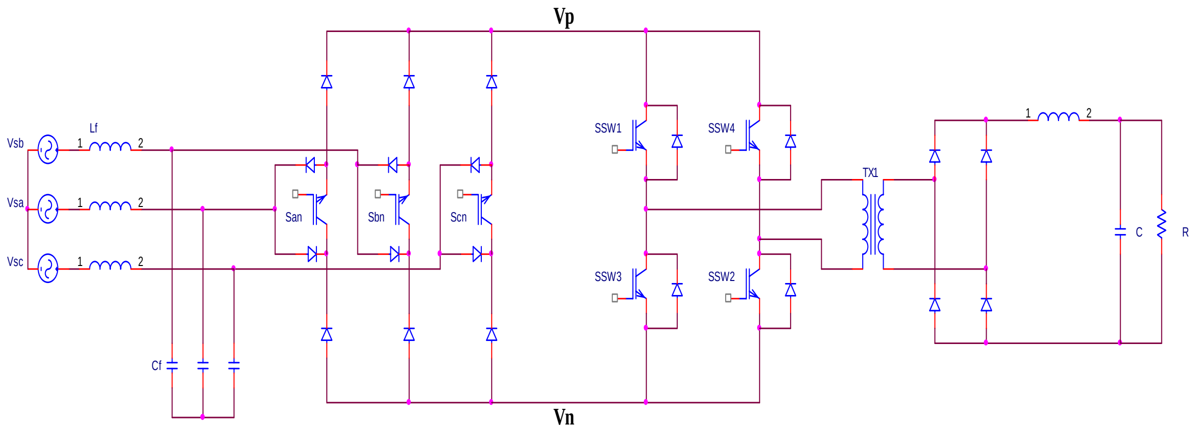

Fig. 1: Proposed power supply

2 Problem Formulation

The proposed power supply is shown in Fig. 1. In rectifier mode, the low frequency (50 Hz, three-phase) input is converted to a DC-link by proper switching of three switches that these switches have specific arrangement of diodes. In inverter mode, a single phase bridge inverter converts the DC-link to a high frequency (25 KHz, one-phase) ac output. The output is then processed via a high frequency isolation transformer and rectified to-48VDC.

3 Proposed PWM Method

3.1 Rectifier Mode of Operation

In order to simplify the analysis of the rectifier, it is supposed that there is no input filter in the line side. The aim of the pulse width modulation of the rectifier is to maintain positive voltage in the DC side as well as to maintain the input power factor as unity. It is assumed that the input source voltages are described by the following relation:

$$\begin{cases} v_a(t) = V_m Cos\theta_a = V_m Cos(\omega_i t) \\ v_b(t) = V_m Cos\theta_b = V_m Cos(\omega_i t - \frac{2\pi}{3}) \\ v_c(t) = V_m Cos\theta_c = V_m Cos(\omega_i t + \frac{2\pi}{3}) \end{cases} \tag{1}$$

With in any 60° interval between two successive zero crossing of input phase voltages, shown in Fig.2, only one of the three-phase voltages have opposite polarity voltage. For example in the mode 3, phase b has the maximum positive values and phase a and c have negative values in Fig. 2

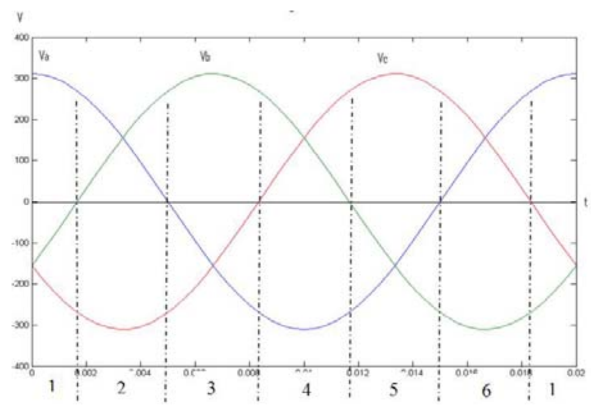

Fig. 2: Six modes of input phase voltages

Since the input line voltages are balanced, there are two possible conditions for the input phase voltages:

1. Two voltages are negative, and one is positive (In the mode 3) Phase a and c are negative, phase b is then positive. One can derive:

$$|V_b| = |V_a| + |V_c|$$

Under this conditions, switch S_{bn} must be maintained in the conducting state while S_{an}, S_{cn} are modulated. While S_{an} is turned on, the DC voltage is equals to V_{ba} and is positive. The duty ratio of switch S_{an} is given by

$$d_{ab} = \frac{|Cos\theta_a|}{|Cos\theta_b|} \tag{2}$$

While S_{cn} is turned on, the DC voltage equals to V_{bc} and is also positive. The duty ratio of S_{cn} is given by

$$d_{cb} = \frac{|Cos\theta_c|}{|Cos\theta_b|} \tag{3}$$

The average DC side voltage in this switching interval is:

$$V_{dc} = d_{ab}(V_b - V_a) + d_{cb}(V_b - V_c) \tag{4}$$

Substituting (1), (2), and (3) in (4), one can finally obtain

$$V_{dc} = \frac{3V_m}{2|Cos\theta_b|}$$

2. Two voltages are positive and one is negative (In the mode 6) Phase a and c are positive, phase b is then negative. One can establish that:

$$|V_b| = |V_a| + |V_c|$$

Under this condition, switch S_{bn} must be maintained in the conducting state while S_{an}, S_{cn} are modulated. During the time when S_{an} is turned on, the DC voltage equals to V_{ab} and is positive. The duty ratio of S_{an} can be expressed as:

$$d_{ab} = \frac{|Cos\theta_a|}{|Cos\theta_b|} \tag{5}$$

When S_{cn} is turned on, the DC voltage equals to V_{cb} and is positive. The duty ratio of S_{cn} is:

$$d_{cb} = \frac{|Cos\theta_c|}{|Cos\theta_b|} \tag{6}$$

Finally the average value of the DC voltage during this switching interval is:

$$V_{dc} = d_{ab}(V_a - V_b) + d_{cb}(V_c - V_b) \tag{7}$$

Substituting Eqs. (1), (5), and (6) in (7), one obtains

$$V_{dc} = \frac{3V_m}{2|Cos\theta_b|}$$

Utilizing the same approach, one can obtain the corresponding duty ratio and switching state for all other mode conditions. The average value of DC voltage during each of these switching intervals is:

$$V_{dc} = \frac{3V_m}{2Cos\theta_{\max}} \tag{8}$$

Where,

$$Cos\theta_{\max} = \max(|Cos(\theta_a)|, |Cos(\theta_b)|, |Cos(\theta_c)|)$$

Fig.3 shows the gating signals of the three switches (S_{an}, S_{bn} and S_{cn}) in the six switching intervals based on line side voltages.

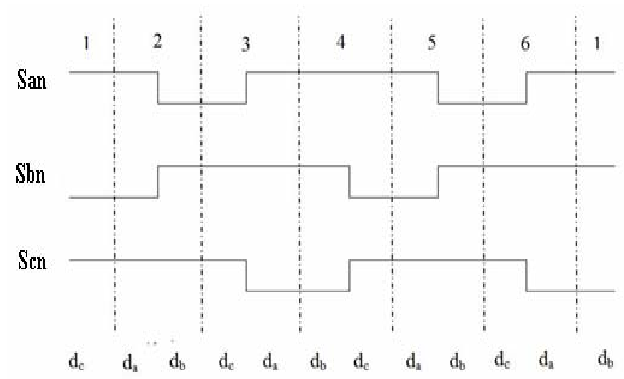

Fig.3: The gating signals of the three switches (S_{an}, S_{bn} and S_{cn}) in the six switching intervals based on line side voltages

In order to satisfy unity displacement power factored input current requirement and full utilization of input source voltage, the duty ratios d_a, d_b and d_c are given by

$$d_a = \frac{|Cos(\theta_a)|}{Cos\theta_{\max}}, d_b = \frac{|Cos(\theta_b)|}{Cos\theta_{\max}}, d_c = \frac{|Cos(\theta_c)|}{Cos\theta_{\max}}$$

The fictitious DC voltage in a conventional matrix converter which the space vector modulation (SVM) method is utilized for the its rectifier side is given by,

$$V_{dc} = 1.5 \times m_c \times V_m \tag{9}$$

Where, m_c is the modulation index

From (8) and (9), it can be shown that proposed matrix converter do not need the additional control loop for controlling input currents

3.2 Inverter Mode of Operation

The objective of this mode of operation is to generate a high frequency single phase output voltage. The operating frequency in this mode is the same as desired output frequency. From the rectifier mode DC voltage (V_{pn}), is found. It is used as the input of single phase inverter.

Gating signals of the inverter mode are shown in Fig.4. Its operating principle is that the diagonal switches of the full bridge inverter turn on at the same time, and the leading-leg switches turn off earlier than the lagging-leg. The turn on time of the leading-leg is adjustable and the turn on time of the lagging-leg is fixed. So, the output power can be adjusted by changing the turn on time of the leading-leg. Output voltage is regulated by control signal.

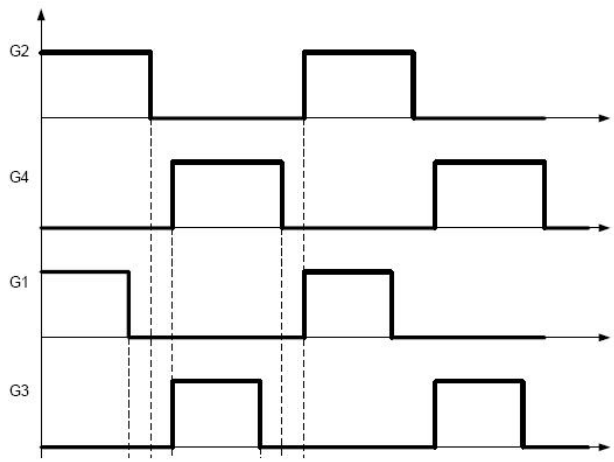

Fig.4: Gating signals of the inverter switches

4 Simulation Results

In this section, simulation results of the proposed approach are discussed. Fig.5 and Fig.6 show the input current Ia at 6KW output power and its THD respectively. It is clear that input current is of high quality. Fig.7 shows the 48-VDC output voltage. Fig.8 shows the high frequency output voltage of the matrix converter. Fig.9 shows input current Ia due to abrupt variation of the load. Fig.10 shows output voltage due to abrupt variation of the load. Fig.11 shows input current Ia due to 15% reduction of the V_{rms} among each input source voltage phases. Fig.12 shows output voltage due to 15% reduction of the V_{rms} among each input source voltage phases.

Table1: Design specifications of the proposed approach

Design Specification	Values
Input line voltage (v_i)	380 *V*
Input frequency (f_i)	50 *Hz*
Switching freq. in rectifier mode	10 *KHz*
Switching freq. in inverter mode	25 *KHz*
Output DC Voltage (V_{dc})	48 *V*
Load power (P_o)	6 *KW*

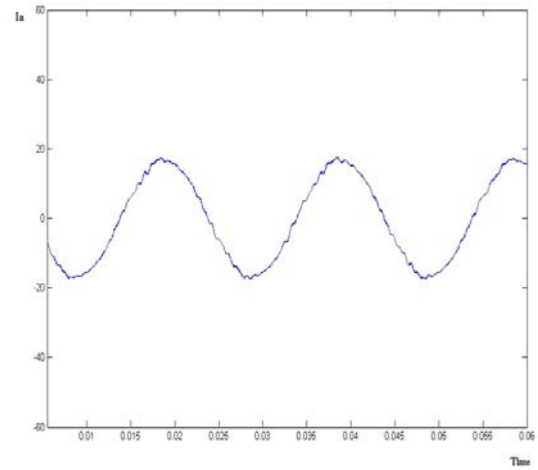

Fig.5: The input current I_a at 6*KW* output power

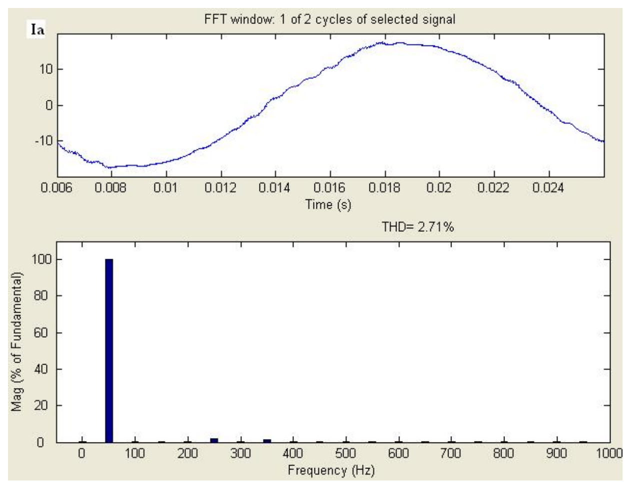

Fig.6: The input current *THD*

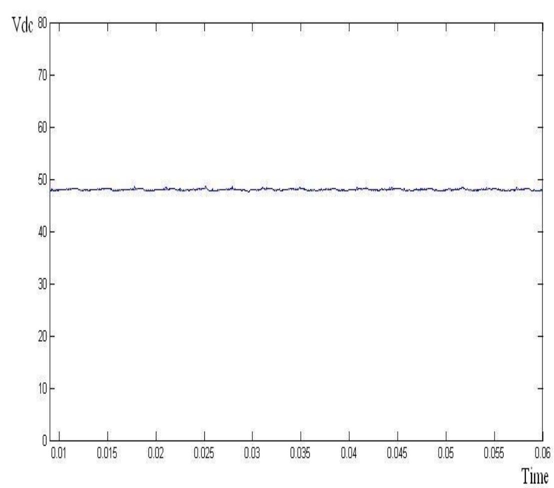

Fig.7: 48-*VDC* output voltage

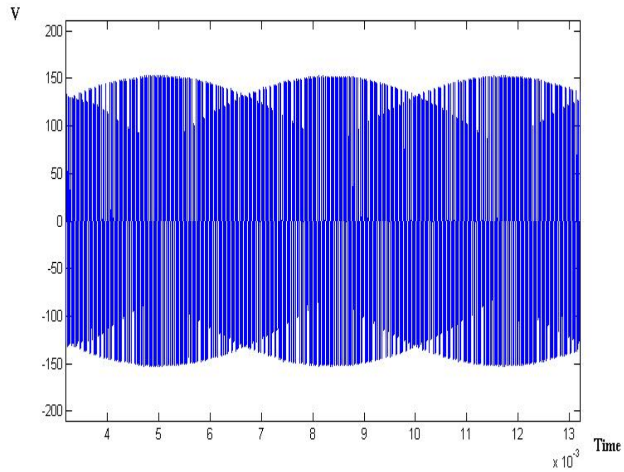

Fig.8: High frequency output voltage of the matrix converter

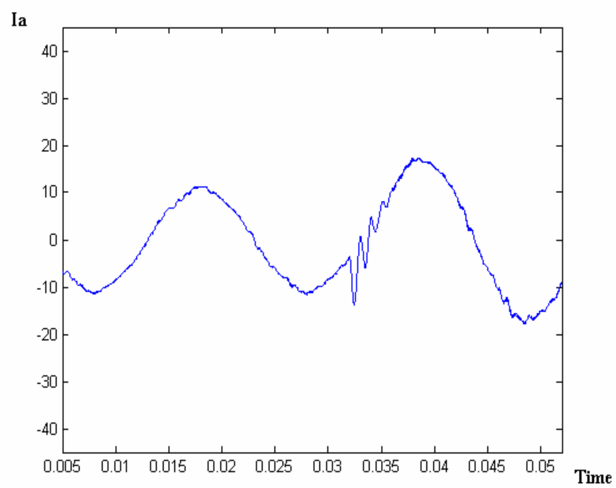

Fig.9: Input current I_a due to abrupt variation of the load

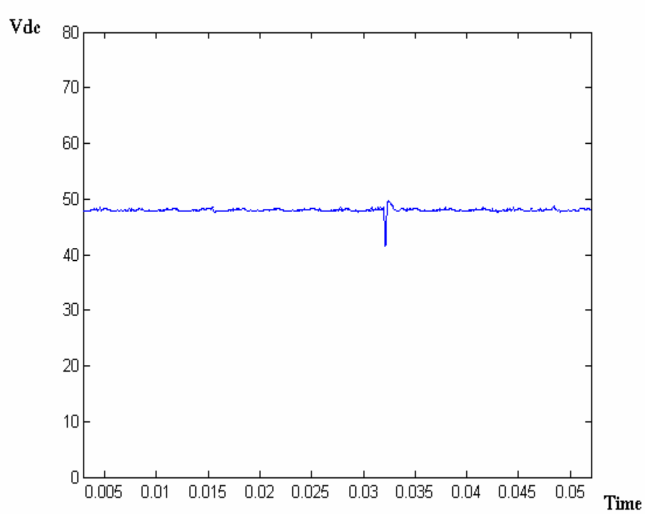

Fig.10: Output voltage due to abrupt variation of the load

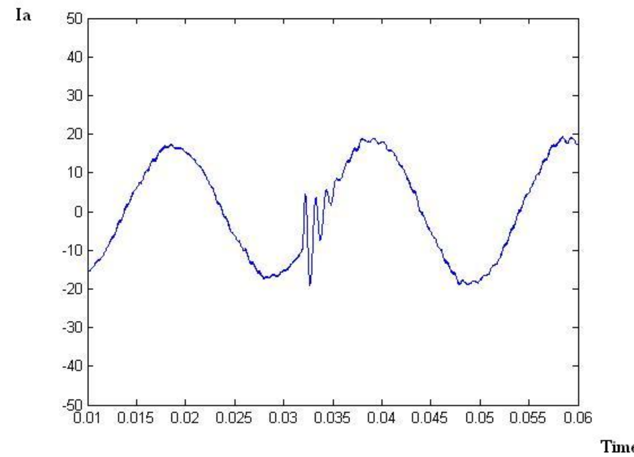

Fig.11: input current I_a due to 15% reduction of the V_{rms} among each input source voltage phases

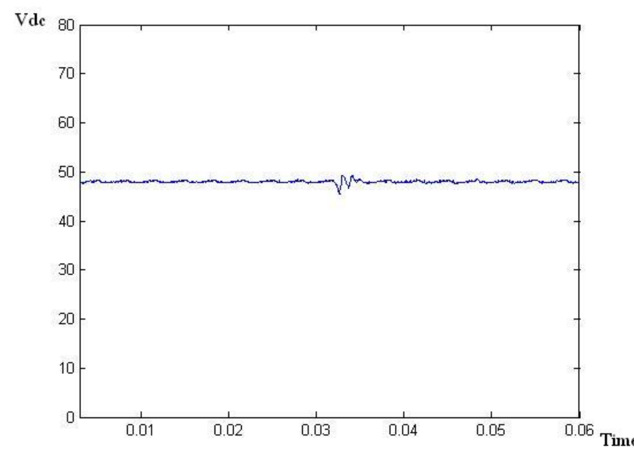

Fig.12: Output voltage due to 15% reduction of the V_{rms} among each input source voltage phases

5 Conclusion

This paper presents a DC power supply based on matrix converter with reduced number of switches. In the proposed topology only a simple voltage control loop is used, which can largely simplify its control complexity and the bidirectional switches construction which have specific commutation and protection problems are not needed to use.

Simulation results verify the feasibility of the proposed converter.

References:

[1] S.Ratanapanachote, H.J.Cha and P.N Enjeti,"*A digitally controlled switch mode power supply based on marrix converter*," in IEEE Transactions on Power Electronics, Vol.21, No.1, January 2006

[2] Garcia-Gil, R. Espi, J.M. Dede, E.J. Maset, E. , " *An all-digital controlled AC-DC matrix converter with high-frequency isolation and power factor correction*", on proceedings of the 2004 IEEE International Symposium on Industrial Electronics, Ajaccio, France, May 4-7, 2004

[3] P. W. Wheeler, J. Rodriguez, J. C. Clare, L. Empringham and A. Weinstein, "*Matrix Converters: A Technology Review*" IEEE Trans., Vol. 49, No. 2, April 2002

[4] C. Huber, and D. Borojevic, "*Space vector modulated threephase to three-phase matrix converter with input power factor correction*", IEEE Trans. on Industry Applications, vol. 31, No. 6, 1995, pp. 1234-1246

[5] J.B. Ejea, E. Sanchis-Kilders, J.A.Carrasco, R.de la Calle, J.M. Espi, " *High-frequency bi-directional three-phase rectifier with power factor correction* "Power Electronics Specialists Conference, 2001. PESC. 2001 IEEE 32nd Annual, Volume: 3, On page(s): 1303-1308 vol. 3

[6] Holmes, D.G.; Lipo, T.A.; "*Implementation of a controlled rectifier using AC-AC matrix converter theory*"; IEEE Transactions on Power Electronics, Volume: 7, Issue: 1, Jan.1992; Pages: 240 – 250

[7] L. Wei, T. Lipo, and H. Chan, "*Matrix converter topologies with reduced number of switches*", in Proc. of IEEE Power Electronics Specialists Conference, PESC 2002. PESC 2002, Vol. 1, pp. 57 – 63.