MATLAB SIMULATION OF 3-PHASE AC-AC MULTILEVEL MATRIX CONVERTER

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ABSTRACT: M*ultilevel voltage source converters are extensively used in high power applications now a day. In contrast, the study on matrix converters has largely been restricted to the low power application. In order to get benefits from both direct power conversion and multilevel structure, diverse multilevel matrix converter structures have been proposed in recent years.In this research work, MATLAB Simulation has been performed to simulate H-bridge switch cell based Multilevel Matrix Converter to ensure high power application of the converter. Space vector modulation control algorithm has been established to control nine converter arms which consist of four H-bridge switch cells each. Converter operation at different input/output frequency has also been analyzed.*

-INTRODUCTION

In recent years, multi-level voltage source converters have been preferably employed in medium voltage level but high power drives [1]. Similar to the two-level VSC, multi-level voltage source converters share many mutual advantages: individual power switches, face low voltage stress, which allows the utilization of power switches having low-voltage operation and eludes the requirement of combining devices in series hence lower dv/dt during device switching. Compare to the two-level voltage source converters, each device in a multi-level is generally switched between two neighboring voltage levels as a replacement for entire dc-link voltage. This multilevel approach generates better quality input output waveforms in terms of total harmonic distortion, and better harmonic profile because of the generated multi-step waveforms. In turn, this reduces the requirement of ac filters to significant level or even excluded. [2]

On the other hand, cycloconverters still have their extensive use in high power applications such as low speed high torque ac drives [3]. Being direct power converters, they also eliminate the necessity of any dc energy storage element and use naturally commutated thyristors that can be operated by phase angle control. Inspite of having features like strong configuration, bidirectional power flow, and high efficiency, poor input power factor and distorted harmonic profile are disparaging drawbacks of the power converters; also, their output frequency conversion is limitted to a portion of the input [2, 3].

In the direct power converter category, forced-commutated Matrix Converter (MC) stands alongwith the cycloconverter. The conventional matrix converter having three inputs and three outputs has attracted substantial research consideration over since its inception, with high prospects that it may be the eventual pure-silicon power conversion elucidation. Pulse width modulation (PWM) algorithm is normally employed to fully control the MC. MC and cycloconverters share some common features such as avoidance of bulk dc component, robust dnamic response, and four quadrant operation. Unlike cycloconverter, MC provides sinusoidal input output waveforms with amendable input power factor and flexible operational range of output frequency. Because of high switching operation, MCs have mainly found their applications in the low voltage class. But it has been a tough journey for MC to create place in high power applications where the concerns about efficiency and stress limitations of power devices exist mainly [2].

The multilevel matrix converter opens new horizons to the family of matrix converter that integrates the multilevel converter thought with a conventional matrix converter. Many topologies for multilevel matrix converter have been proposed in [4-6]. The aptitude to generate multilevel output voltages results in superior quality output waveforms in terms of harmonic content, but more complex circuit configuration and modulation strategy [7].

The multi-level matrix converter is one of auspicious high power frequency converters which apprehend ac to ac direct conversion. It has a number of H-bridge cells connected in series as bidirectional switches, instead of semiconductor switching devices in a conventional matrix converter [8].

It is easy to assosiate the multilevel matrix converter (MMC) to high voltage and high power application where it can lessen waveform distortion because of multilevel configuration of switch cells. Moreover, it is particularly extraordinary that matrix converter has the lead that current commutation among converter is easily attained even in very low frequency operation. Furthermore, the MMC can control reactive power of both input and output terminals rapidly. Therefore, it does not need huge capacitor for reactive power compensation and can add to stabilization of associated power systems [9].

II-MULTILEVEL MATRIX CONVERTER TOPOLOGY

Fig. 1 illustrates that voltage clamped switch cells are connected in matrix configuration. Each leg of the converter comprises of a switch cell which contains an H-bridge with a DC capacitor as displayed in Fig. 2. The bus-bar structures are relatively easy to construct for this multilevel approach. In matrix configuration, the need of a DC voltage source at individual switch cell can be eliminated because of the presence of DC capacitor in each switch cell. There exist many differences between multilevel matrix converter and conventional matrix converter [8]. MMC is proficient of both decreasing and increasing the voltage magnitude and frequency, while working with random power factors. Some major differences among the two topologies have been presented in Table 1 [8].

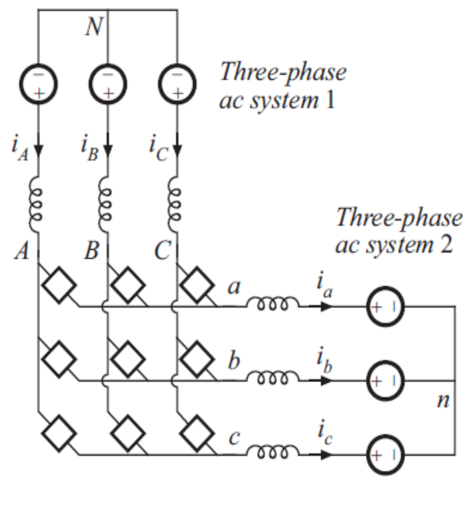

Fig. 1: Multilevel Matrix Converter Topology

Table 1: Multilevel Matrix Converter VS Conventional Matrix Converter

Factors	Conventional Matrix Converter	Multilevel Matrix Converter
Voltage Conversion Ratio Vout/Vin	Buck: Vout ≤ 0.866 Vin	Buck-Boost: 0 ≤Vout<∞
Switch Commutation	Coordination of 4-quadrant switches	Simple transistor and freewheeling diode
Bus Bar structure	Complex	Multilevel and Simple
Multilevel Operation	Not any	Promising
Filter Elements	Capacitors and Inductors	Only Inductors

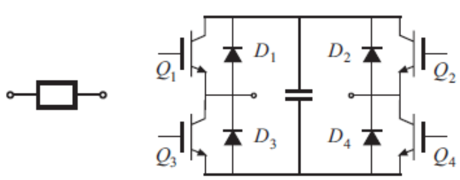

Fig. 2: H-bridge Switch Cell

III-SPACE VECTOR MODULATION

Space vector control approach has been adapted for the multilevel matrix converter as a procedure to synthesize the terminal voltages of the converter. This control technique is centered on a transformation of three phase variables into a simpler two coordinate variables without loss of information, generally called dq coordinates.

SVM technique has been proven promising to considerably simplify the difficulty of the mathematical model. In addition, the SVM can execute a better harmonic rejection capability than does the sinusoidal PWM [10].

$$v(t) = \begin{bmatrix} vd(t) \\ vq(t) \end{bmatrix} = \frac{2}{3}\begin{bmatrix} \cos(0) & \cos(\frac{2\pi}{3}) & \cos(\frac{4\pi}{3}) \\ \sin(0) & \sin(\frac{2\pi}{3}) & \sin(\frac{4\pi}{3}) \end{bmatrix}\begin{bmatrix} vx(t) \\ vy(t) \\ vz(t) \end{bmatrix} \quad (1)$$

Where $vx(t)$, $vy(t)$, and $vz(t)$ are voltages in a three phase system. The steady state quantities of $vd(t)$ and $vq(t)$ from the transformation of Eq. 1 are sinusoidal. The second transformation using Eq. 2 transforms these sinusoids to frame of reference that is stationary with respect to time.

$$\begin{bmatrix} vd \\ vq \end{bmatrix} = \begin{bmatrix} \cos(wt) & \sin(wt) \\ -\sin(wt) & \cos(wt) \end{bmatrix}\begin{bmatrix} vd(t) \\ vq(t) \end{bmatrix} \quad (2)$$

For the three phase converter applications, balanced three phase sinusoidal voltages are usually desired. The SVM control technique relates to creating a space vector of constant amplitude, which rotates at the desired frequency. Suppose that the desired line-line voltages are expressed as,

$$vab(t) = Vm\cos(wt)$$
$$vbc(t) = Vm\cos(wt - 120^\circ) \quad (3)$$
$$vca(t) = Vm\cos(wt - 240^\circ)$$

Where, Vm denotes the magnitude of the line to line voltages. By solving Eq. 1 and 3 together we get

$$\begin{bmatrix} vd(t) \\ vq(t) \end{bmatrix} = \frac{2}{3}\begin{bmatrix} \cos(0) & \cos(\frac{2\pi}{3}) & \cos(\frac{4\pi}{3}) \\ \sin(0) & \sin(\frac{2\pi}{3}) & \sin(\frac{4\pi}{3}) \end{bmatrix}\begin{bmatrix} Vm\cos(wt) \\ Vm\cos(wt-120^\circ) \\ Vm\cos(wt-240^\circ) \end{bmatrix}$$
$$= \begin{bmatrix} Vm\cos(wt) \\ Vm\,Sin(wt) \end{bmatrix} \quad (4)$$

The desired reference space vector can be articulated as a linear combination of their neighboring space vectors using

$$Vref(t) = daVa + dbVb + dcVc \quad (5)$$

Where da, db, and dc are the duty cycles of the space vectors Va, Vb, and Vc respectively, and

$$da + db + dc = 1 \quad (6)$$

For a matrix converter with 9 switches, there are 27 permissible switching states, stated as space vectors, 18 out of these 27 states give rise to stationary vectors, 3 produce zero vectors, and rotating vectors having variable magnitudes are generated by remaining six vectors which are generally not valuable in the space vector modulation formulation. Fig. 3 shows the targeted output vector diagram, and Fig. 4 shows the input current space vector. Along with appropriate zero vector, these voltage and current vectors can be applied to create the required magnitude and direction of output voltage vector as well as input current vector. The duty cycle calculations and vector sequence selected for conventional matrix converter have been discussed in detail in [11, 12].

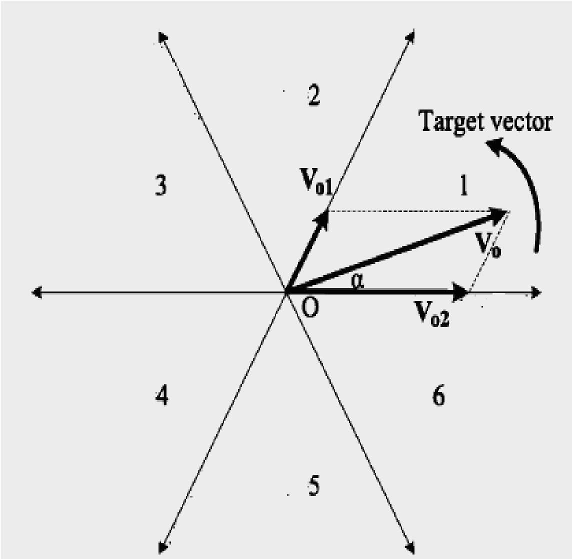

Fig. 3: Output side Voltage Space Vector Trajectory

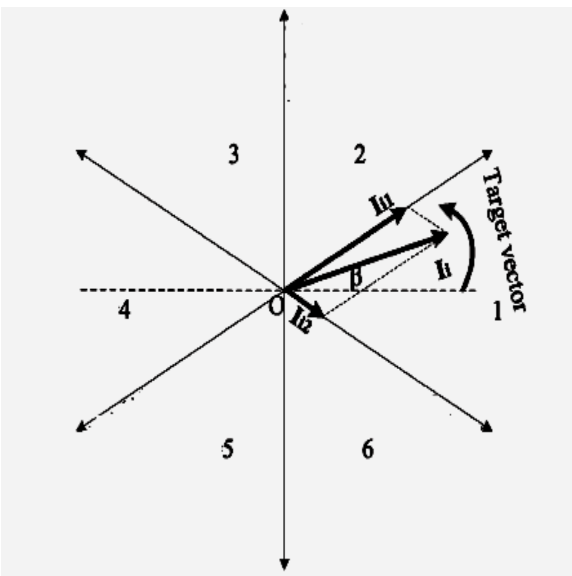

Fig. 4: Input Side Current Space Vector Trajectory

IV-SIMULATION AND RESULTS

The three phase Ac to Ac, H-bridge switch cell based, Multilevel Matrix Converter has been simulated for high power application in MATLAB/SIMULINK environment. Fig. 5 describes the simulation scheme in MATLAB. Fig. 6 illustrates the H-bridge switch cell configuration. SVM control strategy has been developed and implemented for operation of converter at different frequency levels. Fig. 7 shows the converter operating at 50 Hz frequency at both input and output sides. Fig. 8 shows behavior of the converter when the input frequency is 50 Hz and output frequency is 100 Hz while Fig. 9 describes the operation when input is at 50 Hz and output at 20 Hz frequency.

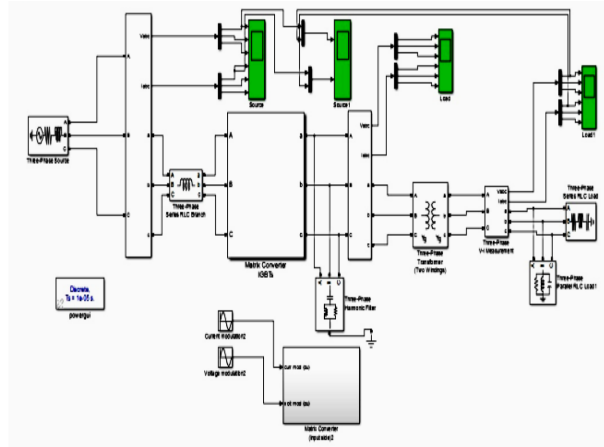

Fig. 5: 3-phase Multilevel Matrix Converter Simulation

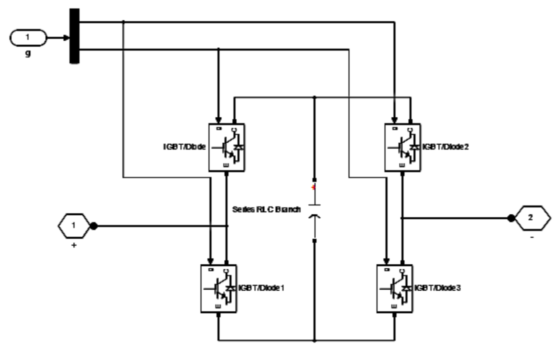

Fig. 6: H-bridge Switch Cell Configuration

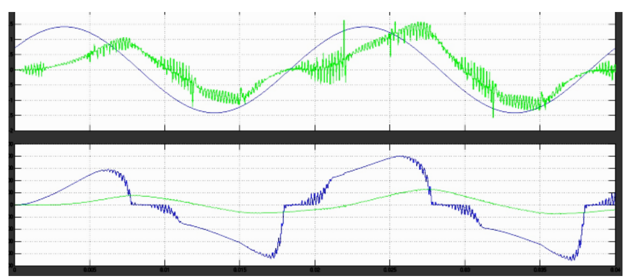

Fig. 7: Input/Output at 50Hz, Voltage & Current waveforms

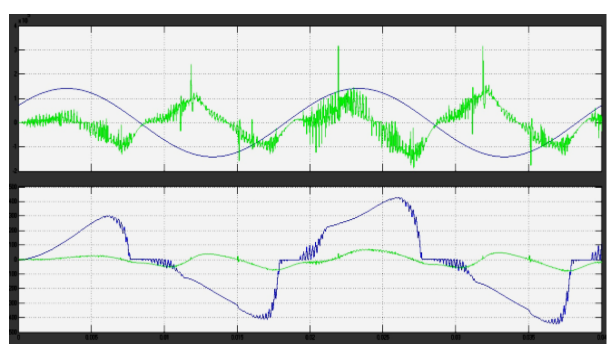

Fig. 8: Input at 50Hz/Output at 100Hz, Voltage and Current waveforms

Four H-bridge switch cells have been employed to ensure multilevel performance of the converter. Input line inductor is used as a filter for input current and a small LC filter has been placed at output to mitigate higher order harmonics and improve THD of the converter. In Fig. 7, 8, & 9, the blue lines show the input side Voltage and Current waveforms and green lines indicate the output side Voltage and Current of the converter.

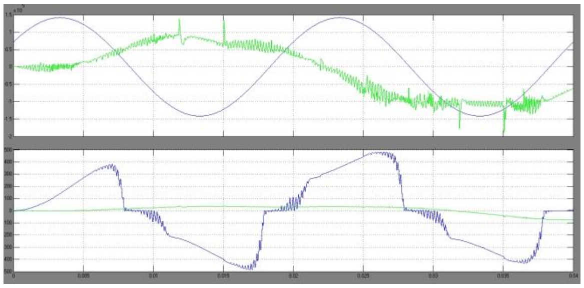

Fig. 9: Input at 50Hz/Output at 20Hz, Voltage & Current waveforms

V-CONCLUSIONS

Three phases Ac to Ac Multilevel Matrix Converter has been presented in this paper. SVM control scheme provides robust control of input and output side voltage and current waveforms. The converter under consideration is operating at 220kV with 100MVA load. The working of converter at low frequency as well as high frequency has been analyzed which confirms that the converter can operate at wide ranges of frequency without losing control. This confirms the application of converter at off shore wind power plants where robust control of input and output quantities is required and high frequency operation of the converter has been suggested to reduce the size of transformer at offshore station [13]. This wide range frequency conversion phenomenon can easily be adopted for controlling of variable frequency drives.

In future, application based simulation will be carried out especially in offshore wind energy conversion stations. Hardware verification will also be the part of future work.

VI-REFERENCES

[1] Rodríguez, J., Bernet, S., Wu, B., Pontt, J. O., & Kouro, S. Multilevel voltage-source-converter topologies for industrial medium-voltage drives.*Industrial Electronics, IEEE Transactions on*, ***54***(6), 2930-2945 (2007).

[2] Wang, J., Wu, B., & Zargari, N. R. High-power multi-modular matrix converters with sinusoidal input/output waveforms. In *Industrial Electronics, 2009. IECON'09. 35th Annual Conference of IEEE* (pp. 542-547) (2009).

[3] Wu, B., Pontt, J., Rodríguez, J., Bernet, S., & Kouro, S. Current-source converter and cycloconverter topologies for industrial medium-voltage drives.*Industrial Electronics, IEEE Transactions on*, ***55***(7), 2786-2797 (2008).

[4] Erickson, R. W., & Al-Naseem, O. A. A new family of matrix converters. In *Industrial Electronics Society, 2001. IECON'01. The 27th Annual Conference of the IEEE* (Vol. **2**, pp. 1515-1520) (2001).

[5] Shi, Y., Yang, X., He, Q., & Wang, Z. Research on a novel multi-level matrix converter. In *Power electronics specialists conference* (pp. 2413-2419) (2004).

[6] Lee, M. Y., Wheeler, P., & Klumpner, C. A new modulation method for the three-level-output-stage matrix converter. In *Power Conversion Conference-Nagoya, PCC'07* (pp. 776-783) (2007).

[7] Lee, M. Y., Wheeler, P., & Klumpner, C. (2010). Space-vector modulated multilevel matrix converter. *Industrial Electronics, IEEE Transactions on*, ***57***(10), 3385-3394 (2010).

[8] Angkititrakul, S., & Erickson, R. W. Control and implementation of a new modular matrix converter. In *Applied Power Electronics Conference and Exposition, 2004. APEC'04. Nineteenth Annual IEEE* (Vol. **2**, pp. 813-819) (2004).

[9] Miura, Y., Mizutani, T., Ito, M., & Ise, T. Modular multilevel matrix converter for low frequency AC transmission. In *Power Electronics and Drive Systems (PEDS), 2013 IEEE 10th International Conference on* (pp. 1079-1084) (2013).

[10] Erickson, R., Angkititrakul, S., & Almazeedi, K. A new family of multilevel matrix converters for wind power applications: Final report. *NREL National renewable energy laboratory US., Tech. Rep*. (2006).

[11] Casadei, D., Serra, G., Tani, A., & Zarri, L. Matrix converter modulation strategies: a new general approach based on space-vector representation of the switch state. *Industrial Electronics, IEEE Transactions on*, ***49***(2), 370-381 (2002).

[12] Lie, X., Clare, J. C., Wheeler, P. W., Empringham, L., & Yongdong, L. Capacitor clamped multilevel matrix converter space vector modulation.*Industrial Electronics, IEEE Transactions on*, ***59***(1), 105-115 (2012).

[14] Holtsmark, N., & Molinas, M. Matrix converter efficiency in a high frequency link offshore WECS. In *IECON 2011-37th Annual Conference on IEEE Industrial Electronics Society* (pp. 1420-1425). (2011).