A Survey on 3 phase Matrix Converter

Poonam B. Shinde[1], Prof. T. N. Date[2]

[1]Department of Electrical Engineering, K. K. W. I. E.E & R. Savitribai Phule University of Pune, India
[2]Department of Electrical Engineering, K. K. W. I. E.E & R. Savitribai Phule University of Pune, India

Abstract: *This paper presents a review of 3 phase matrix converter, which is an IGBT based frequency converter that fulfills all the requirements of the conventionally used rectifier and inverter with an intermediate dc link structures. Matrix converter can convert three phase AC input to three phase AC output with variable voltage amplitude and frequency directly, as it can produce any output frequency that is an integer multiple of the input frequency. The advantages of MC are such as lack of a dc link capacitor, bidirectional power-flow capability, sinusoidal input/output waveform, controllable input-power factor, light weight design, and long life. However, with these advantages there are still some problems with the use of matrix converter. This paper presents use of matrix converter in different applications for adjustable speed drives or variable frequency drives with problems need to be discussed to achieve desire performance of matrix converter.*

Keywords: *Matrix converter, ac-ac power converter, pulse width modulation, space-vector modulation method.*

I. Introduction

A direct AC-AC converter is proposed in reference [1] called Matrix Converter. A matrix converter (MC) consists of bidirectional switches that provide bidirectional power conversion. MCs have received considerable interest because they provide several advantages over back to back converter, such as the lack of a dc link capacitor, bidirectional power-flow capability, sinusoidal input/output waveform, controllable input-power factor, light weight design, and long life [2], [3], [4]. However with this advantages, Matrix converter still have some problems need to be solved, such as input filters, multistep commutation techniques, a control algorithm under unbalanced input voltages, common mode voltage (CMV) result in motor winding failures, and electromagnetic interference [5], [6], [7]. The idea of matrix converter was first presented by Gyugi in 1970 [8] and later in 1976 [9], which was described as a force commuted cyclo-converters. In [1], the first modulation strategy allows full control of the output voltages and input power factor. In this proposed algorithm the maximum voltage transfer ratio is limited to 0.5 and for controlling the input power factor knowledge of the output power factor is required. This voltage transfer ratio has been increased up to 0.866, with inclusion of third harmonics in the input and output voltage waveforms [2]. This value of voltage transfer ratio represents an intrinsic limitation of the three-phase matrix converter. The same technique has been extended in [3] with input power factor control having very powerful modulation strategy called optimum AV method. The modulation algorithm proposed in [4] based on a different approach, gives performance similar to the optimum AV method. With a feature of the fictitious dc link algorithm, there is a sensible increase of the maximum voltage transfer ratio up to 1.053 presented in [5]. This indirect matrix converter strategy consist the modulation as a two-step process, rectification and inversion. After this some PWM and SVM technique are developed. The rest of the report is as follows: Section 2 explores the matrix converter fundamental. Sections 3 and 4 describe the technological issues and application of matrix converter. Finally the conclusion is given.

II. Matrix Converter

The 3ph-3ph matrix converter scheme is shown in Figure 1. The matrix converter consists of nine bidirectional switches. Using bidirectional switches it is possible to connect any of input side phases a, b, or c to any of output side phases A, B, or C at any moment. The input phases of matrix converter should not be shorted due to the input voltage sources, and the output phases should not be opened due to the inductive nature of the load.

The switch function, $s\alpha\beta$ can be defined as,

$$S_{\alpha\beta} = \{ \begin{matrix} 0 \rightarrow S_{\alpha\beta} : open \\ 1 \rightarrow S_{\alpha\beta} : close \end{matrix}$$
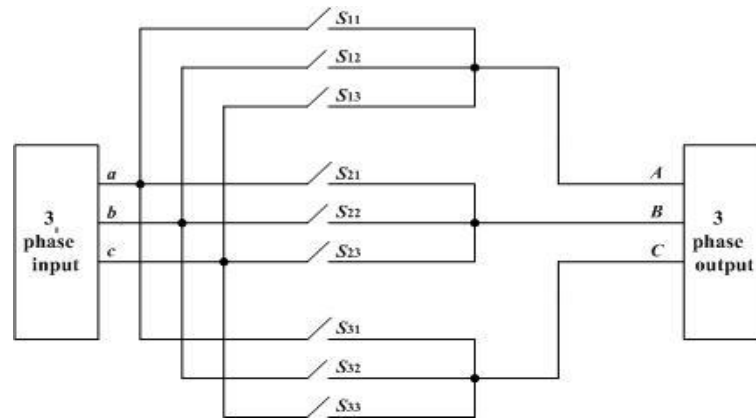
$$a \in \{a,b,c\}$$

$$\beta \in \{A, B, C\}$$

Fig.1 Three Phase AC-AC Matrix converter [10]

The restriction is expressed as,

$$S_{a\beta} + S_{b\beta} + S_{c\beta} = 1$$

The output voltages and the input currents of the matrix converter can be represented by the switching function S and the transposed S^T such as,

$$[V_{out}] = [S] \times [V_{in}]$$

$$\begin{bmatrix} V_{AN} \\ V_{BN} \\ V_{CN} \end{bmatrix} = \begin{bmatrix} S_{11} & S_{21} & S_{31} \\ S_{12} & S_{22} & S_{32} \\ S_{13} & S_{23} & S_{33} \end{bmatrix} \begin{bmatrix} V_{an} \\ V_{bn} \\ V_{cn} \end{bmatrix}$$

$$[I_{in}] = [S] \times [I_{out}]$$

$$\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{21} & S_{22} & S_{23} \\ S_{31} & S_{32} & S_{33} \end{bmatrix} \begin{bmatrix} i_A \\ i_B \\ i_C \end{bmatrix}$$

Where V_a, V_b, and V_c are input phase voltages: V_A, V_B and V_C are output phase voltages: I_a, I_b, and I_c are output currents.

III. Types Of Matrix Converter

Two basic types of AC-AC matrix converter structures have been proposed in literature, the Direct Matrix Converter (DMC) and the Indirect Matrix Converter (IMC). Both converters use the same number of power devices and can achieve the same quality of input current and output voltage if controlled using the same type of modulation, which means that they need the same input filters to achieve the same performance on the line current. Also both converters have the same limitations, mainly regarding the maximum output voltage available and power factor correction especially at very low output power. The main differences between the two converters are efficiency and losses distribution among the devices, Presented in [10], [11].

The matrix converters are further classified into many types [12].

A. Sparse Matrix Converter-In this type of matrix converter, the numbers of required switches are less, so the complexity of the gate drive circuit is reduced. The function is identical to direct matrix converter. 18 diodes and 15 switches are required for the sparse type matrix converter.

B. Very Sparse Matrix Converter-In this type, the number and diodes are increased and correspondingly the number of switches is reduced as compared to the sparse matrix converter. Though gate drive complexity is reduced but due to increase in the number of diodes, the conduction losses are increased.

C. Ultra Sparse Matrix Converter-Only unidirectional switches are used in the input stage of ultra-sparse matrix converter. So, these types of matrix converters are used for the variable speed drives which are of low dynamics. The topology of ultra-sparse matrix converter introduces phase displacement between input voltages and input currents. Only 12 diodes and 9 switching devices are required for this type of matrix converter.

D. Hybrid Matrix Converters-The hybrid matrix converter converts AC/DC/AC but does not use any dc link or reactive elements like capacitor or inductor. The hybrid matrix converters are further classified into two types depending on their operation. If hybrid matrix converter converts both voltage and current commutation in same stage then this is called hybrid direct matrix converters. If current and voltages are converted in different steps then these are called hybrid indirect matrix converter.

The control of the matrix converter topology is complex. Two modulation methods are:
1. Pulse Width Modulation (PWM) and
2. Space Vector Modulation (SVM).

Space vector modulation techniques for matrix converter are classified into two different strategies: Indirect space vector modulation which takes the advantage of a virtual dc link an Direct space vector modulation that provides direct conversion.[10][11].

IV.   Pulse Width Modulation

Pulse width modulation is a technique in which a message or a signal is encoded in such a way that it takes the form of a pulsating signal. This technique is used to encode any information that can be used for transmission. One of the main use of PWM is the control of power that can be supplied to the load. By constantly turning on and off the switching device between load and the source, the value of voltage required is achieved. This phenomenon is carried out at high switching frequency. By varying the duty cycle of the PWM signal, the amount of power supplied to the load is varied. Due to constantly on and off the switching device the desired output waveform will not be smooth. So, in order to keep the output waveform smooth, the switching frequency should be as high as possible. The switching frequency of a PWM signal is very high which enables the power electronic switching devices to be saturated hardly. So, between on and off state of the switching the transition interval is very short and hence, switching losses are also less. During off state of a controlled switch, there is no flow of current and during on state, the forward voltage drop is almost zero. So, using PWM signal for switching the switching losses are almost zero. Depending on the requirement, width of the pulse is modulated. The term duty cycle is defined as the ratio of on time of signal to the total time period of the signal. Duty cycle is represented in percentage like 50 percent, means on for half of the time and off for half of the time, 100 percent duty cycle defines fully on [12]. As the output of matrix converter is rich in harmonics. There are PWM techniques presented [43] to reduce harmonics namely sinusoidal pulse width modulation (SPWM), delta modulation (DM), and trapezoidal modulation (TM).

V.   Space Vector Modulation

Space vectors represent a three phase ac system of time variant quantities such as voltage, current or flux in a complex plane and were originally used to model the dynamic behavior of ac machines. However, they can be used to describe any kind of three-phase system, e.g. three phase power electronic converters and their modulation. In addition, space vector theory is used in the control of ac machines. The generated three phase voltages vary from each other by 120 degrees with the frequency same as of reference signal. The reference signal can be varied by varying the time period Ts as Ts = 1/fs, where fs is switching frequency. The reference signal can be generated from a three phase using d-q or α-β-γ transformation. Various combinations exist for selecting the switching sequence of switches but each strategy has its own switching losses. According to the type of loads space vector topology provides the best suitable switching sequence like pulsating load, non-linear load and static load etc.

The advantages of SVM are: THD of the output voltage is low, SVM offers low peak currents in controlled switches as compared to PWM, Higher performance, efficiency and reliability is achieved using SVM as compared to PWM based inverters of similar type.

The SVM approach was initially proposed in [6] to control only the output voltages, which has been successively developed in [7]–[10] to control the input power factor irrespective of the output power factor, to reduce the number of switch commutations in each cycle period and to fully utilize the input voltages. Also, it allows an immediate comprehension of the modulation process, a fictitious dc link, and not includes the third-harmonic components. As common mode voltage (CMV) is found as one of the major problem with matrix converter (MCs). There are several space vector modulation methods are introduced in recent years to suppress this CMV of MCs. In [13], [14] current control uses a predictive control to reduce CMV by adding a new quality function. Space-vector modulation has a clear comprehension of the modulation process and a relatively simple algorithm [15]. Therefore it is widely used CMV reduction method for MCs.

The SVM method is classified into two categories:
1. Indirect Space Vector Modulation (ISVM) and
2. Direct Space Vector Modulation (DSVM).

In the ISVM method, the CMV is reduced to 34 percent by using zero vectors [16] or by using four active vectors [17] to generate the desired output voltage. The DSVM method presented in [18] is more attractive due to the avoidance of additional third-harmonic components for CMV reduction in MCs. In DSVM method, use of vectors from different group have been introduced in recent years to limit this peak value of CMV to 42 percent, by replacing zero vectors with active vectors [19], or by replacing zero vectors with rotating vectors [20], or by using two lower input line-to-line voltages [21]. In [22] zero CMV has been achieved by using only rotating vectors but voltage transfer ratio is limited up to 0.5 only. All the previous methods reduce CMV, but they also increase the switching losses. In [23], paper proposes a new method which suppresses switching losses as well as CMV. This method uses three pairs of active vectors to generate the desired output-voltage vector. This method is compared with the other CMV reduction methods in [19] and [20], which provide the maximum voltage transfer ratio among the methods in [19]–[22].

VI.   Matrix Converter Technology

The matrix converter is an ac to ac power converter technology based on bidirectional semiconductor switches with minimal passive component. The control and modulation of a matrix converter is a very important research subject area. Once the modulation functions correctly and the converter output voltage follows the demanded voltage, the control of current and speed is same as compared to a VSI inverter. Due to the absence of bulky dc link component, these control methods provide some attributes of this converter technology such as controllable input power factor, sinusoidal input and output current. Since there is no energy storage component, any power pulsation at the output of the converter will also be present at the input. Therefore, the Matrix converter will not be ideal solution for pulsed loads when the input power quality is important for the application. It is highly sited for constant power loads such as sinusoidal motor drives like induction machines or permanent magnet synchronous machines.

The reliability of matrix converter is less than that of rectifier-inverter topologies because of the increase in the number of semiconductor used. The failure rate for the matrix converter is increased because of the increased number of devices, but the voltage stress on matrix converter devices is much reduced compared to the VSI topologies. Another advantage of matrix converter is input filters size. A typically sized input inductor for a matrix converter will almost smaller than the equivalently rated input inductor of a PWM rectifier. The input capacitors can be arranged in either a delta or star arrangement. The advantage in a delta arrangement is that capacitance of 1/3 of that of the star arrangement can be used whereas higher voltages must be sustained. The input inductor can be realized as a three-phase reactor or three individual inductances. The three-phase reactor offers a smaller solution but little common mode attenuation. Although this is not necessary, it may be important if an electro-magnetic interference (EMI) filter is to be integrated.

VII.   Application Of Matrix Converter

In [24], a fast technique to detect and localize a faulty power device using a correlation of the protective clamp circuit current and the output phase currents is presented. The converter then uses a fourth leg of the converter to continue the operation of the motor. In [25], a multistage fault diagnosis strategy based on the output current magnitudes and the input voltage sector is described together with a modulation strategy to avoid the use of the failed device. Fault-tolerant four-leg detection and modulation schemes are presented in [26]. These strategies can be employed to continue satisfactory operation after a failure has occurred. The potential size and weight advantages of the matrix converter and the elevated temperature capability due to the lack of dc-link components lend themselves to aircraft applications. In [27], prototype aircraft actuator projects have been reported in this application where matrix converter was chosen in because of its ability to be driven from a frequency wild supply.

A deep sea remotely operated vehicle (ROV) matrix converter drive application was the subject presented in [28]. Because of the extreme pressure experienced by ROVs and the lack of large dc-link components the matrix converter was chosen as a potential topology for the application. Research into the effects of high atmospheric pressure on the constituent parts of typical drive systems was carried out at 300 bar. The paper also discussed the use of observer-based sensor-less control of a PMSM using the matrix converter. The matrix converter has also been applied to drive the rotor circuit of a doubly fed induction generator in wind turbine applications using direct [29] and indirect matrix converters [30], with an advantage that a relatively low power four-quadrant power converter can be used to control a high-power generator system. In [31] research into the stability of such systems is presented, and the effects of rotor-side harmonics in a similar system were presented in [32]. A three phase to two phase matrix converter (reduced) was used to control a wind turbine generator and to drive a single phase transformer which was then connected through an ac rectifier to a dc transmission line presented in [33]. The efficiency comparison of this reduced matrix converter under different

modulation and control techniques was addressed in [34]. A novel matrix converter topology for the coupling of energy generation resources and the grid was presented in [35].

The application of the matrix converter in poly-phase generator systems has been investigated in [36] and [37]. In this case, with the input frequency and voltage the matrix converter also transform the number of phases. As the matrix converter circuit is modular, any number of input and output phases can be implemented. In [38], protection strategies for the matrix converter when used as a grid supply converter are discussed. A micro turbine generation system was described in [39]. The challenge here was the high input frequency of 2221 Hz. A new switching technique is proposed in order to minimize the number of switching events while maintaining harmonic performance. A use of a matrix converter using only unidirectional switches was described in [40], to drive an induction machine. Since using nine unidirectional switches, the current can only flow in one direction and current commutation process becomes inherently safe. Another one application of a unidirectional matrix converter was to drive a five-phase fault-tolerant brushless dc (BLDC) motor for the pump in an electro hydrostatic actuator [41]. A unidirectional matrix converter was also used to drive a switched reluctance motor (SRM) in [42]. In [43], multilevel inversion strategy is presented. In this study main objective was to reduce harmonics by observing stator current and speed-torque characteristics, considering load as an induction motor.

VIII. Conclusions

In this research, it is found that the output of the matrix converter is rich in harmonics and the voltage transfer ratio has a limitation of maximum value of 0.866. Upper limit of the range of variation of the output frequency is lower than the input frequency. Some of the methods which are employed for harmonic reduction are based on modulation techniques and conventional filter systems. With modulation technique PWM and SVM based three phases AC to AC matrix converters is developed. It is found out that PWM and SVM based matrix converter can be deployed to achieve any desired output and input characteristics. These converters are highly applicable for adjustable speed drives or variable frequency drives because of variable desired frequency can be attained. Secondly, any desired output voltage can be achieved. Therefore, interconnected systems can be free of synchronization issues by employing these converters.

References

[1]. Alensina and M. Venturini, '*Analysis and design of optimum amplitude nine switch direct ac-ac converter*. IEEE TRANS PAPER power electron*, vol4*, no. 1, pp.101-112, jan.1989.

[2]. D. Casadei, G. Serra, A. Tani, and L. Zarri "*Matrix converter modulation strategies: A new general approach based on space vector representation of switch state*," IEEE Trans. Ind. Electron*., vol. 49*, no. 2, pp. 370–381, Apr. 2002.

[3]. H. M. Nguyen, H. H. Lee, and T. W. Chun, "*Input power factor compensation algorithms using a new direct svm method for matrix converter,"* IEEE Trans. Ind. Electron., *vol. 58,* no. 1, pp. 232–243, Jan. 2011.

[4]. J.W. Kolar, T. Friedli, J. Rodriguez, and P.W. Wheeler, "*Review of three phase PWM AC–AC converter topologies,"* IEEE Trans. Ind. Electron*., vol. 58*, no. 11, pp. 4988–5006, Nov. 2011.

[5].] S. Chen, T. A. Lipo, and D. Fitzgerald, "*Source of induction motor bearing currents caused by PWM inverters*," IEEE Trans. Energy Convers., *vol. 11*, no. 1, pp. 25–32, Mar. 1996.

[6]. J.M.Erdman,R.J.Kerkman,D.W.Schlegel,andG.L.Skibinski,"*Effect of PWM inverters on AC motor bearing currents and shaft voltages,"*IEEE Trans. Ind. Appl., *vol. 32*, no. 2, pp. 250–259, Mar./Apr. 1996.

[7]. H. N. Nguyen and H. H. Lee, "*A new SVM method to reduce common mode voltage in direct matrix converter,"* in Proc. Int. Power Electron. Conf., 2014, pp. 1013–1020.

[8]. Gyugyi, L. (1970). "*Generalized theory of static power frequency changers"*. PhD thesis, Electrical Engineering Department, University of Salford, Salford, UK. 473 p.

[9]. Gyugyi, L. and Pelly, B.R. (1976). "*Static power frequency changers; theory, performance, and application"*. John Wiley & Sons, New York, USA. 442p.

[10]. Research Article "*Comparative Studies of Different Switching Patterns for Direct and Indirect Space Vector Modulated Matrix Converter"*. Amin Shabanpour,Sasan Gholami,and Ali Reza Seifi School of Electrical and Computer Engineering, Shiraz University, Shiraz 71345.

[11]. F. Gruson, P. Le Moigne, "*Comparison of Losses between Matrix and Indirect Matrix Converters with an Improved Modulation"* 978-1-4244-6392-3/10/$26.00 ©2010 IEEE.

[12]. "*Comprehensive Comparison of PWM and SVM based Three Phase AC to AC Matrix Converters"*,Automatic Control and System Engineering Journal, ISSN 1687-4811, *Volume 16*, Issue 2, ICGST, Delaware, USA, December 2016.

[13]. R. Vargas, U. Amman, J. Rodriguez, and J. Pontt, "*Predictive strategy to control common-mode voltage in loads fed by matrix converters*," IEEE Trans. Ind. Electron., *vol. 55*, no. 12, pp. 4372–4380, Dec. 2008.

[14]. R.Vargas, J.Rodriguez,C.A.Rojas, and M.Rivera,"*Predictive control of an induction machine fed by a matrix converter with increased efficiency and reduced common-mode voltage*," IEEE Trans. Energy. Convers, *vol. 29*, no. 2, pp. 473–485, Jun. 2014.

[15]. X. Li, M. Su, Y. Sun, H. Dan, and W. Xiong, "*Modulation strategies based on mathematical construction method for matrix converter under unbalanced input voltages,*" IET Trans. Power Electron*., vol. 6*, no. 3, pp. 434–445, Mar. 2013.

[16]. H.J.ChaandP.N.Enjeti,"*An   approach   to   reduce   common-mode   voltage   in   matrix converter,*"IEEETrans.Ind.Appl.,*vol.39*,no.4,pp.1151–1159, Jul./Aug. 2003.

[17]. F. Yue, P. W. Wheeler, and J. C. Clare*, "Mitigation of common-mode voltage in matrix converter,*" in Proc. 3rd Int. Conf. Power Electron., Mach. Drives, 2006, pp. 296–300.

[18]. D. Casadei, G. Serra, A. Tani, and L. Zarri "*Matrix converter modulation strategies: A new general approach based on space vector representation of switch state,*" IEEE Trans. Ind. Electron., *vol. 49*, no. 2, pp. 370–381, Apr. 2002.

[19].] H. M. Nguyen, H. H. Lee, and T. W. Chun, "*A novel method of common mode voltage reduction in matrix converters,*" Int. J. Electron., *vol. 99*, no. 1, pp. 1–14, Jan. 2012.

[20]. J. Espina, C. Ortega, L. D. Lillo, L. Empringham, J. Balcells, and A. Arias, "*Reduction of output common mode voltage using a novel SVM implementation in matrix converters for improved motor lifetime,*" IEEE Trans. Ind. Electron., *vol. 61*, no. 11, pp. 5903–5911, Nov. 2014.

[21]. H.H.Lee and H.M.Nguyen,"*An effective direct-SVM method for matrix converters operating with low-voltage transfer ratio,*" IEEE Trans. Power Electron., *vol. 28*, no. 2, pp. 920–929, Feb. 2013.

[22]. H. N. Nguyen and H. H. Lee, "*An enhanced SVM method to drive matrix converters for zero common-mode voltage,*"IEEE Trans.Power Electron*., vol. 30*, no. 4, pp. 1788–1792, Apr. 2015.

[23]. Huu-Nhan Nguyen, Student Member, IEEE, and Hong-Hee Lee, Senior Member, IEEE,"*A DSVM Method for Matrix Converters to Suppress Common-mode Voltage With Reduced Switching Losses* ",*,*" IEEE Trans. Ind. Electron.*,vol.31*,no.6,june2016 .

[24]. S.Khwan-on,L.deLillo,L.Empringham,andP.Wheeler,"*Fault-tolerant matrix converter motor drives with fault detection of open switch faults*," IEEE Trans. Ind. Electron*., vol. 59*, no. 1, pp. 257–268, Jan. 2012.

[25]. K. Nguyen-Duy, T.-H. Liu, D.-F. Chen, and J. Hung, "*Improvement of matrix converter drive reliability by online fault detection and a fault tolerant switching strategy,*" IEEE Trans. Ind. Electron., *vol. 59*, no. 1, pp. 244–256, Jan. 2012.

[26]. S. Kwak, "*Four-leg-based fault-tolerant matrix converter schemes based on switching function and space vector methods*," IEEE Trans. Ind. Electron*., vol. 59*, no. 1, pp. 235–243, Jan. 2012.

[27].] P. Wheeler, J. Clare, M. Apap, L. Empringham, L. De Lilo, K. Bradley, C. Whitley, and G. Towers, "*An electro-hydrostatic aircraft actuator using a matrix converter permanent magnet motor drive,*" in Proc. 2nd Int. Conf. (Conf. Publ. No. 498) PEMD, 2004, *vol. 2*, pp. 464–468.

[28]. P. Snary, B. Bhangu, C. Bingham, D. Stone, and N. Schofield, "*Matrix converters for sensorless control of PMSMs and other auxiliaries on deep sea ROVs,*" Proc. IEE Elect. Power Appl., *vol. 152*, no. 2, pp. 382–392, Mar. 2005.

[29]. L. Zhang, C. Watthanasarn, and W. Shepherd*, "Application of a matrix converter for the power control of a variable-speed wind-turbine driving a doubly-fed induction generator,*" in Proc. IECON, Nov. 1997*, vol. 2*, pp. 906–911.

[30]. R. Pena, R. Cardenas, E. Reyes, J. Clare, and P. Wheeler, "*Control of a doubly fed induction generator via an indirect matrix converter with changing dc voltage,*" IEEE Trans. Ind. Electron., *vol. 58*, no. 10, pp. 4664–4674, Oct. 2011.

[31]. R. Cardenas, R. Pena, G. Tobar, J. Clare, P. Wheeler, and G. Asher, "*Stability analysis of a wind energy conversion system based on a doubly fed induction generator fed by a matrix converter,*"IEEE Trans.Ind.Electron., *vol. 56*, no. 10, pp. 4194–4206, Oct. 2009.

[32]. K. Spiteri, C. Staines, and M. Apap, "*Power control of doubly fed induction machine using a rotor side matrix converter,*" in Proc. ISIE, 2010, pp. 1445–1450.

[33]. A. Garces and M. Molinas, "*Reduced matrix converter operated as current source for off-shore wind farms,*" in Proc. EPE/PEMC, 2010, pp. T12-149–T12-154.

[34]. A. Garces and M. Molinas, "*A study of efficiency in a reduced matrix converter for offshore wind farms,*" IEEE Trans. Ind. Electron., *vol. 59*, no. 1, pp. 184–193, Jan. 2012.

[35]. X. Liu, P. Wang, P. Loh, and F. Blaabjerg, "*A three-phase dual-input matrix converter for grid integration of two ac type energy resources,*" IEEE Trans. Ind. Electron*., vol. 60*, no. 1, pp. 20–30, Jan. 2013.

[36]. S. Turri, A. Lacaze, and J. Kauffmann, "*De-synchronized generator using a synchronous turbo-generator and a matrix converter,*" in Proc. IEEE IEMDC, 2003*, vol. 1*, pp. 60–66.

[37]. A. Beguin, A. Rufer, and A. Lacaze, "*Poly-phased matrix converter for large synchronous generators—Design of the voltage surge protection,*" in Proc. EPE, 2009, pp. 1–10.

[38]. B. Augdahl, H. Hess, and B. Johnson*, "Output protection strategies for matrix converters in distributed generation applications,*" in Conf. Rec. IEEE IAS Annu. Meeting, 2006, *vol. 4*, pp. 2082–2089.

[39]. H. Nikkhajoei and M. Iravani, "*A matrix converter based micro-turbine distributed generation system,*" IEEE Trans. Power Del., *vol. 20*, no. 3, pp. 2182–2192, Jul. 2005.

[40]. M. Ziegler, D. Domes, W. Hofmann, and S. El-Barbari, "*A new rectifier based topology for electrical drives: S-A-X-converter,*" in Proc. IEEE PESC/IEEE Power Electron. Spec. Conf., 2004*, vol. 4,* pp. 2924–2928.

[41]. C. Gerada, K. Bradley, X. Huang, A. Goodman, C. Whitley, and G. Towers, "*A 5-phase fault-tolerant brushless permanent magnet motor drive for an aircraft thin wing surface actuator,*" in Proc. IEEE IEMDC, May 2007, *vol. 2*, pp. 1643–1648.

[42]. A. Goodman, K. Bradley, and P. Wheeler, "*Evaluation of the single sided matrix converter driven switched reluctance motor,*" in Conf. Rec. IEEE IAS Annu. Meeting, 2004, *vol. 3,* pp.

[43]. Bibhu Prasad Ganthia, Preeti Kumari Sahu, Anindita Mohanty, *"Minimization of Total Harmonic Distortion Using Pulse Width Modulation Technique."* IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE) e-ISSN: 2278-1676,p-ISSN: 2320-3331, *Volume 10*, Issue 3 Ver. IV (May – Jun. 2015), PP 01-12 www.iosrjournals.org