International Journal of Electrical and Computer Engineering (IJECE)
Vol. 4, No. 1, Feburary 2014, pp. 138~144
ISSN: 2088-8708

Unity Power Factor at the Power Supply Side for MATRIX Converter Fed PMSM Drives

F Safargholi
Departement of Electrical Engineering, Amirkabir University of Technology Tehran, Iran

Article Info

Article history:

Received Oct 16, 2013
Revised Nov 6, 2013
Accepted Nov 29, 2013

Keyword:

MATRIX converter
PMSM
Power factor
SVM

ABSTRACT

To reduce the high harmonic components at the main power supply current and to improve the input voltage distortion for matrix converter, design of input filters characteristics for matrix converter system is very important. Also, the input filter can be applied to the near unity power factor operation at the input side. It can be used to improve the power quality of the input current. This paper represents a direct space vector modulation (SVM) method and introduces switching patterns for SVM method and then design of input filter to compensate the power factor is analyzed. Simulation results with inductive load (RL) and Permanent-magnet synchronous motor (PMSM) are shown to validate the effectiveness of the proposed method.

Corresponding Author:

F Safargholi,
Departement of Electrical Engineering,
Amirkabir University of Technology Tehran, Iran,
Email: f-safargholi@aut.ac.ir

1. INTRODUCTION

The MATRIX converter (MC) is a AC-AC power converter without energy storage devices that it can be fed a *m*-phase load from a *n*-phase source ($n \times m$) [1]. The matrix converter was presented by Peter Wood in 1979. He was used a simple switching matrix topology. Later, Alesina and Venturiniused this topology to develop the first ac to ac forced commutated converter [2].

The first modulation for matrix converter [3] presented by Alesina and Venturini in the 1980 that it does not control harmonic and unbalanced voltages. Later, three other more modulation introduced that include as the Space Vector Modulation (SVM) [4]-[6], the Rectifier and Inverter Vector Modulation (RIV) [7], [8] and natural modulation [9]. These modulations can be produce sinusoidal output voltages, even when there are unbalanced voltages or harmonics in the main network.

Almost, all of modulation strategies similar to multilevel converters can be applied for MC. In [10], Helle et al. have reviewed modulation strategies for MCs which have also proposed a double-sided SVM employing minimum line-to-line input voltages, or small vectors, to reduce switching losses (but at the expense of both input and output current waveform quality deterioration).

At the same time, researches analyze effect of filters between input side of a power supply and a MC [11]-[13]. The input filter should provide the near unity power factor operation at the input side. It can be used to improve the power quality of the input current which has the sinusoidal waveforms with harmonic components and to reduce the input voltage distortion which supplies to MC module [13].

Permanent-magnet synchronous motors (PMSMs) have achieved popularity in variable-speed drives that can be used as wind generation systems, electric propulsion systems, paper and textile mills and etc [14]. The efficiency of PMSMs is higher than induction motor (IM) because PMSMs do not carry rotor currents. Moreover, eliminating copper in the rotor allows the design of machines with smaller rotor diameters, actually resulting in smaller machine size with higher power density and lower rotor inertia [15].

This paper introduces a direct SVM method which uses from displacement angle between input current and input voltage of MC module to control of load or motor. Firstly, the theoretical analysis is carried out with the DSVM method, and secondly, theoretical analysis of filteris presented and simulated to achieve the near unity power factor at the power source side.

Simulation results on three phase inductive load and PMSM are shown to validate the theoretical analysis.

2. DIRECT SVM METHOD FORMATRIX CONVERTER

Three-phase matrix converter is shown in Figure 1 which has nine fully controlled bidirectional switches which directly connects the mains (input) phases to the load (output) phases.

Matrix converters can be used for the problem of converting AC power from one frequency to another. In general, the desirable characteristics of MATRIX converter are [16]:

- Sinusoidal input and output wave forms of Current and voltage with minimal higher order harmonics and no sub-harmonics.
- Bidirectional energy flow capability.
- Minimal energy storage requirements.
- A controllable power factor.

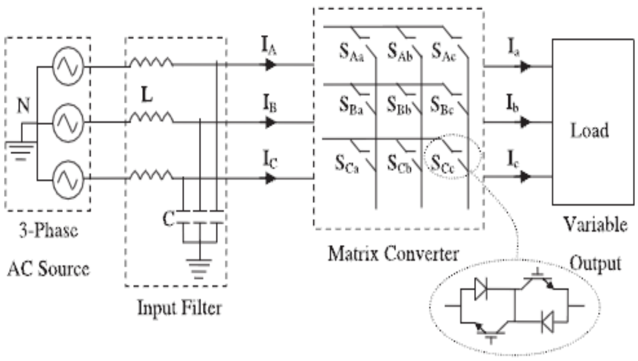


Figure 1. MATRIX converter schematic

From Figure 1 it has been shown that the control of the MC involves 2^9 different switch states (SCs). However, the input side of MC must never be shorted because the MC is fed by voltage sources and as well as to the inductive nature of the load, the output of MC must not be open. Therefore, according to these two basic control principles, only 27 SCs are valid.In the other 6 SCs, the output phases have connected to the different input. In this model, the output voltage vector and input current vector have variable directions and cannot be usefully used. From 27 combinations, only 21 SCs can be useful to the modern control algorithms for MC such as Space Vector Modulation, DTC method and etc. These SCs are shown in Table 1 that can be devised three group: group I (±1, ±2, …, ±9) includes the SCs which, two output phases have been connected to the same one of the other input phase; group II (0a, 0b, 0c) includes the SCs which, all output phases have been connected to a common input phase.

The state switches of the MC can be represented by a transfer matrix that is called transfer matrix *T* which has the following form:

$$T = \begin{bmatrix} S_{Aa}(t) & S_{Ba}(t) & S_{Ca}(t) \\ S_{Ab}(t) & S_{Bb}(t) & S_{Cb}(t) \\ S_{Ac}(t) & S_{Bc}(t) & S_{Cc}(t) \end{bmatrix} \tag{1}$$

Due to survival of the instantaneous power in the MCs, voltages and currents in one side can be calculated the accordancewith voltages and currents in the other side, at any instant [17]. The MC is connected to the grid, therefore the input line-to-neutral voltages arespecified and the output currents are achieved from load; therefore, the output line to- neutral output voltages and the input currents are found as follows:

$$\begin{bmatrix} \vec{v}_o \\ \vec{i}_i \end{bmatrix} = \begin{bmatrix} T & 0 \\ 0 & T^T \end{bmatrix} \times \begin{bmatrix} \vec{v}_i \\ \vec{i}_o \end{bmatrix} \tag{2}$$

where T^T is the transpose of the transfer matrix T.

The input and output voltages can be converted to space phasor form as:

$$\begin{bmatrix} \vec{v}_i \\ \vec{v}_o \end{bmatrix} = \frac{2}{3} \begin{bmatrix} 1 & e^{j2\pi/3} & e^{j4\pi/3} \\ 1 & e^{j2\pi/3} & e^{j4\pi/3} \end{bmatrix} \times \begin{bmatrix} v_A & v_a \\ v_B & v_b \\ v_C & v_c \end{bmatrix} = \begin{bmatrix} V_i.e^{j\alpha_i} \\ V_o.e^{j\alpha_0} \end{bmatrix} \tag{3}$$

where V_i and V_o are the magnitudes of the input and output voltage vectors, respectively, and α_i and $\alpha_o$are the phase angles of the input and output voltage vectors, respectively.

The input and output currents can also be written as follows:

$$\begin{bmatrix} \vec{i}_i \\ \vec{i}_o \end{bmatrix} = \frac{2}{3} \begin{bmatrix} 1 & e^{j2\pi/3} & e^{j4\pi/3} \\ 1 & e^{j2\pi/3} & e^{j4\pi/3} \end{bmatrix} \times \begin{bmatrix} i_A & i_a \\ i_B & i_b \\ i_C & i_c \end{bmatrix} = \begin{bmatrix} I_i.e^{j\beta_i} \\ I_o.e^{j\beta_0} \end{bmatrix} \tag{4}$$

whereI_i and I_o are the magnitudes of the input and output current vectors, respectively, and $\beta_i$and β_o are the phase angles of the input and output voltage vectors, respectively.

For each SC, the based on voltage vector and input line current vector, can be calculated α_i and β_i (According toFigure 2). Then, SCs must be selected according to Table 1.

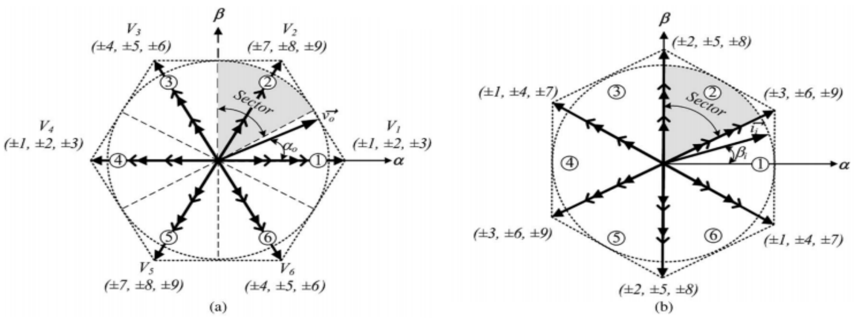


Figure 2. MC vectors. (a) Output voltage vectors. (b) Input current vectors.

3. MATRIX CONVERTER INPUT FILTER ANALYSIS

Input filter is designed to filter the high harmonic components of the input current of matrix converter module.

From Figure 3, following equations can be achieved.

$$v_s - v_i = L\frac{di_s}{dt} \tag{5}$$

$$i_{fc} = C\frac{dv_i}{dt} \tag{6}$$

$$i_s = i_{fc} + i_i \tag{7}$$

The main power supply frequency will be taken as the basic frequency in above equation. For achieving the load control requirements and the unity power factor at the power source side as well must be design input filter of MC according to following equation:

$$v_s = V_s.e^{j0} \tag{8}$$

$$V_i = V_s - j\omega L I_s = \sqrt{V_s^2 + (\omega L I_s)^2}.e^{-\tan^{-1}\frac{\omega L I_s}{V_s}} \tag{9}$$

$$I_i = (1-\omega^2 LC)I_s - j\omega C V_s = \sqrt{\left(\left(1-\omega^2 LC\right)I_s\right)^2 + (\omega C V_s)^2}.e^{-j\tan^{-1}\frac{\omega C V_s}{\left(1-\omega^2 LC\right)I_s}} \tag{10}$$

Table 1. Possible switching configurations of MC

configuration	MATRIX state	α_o	β_i
+1	122	0	$-\pi/6$
-1	211	0	$-\pi/6$
+2	233	0	$\pi/2$
-2	322	0	$\pi/2$
+3	311	0	$7\pi/6$
-3	133	0	$7\pi/6$
+4	212	$2\pi/3$	$-\pi/6$
-4	121	$2\pi/3$	$-\pi/6$
+5	323	$2\pi/3$	$\pi/2$
-5	232	$2\pi/3$	$\pi/2$
+6	131	$2\pi/3$	$7\pi/6$
-6	313	$2\pi/3$	$7\pi/6$
+7	221	$4\pi/3$	$-\pi/6$
-7	112	$4\pi/3$	$-\pi/6$
+8	332	$4\pi/3$	$\pi/2$
-8	223	$4\pi/3$	$\pi/2$
+9	113	$4\pi/3$	$7\pi/6$
-9	331	$4\pi/3$	$7\pi/6$
0_a	111	–	–
0_b	222	–	–
0_c	333	–	–

Finally, power factor of the main power supply current (the MC input current) can be calculated by the equation 11.

$$PF = \cos(\tan^{-1}(\frac{\omega C V_s}{(1-\omega^2 LC)I_s})) \tag{11}$$

According to equation 11, the input power factor depends on 3 criteria: *L*, *C* values of input filter and fundamental input current amplitude I_s which depends on the output load conditions of MC. In order to improve power factor, the small *L*, *C* values design are used. However, with the small LC design, the main power supply current contains many higher harmonic components due to the well-known higher cut-off frequency ($f_{cut-off} = 1/(2\pi\sqrt{LC})$).

As a result, the space vector modulation (SVM) technique to guarantee the near unity power factor operation at the power supply side of MC.

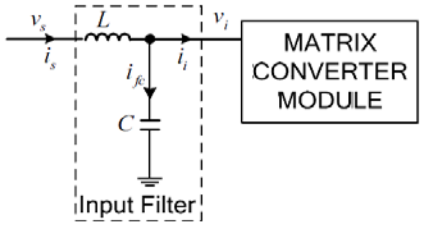


Figure 3. Equivalent circuit of input filter of MATRIX converter

4. SIMULATION RESULT

The simulation has been on both 3-phase RL load and PMSM in The Environment of Matlab/simulink. The simulation parameters for RL load are listed in appendix A and parameters for PMSM are listed in appendix B. Figure 4 is shows the input/output waveforms of matrix converter with and without the input filter that is simulated for RL load.As can be easily seen, the unity power factor can be achieved in input of matrix converter by input filter. Also, the input current of matrix converter in the case without filter contains so many high harmonic components. The input filter can eliminate all these high harmonic components above the filter cut-off frequency.

In this paper, the offline method is used to design the input filter of MC for anytime to correct the main input power factor and reduce harmonic components. Furthermore, the unity power factor at the input of MC can easily be achieved main power supply side. This offline method requires the fully understanding of input power factor, the output load power. The closed-loop compensation method can also be applied to the filter of MC with the online compensation angle.

Figure 5 and Figure 6 are shows the input/output waveforms of matrix converterusing the SVM method without and with the input filter that is simulated for PMSM, respectively. The motor operates at rated speed and the load torque decreases as the down steps response. As can be easily seen, the main input power factor reduces quickly as the load torque decreases.

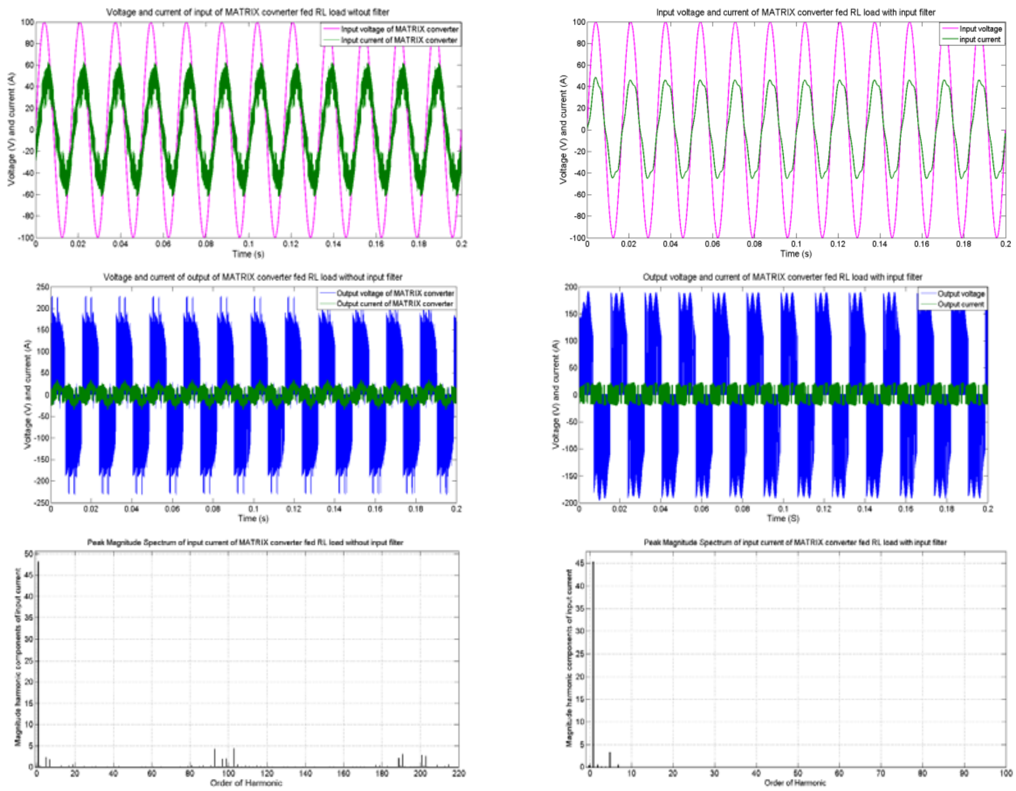


Figure 4. Waveform of voltage and current of MATRIX converter fed RL load

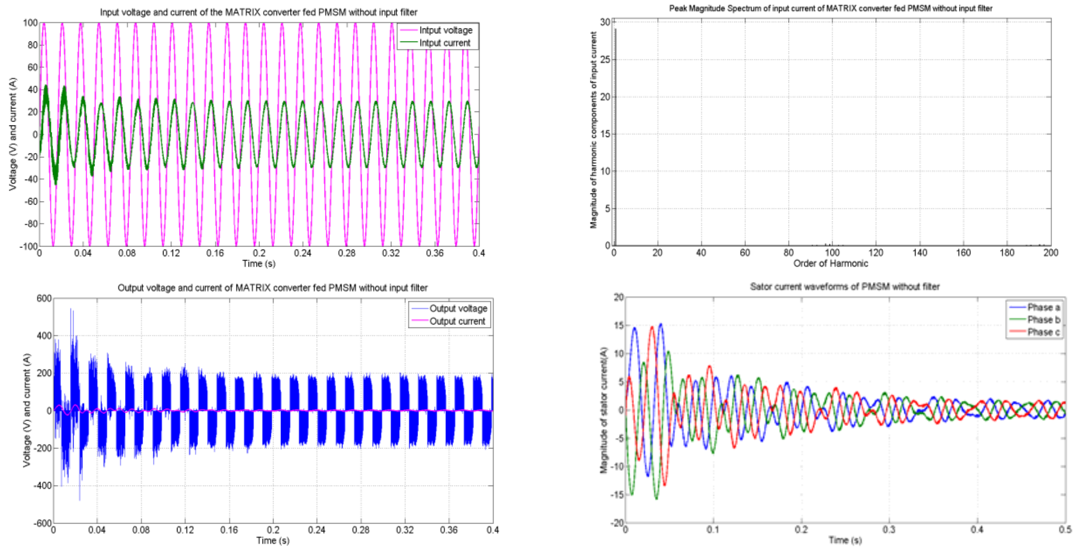
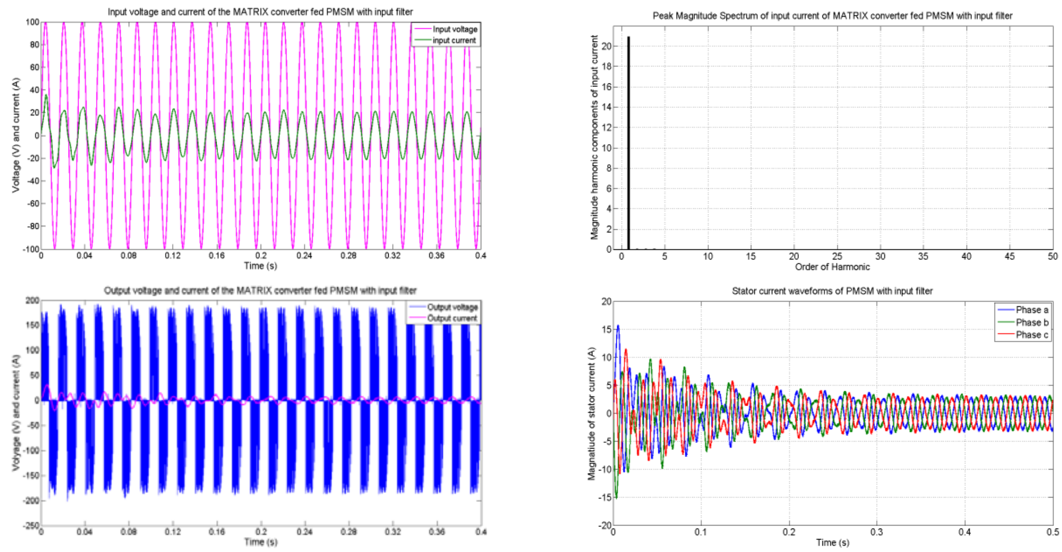


Figure 5. Waveform of voltage and current of MATRIX converter fed PMSM without input filter



5. CONCLUSION

This paper represents a direct space vector modulation (SVM) method technique for matrix converter that feeds RL load or PMSM derives. Also, the input filter is applied to the near unity power factor operation at the input side. It is used to improve the power quality of the input current. Simulation results with inductive load (RL) and Permanent-magnet synchronous motor (PMSM) are shown to validate the effectiveness of the proposed method.

APPENDIX A:
Main power supply 220V/60Hz. Three-phase RL load 10Ω, 20mH

APPENDIX B:
Rated power: 380V/60Hz & Stator phase resistance (Rs): 2.875 Ω& Stator inductance [L_d, Lq]: [8.5e-3, 8.5e-3] H

REFERENCES

[1] P Wheeler, J Rodríguez, J Clare, L Empringham and A Weinstein. "Matrix converters: A technology review". *IEEE Trans. Ind. Electron.* 2002; 49(2): 276–288.

[2] G Venturini M, Alesina A. "The generalized transformer: a new bi-directional sinusoidal waveform frequency converter with continuously adjustable input power factor". *IEEE power electronics specialist conference (PESC)*. 1980: 242–52.

[3] Alesina, MGB Venturini. "Analysis and Design of Optimum- Amplitude Nine-Switch Direct AC-AC Converters". *IEEE Trans. Power Electronics*. 1989; 4(1): 101-112.

[4] D Casadei, G Grandi, G Serra, A Tani. "*Space vector control of matrix converters with unity input power factor and sinusoidal input/output waveforms*". In proc. European Power Electronics Association EPE. 1993: 170-175.

[5] HH Lee, HM Nguyen, TW Chun. "*New direct-SVM method for matrix converter with main input power factor compensation*". In proc. Industrial Electronics, 2008. IECON 2008. 2008: 1281-1286.

[6] L Helle, KB Larsen, AH Jorgensen, S Munk-Nielsen, F Blaabjerg. "Evaluation of modulation schemes for three-phase to three-phase matrix converters". *IEEE Trans. Ind. Electron*. 2004; 51(1): 158-171.

[7] T Yoshinaga, T Terunuma, K Matsuse. "*Basic characteristic of parallel-connected dual induction motor drives with matrix converter*". In proc. Industrial Electronics, 2008. IECON 2008. 2008: 584-589.

[8] O Simon, M Bruckmann, H Schierling, J Mahlein. "Design of Pulse Patterns for Matrix Converters". *The European Power Electronics EPE Journal*. 2003; 13(1).

[9] A Ishiguro, T Furuhashi. "A Novel Control Method for Forced Commutated Cycloconverters Using Instantaneous Values of Input Line-to-Line Voltages". *IEEE Trans. Industrial Electronics*. 1991; 38(3): 166-172.

[10] L Helle, KB Larsen, AH Jorgensen, SM Nielsen, and F Blaabjerb. "Evaluation of modulation schemes for three-phase to three-phase matrix converters". *IEEE Trans. Ind. Electron.* 2004; 51(1): 158–170.

[11] P Wheeler, D Grant. "Optimized input filter design and low-loss switching techniques for a practical matrix converter". *IEE Proceedings of Electric Power Applications*. 1997; 144(1): 53- 60.

[12] D Casadei, G Serra, A Tani, L Zarri. "*Stability analysis of electrical drives fed by matrix converters*". Proceedings of the 2002 International Symposyum on Industrial Electronics, ISIE 2002. 2002; 4: 1108-1113.

[13] S Ferreira Pinto, J Fernando Silva. "Input filter design for sliding mode controlled matrix converters". *Power Electronics Specialists Conference, 2001. PESC.* 2001 IEEE 32nd Annual. 2001; 2: 648- 653.

[14] C Ortega, A Arias, C Caruana, J Balcells, and GM Asher. "Improved Waveform Quality in the Direct Torque Control of Matrix-Converter-Fed PMSM Drives". *IEEE Transactions on Industrial Electronics*. 2010; 57: 2101-2110.

[15] JY Chai, YH Ho, YC Chang and CM Liaw. "On acoustic-noise reduction control using random switching technique for switch-mode rectifiers in PMSM drive". *IEEE Trans. Ind. Electron*. 2008; 55(3): 1295–1309.

[16] E Babaei, SH Hosseini, and GB Gharehpetian. "Reduction of THD and low order harmonics with symmetrical output current for single-phase ac/ac matrix converters". *International Journal of Electrical Power & Energy Systems*. 2010; 32: 225-235.

[17] L Empringham, P Wheeler, and JL Clare. "*Intelligent commutationof matrix converter bi-directional switch cells using novel gate drivetechniques*". in Proc. IEEE PESC. 1998; 1: 707–713.

BIOGRAPHY OF AUTHOR

Farhad Safargholi was born in Iran on January 19, 1990. He received the Engineering degree from the Bu-Ali Sina University, Hamadan, Iran, in 2012, where he is currently working toward the Master degree in Amirkabir University of Technology (AUT), Tehran, Iran. His research interests focus on power electronics, modulation strategies, FACTS, load flow and harmonic distortion of power system.