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Firing Angles Calculation of Multilevel Inverters using Optimization Techniques



Abstract: - Power electronics field is nowadays growing as a strong and most widely used field in numerous applications such as telecommunication, transportation, aerospace and industrial applications. Power converters such as multilevel inverters are highly recommended in the industrial applications due to the prominent features and advantages offered by these. Some of the advantages are minimum total harmonic distortion, minimum switching losses, better output voltage quality and power quality etc. But the designing of a multilevel inverter system is a very crucial step and it should consider the parameters like the choice of suitable topology of multilevel inverter, number of levels used in multilevel inverter, firing schemes and selection of the optimization techniques. Optimization techniques are required to obtain the optimized firing angles for the semiconductor devices used in the multilevel inverter system, Proper choice of firing angles leads to lower harmonics and lesser total harmonic distortion in multilevel inverter system. Therefore, the foremost challenge with the designing of a multilevel inverter system is the selection of optimum firing angles for the switching devices. In this research paper, two algorithms i.e. Particle Swarm Optimization (PSO) algorithm and Genetic Algorithm (GA) have been used for finding the optimum firing angles of a seven level Cascaded H-bridge (CHB) inverter.

Keywords: Multilevel Inverter (MLI); Cascaded H-bridge (CHB); Particle Swarm Optimization (PSO); Genetic Algorithm (GA); Total Harmonic Distortion (THD); Modulation Index (MI)=

1. Introduction

Multilevel inverter (MLI) plays a crucial role in the field of power electronics and widely been employed in high power low voltage applications [1, 2]. Multilevel inverters (MLIs) have been emerged as the most widely used power electronics devices in the industries during the past few years, because of their numerous advantages such as low harmonics, low switching losses, lower electromagnetic interferences and better output etc.

Conventional multilevel inverters such as diode clamped, flying capacitor and cascaded H-bridge (CHB) inverters [3] have widely been used over last few decades. Neutral-point clamped MLI (NPC-MLI), flying capacitor based MLI (FC-MLI), and cascaded H-bridge MLI (CHB-MLI) are the three topologies of MLI system, which are used for industrial as well as commercial application.

Nowadays, conventional inverters are become completely obsolete and MLIs have taken the important place. Even in, controllers used in power system networks, MLIs are playing a vital role. For better operation and management of power system networks, MLIs are being used in controllers such as Static Synchronous Compensator (STATCOM). In an electrical power system, control of voltage is very essential for better and reliable operation of the electrical appliances. A constant voltage profile and reactive power management in the transmission lines is very important to avoid any damage for e.g. overheating of motors and generators, to reduce the losses in the transmission lines and to improve the ability of a power system to withstand and prevent power outages. Reactive power compensator devices such as STATCOM in the transmission lines provides the better management of reactive power, which further leads to more reliability and the commercial transactions can be done across the transmission lines [4-5]. This paper is organized into five sections. First section presents the introduction related to MLIs and MLI based STATCOM. PSO based MLI is demonstrated in section 2. Design of STATCOM controller is depicted in section 3. Results and discussion is shown in section 4. Finally, section 5 depicts the conclusion part.

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2. PSO Based Multilevel Inverter System

PSO optimization algorithm is being used for calculation of switching angles of MLI system [6-7]. Here, cascaded H-bridge (CHB) topology based seven level inverter is implemented. The objective function has been selected in such a way so as to get the three optimized switching angles (α_i). The harmonic elimination problem is converted into optimization problem. For the proposed seven level CHB MLI, fifth and seventh harmonics can be mathematically represented as:

$$V_5 = \cos 5\alpha_1 + \cos 5\alpha_2 + \cos 5\alpha_3$$

$$V_7 = \cos 7\alpha_1 + \cos 7\alpha_2 + \cos 7\alpha_3$$

(1) Objective function is to minimize these harmonics as: $y = (abs(V_5) + abs(V_7))$

(2)

The particle swarm optimization algorithm results in the optimal switching angles for the proposed seven level CHB MLI, which are depicted in Table 1. Optimal angles are 16.35° , 35.68° and 60.57° obtained at modulation index 0.75 that results in minimum THD.

Table 1 Switching Angles of the Proposed 7 Level CHB MLI using PSO

Modulation Index (M)	α_1 (degree)	α_2 (degree)	α_3 (degree)	V1(rms)	V5	V7	THD (%)
0.1	16.07	33.45	80.43	33.17690	0.00567	1.89765	6.27
0.15	14.21	35.02	82.45	34.00231	0.01235	0.09743	6.5
0.2	13.2	37.23	83.33	37.13201	1.23486	1.23486	6.23
0.25	16.09	24.98	63.98	38.23467	1.03765	1.03897	6.17
0.3	18.76	22.32	58.85	46.78002	0.23459	0.09683	6.23
0.35	10.97	28.34	53.75	47.23879	0.03726	0.08763	6.07
0.4	5.77	30.97	54.34	53.40023	0.04973	0.09247	6.06
0.45	14.65	25.46	56.04	56.93201	0.08543	0.06797	6.25
0.5	17.23	23.67	58.67	67.86435	1.23407	1.23801	6.37
0.55	15.56	35.03	65.78	63.7432	0.00923	0.09843	6.09
0.6	12.45	41.03	83.96	72.00678	0.06741	0.08765	6.05
0.65	16.46	40.78	71.56	70.43085	0.23517	0.12871	6.17
0.7	18.23	43.79	64.56	72.00543	0.43891	0.34231	6.21
0.75	16.35	35.68	60.57	76.34569	0.00356	0.00793	6.01
0.8	12.87	28.03	58.65	67.40321	1.07651	0.65923	6.09
0.85	10.48	28.45	56.34	63.00267	1.00567	0.78451	6.27
0.9	8.93	29.04	54.77	58.45201	0.01876	0.04321	6.08
0.95	8.7	29.46	54.89	57.23765	0.23981	0.05672	6.21
1	7.78	30.38	55.03	62.60256	0.08954	0.84531	6.09

3. Design of STATCOM Controller

Design of STATCOM controller is also an essential step. The most important function of a STATCOM controller is to enhance the transmission power by injecting or absorbing the power to or from the transmission

network. Direct control strategy is proposed for the STATCOM controller here. In this strategy, output reactive current is controlled by the internal voltage of the inverter. Figure 1 represents the STATCOM controller block diagram.

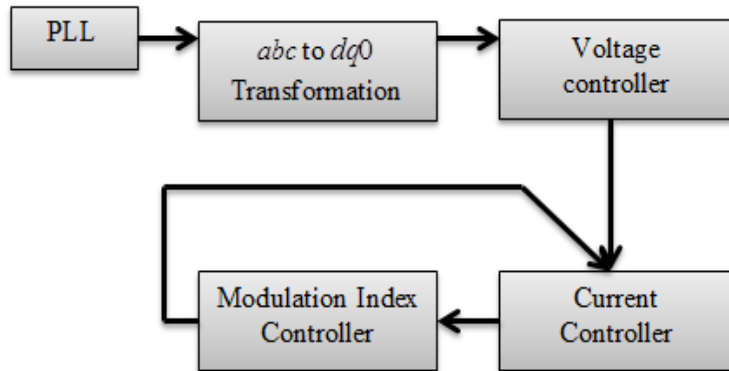


Figure 1 STATCOM Controller Block Diagram

Here, the three phase quantities such as voltage and current are firstly converted into direct and quadrature components in a rotating reference frame as given by equation (3).

$$\begin{bmatrix} V'_\alpha \\ V'_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} V'_a \\ V'_b \\ V'_c \end{bmatrix} \tag{3}$$

Where V_a, V_b and V_c are the three phase voltages in abc coordinates, while V'_α and V'_β are the three phase voltages in $\alpha\beta$ coordinate. System voltage (V_s) is given as:

$$V_s = \begin{bmatrix} V_d \\ V_q \end{bmatrix} = \begin{bmatrix} V_s \\ 0 \end{bmatrix} \tag{4}$$

V_d and V_q are the system voltages in d and q coordinates respectively. Now in dq coordinate system, STATCOM can be expressed as:

$$L \frac{d}{dt} \begin{bmatrix} I_d \\ I_q \end{bmatrix} + \omega L \begin{bmatrix} -I_q \\ I_d \end{bmatrix} + R \begin{bmatrix} I_d \\ I_q \end{bmatrix} = \begin{bmatrix} V_{scd} \\ V_{scq} \end{bmatrix} \tag{5}$$

Here, L and R are the inductance and resistance of coupling capacitor, I_d and I_q are the system currents in d and q axis, V_{scd} is the difference of system voltage and inverter voltage in d coordinates, V_{scq} is the difference voltage in q coordinates, ω is the angular frequency. MLI based STATCOM's output voltage and current is regulated through the switching angles of switching devices used in MLI and always contain harmonics. STATCOM's output voltage contains fundamental and higher order harmonics, represented as:

$$E_s = H_f + H_{f1} + H_{f2} + \dots$$

$$E_s = H_f + \sum_{i=1,2,3,\dots} H_{fi} \tag{6}$$

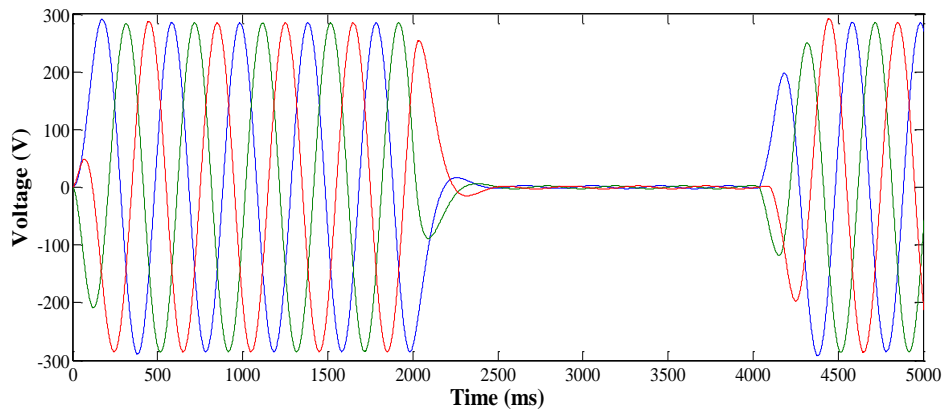
E_S is the RMS output voltage of MLI based STATCOM, H_f is the RMS fundamental harmonic and H_{fi} is the higher order harmonics present in the output of STATCOM.

4. Results and Discussion

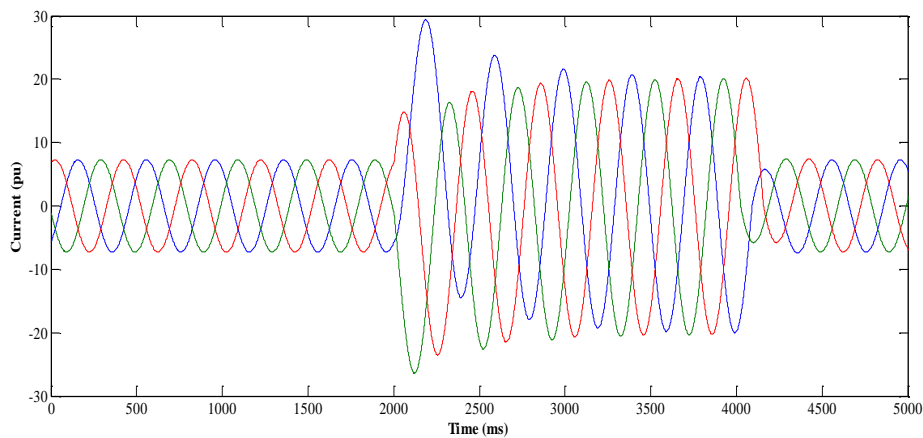
Voltage stability and quality of power is not so much good in a power system without STATCOM. In this context, use of STATCOM in a power system leads to satisfactory results by providing better voltage stability, improved power factor and better power quality. Three cases have been considered for the analysis of the proposed work. Here, case 1 shows the results of the existing power system without STATCOM, case 2 shows the results of existing three-level inverter with STATCOM design and the case 3 shows the proposed 7 level inverter with STATCOM design results.

Case 1: Power System without STATCOM

First case involves the design of a power system without a STATCOM. A three phase source and a fixed RL load are being taken. Discrete second order filter, working as a low pass filter with cut off frequency 50 Hz is also taken for filtering of voltage and current. Output voltage and current waveform obtained from the simulink model is shown in Figure 2. Lots of harmonics are there in both waveforms. In the output voltage, after 2000 ms, voltage abruptly gets reduces to 0 volt, holds this value up to 4200 ms and then again increases. This leads to instability and uncertainty in the voltage and power system does not remain any more reliable one. THD obtained in this case is also very high i.e. 22.36 % and represented in Figure 3. Therefore, there must be some controlling mechanism in the power system, which can control this uncertainty in the output voltage and current and also can maintain the voltage stability in the power system.



(a)



(b)

Figure 2 Power System without STATCOM for (a) Obtained Voltage (b) Obtained Current

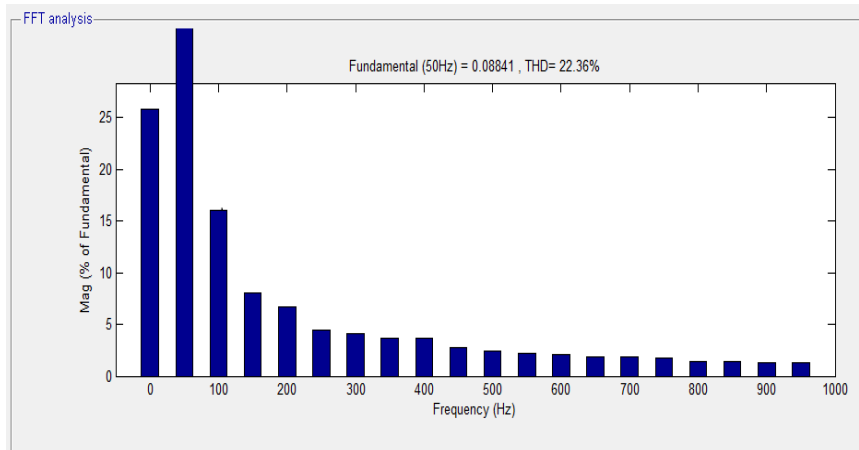
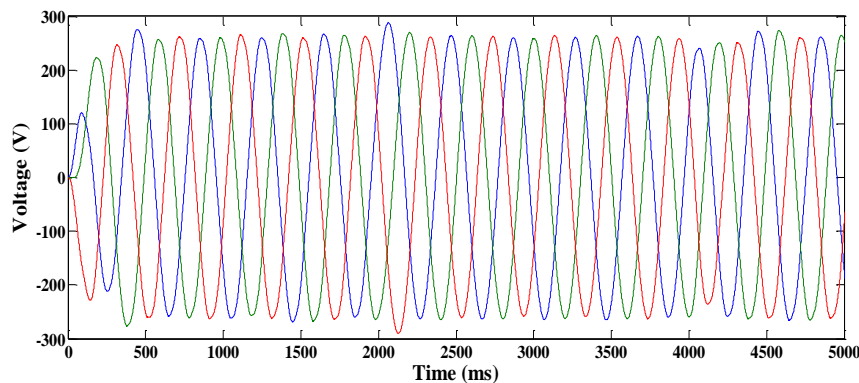


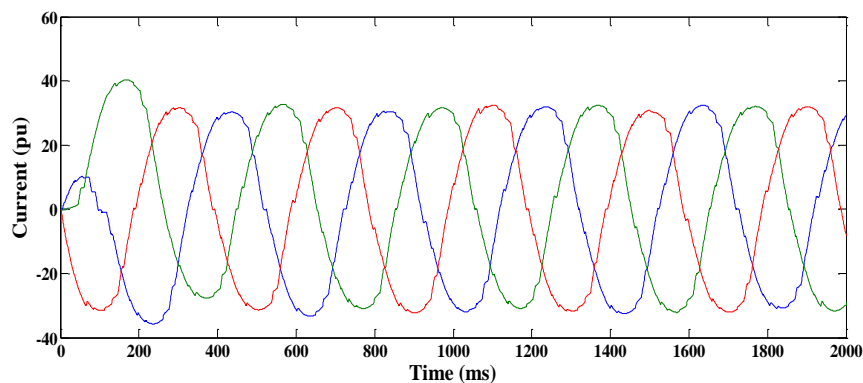
Figure 3 Obtained THD in Power System without STATCOM

Case 2: Power System Interfaced with Three Level CHB STATCOM

Taking into consideration the need of a STATCOM, power system interfaced with three level CHB STATCOM is proposed. In the proposed system, pulse width modulation (PWM) technique is used for firing of semiconductor devices (IGBTs here) of three level CHB STATCOM. Output voltage and current waveform obtained from the simulated model is represented in Figure 4. From Figure 4, it is clear that power system with STATCOM results in better output with lesser harmonics as compared to first case. Also, the THD obtained in this case is 13.92 % as represented in Figure 5, which is less than THD obtained from power system without STATCOM.



(a)



(b)

Figure 4 Obtained Current in Power System Interface with 3 Levels CHB STATCOM for (a) Obtained Voltage (b) Obtained Current

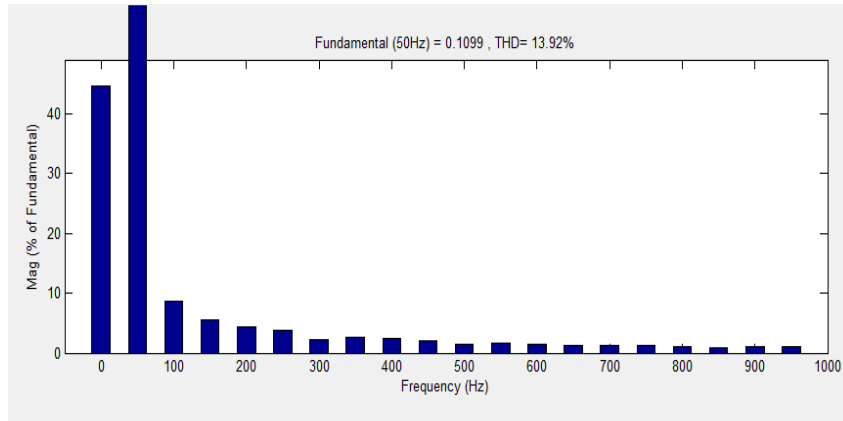


Figure 5 Obtained THD in Power System with 3 Levels CHB STATCOM

Case 3: Power System Interfaced with Seven Level CHB STATCOM

On increasing the levels of MLI, better stepped sinusoidal output voltage is obtained. In third case, MLI based STATCOM is interfaced with the power system. CHB configuration of MLI with seven level is being used and is connected in parallel with the transmission lines. Capacitor voltage of STATCOM is being controlled by the proposed system and also for any load changes supply voltage is maintained. Output voltage and current waveforms are having lesser harmonics and ultimately reduced THD. Obtained THD is 5.42% as depicted in Figure 6, which is less than case1 and 2. Therefore, proposed MLI based STATCOM interfaced with a power system provides a reliable system with reduction in THD and better output voltage.

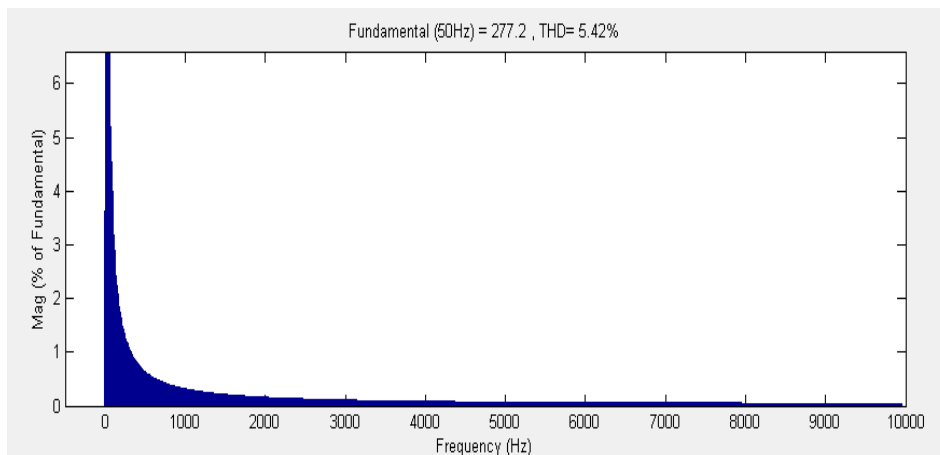


Figure 6 Obtained THD in Power System with 7 Levels CHB STATCOM

Performance of the proposed system in terms of THD and power factor is shown in Table 2. It is clear from the table that on increasing the number of levels in MLI based STATCOM, THD reduces and power factor improves but complexity of the system also increases. Therefore, careful selection of number of levels in MLI is needed and also the balance between complexity and harmonics must be maintained.

Table 2 Performance of the Proposed Systems

S. No.	Power System Description	THD (%)	Power Factor
1	Power System without STATCOM	22.36	0.678
2	Power System with 3 Level	13.92	0.785

STATCOM

3	Power System with 7 Level STATCOM	5.42	0.977
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The comparison graph for three cases such as power system without a STATCOM, Power system interfaced with three levels CHB STATCOM and the power system with the seven level STATCOM is shown in Figure 7. The comparison graph clearly depicts that the performance of the proposed work is better than the existing models.

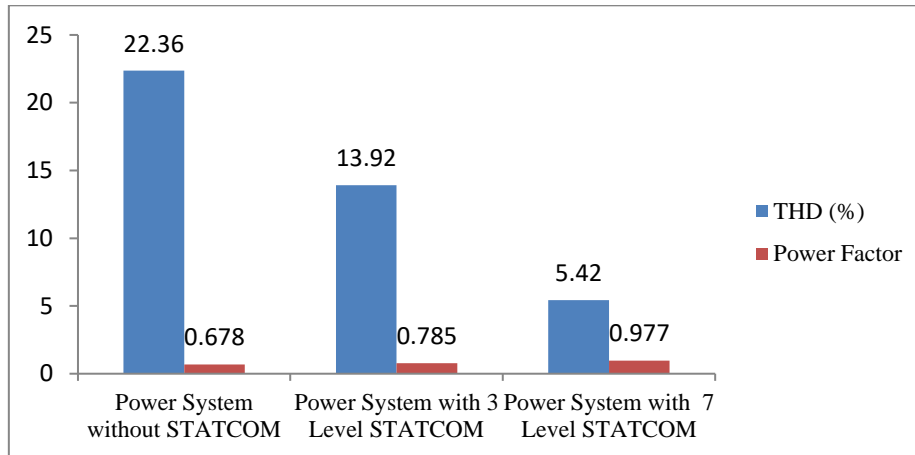


Figure 7 Comparisons of Proposed Systems

6. Conclusion

In this paper seven level CHB topology based on STATCOM interfaced power system are designed. The output voltage, output current and THD for proposed power system with seven level STATCOM and existing power system without a STATCOM model, Power system interfaced with three levels CHB STATCOM model are observed and it was concluded that the proposed power system with seven levels CHB based STATCOM works satisfactorily in terms of power factor and Total Harmonics Distortion. Optimized three firing angles of H-bridges are calculated using PSO, which further leads to minimum THD. The proposed system ensures the better voltage stability by reducing the THD of output voltage and current from 22.36 % to 5.42 %. The improvement in power factor makes the system more reliable and also the seven levels of CHB topology can be equally applied to increase the system performance and efficiency.

References

- [1] S. H. Ashan and M. Monfared: Design and comparison of nine-level singlephase inverters with a pair of coupled inductors and two dc sources, *IET Power Electronics*, Vol. 9, No. 11, pp. 2271-2281, 2016
- [2] S. H. Ashan and M. Monfared: Generalised single-phase N-level voltagesource inverter with coupled inductors, *IET Power Electronics*, Vol. 8, No. 11, pp. 2257-2264, 2015.
- [3] J. Rodriguez, J.Holtz, H .A. Rub, and G. Baoming, "Medium voltage multilevel converters-state of the art, challenges and requirements in the industrial applications", *IEEE Transactions on Industrial Electronics*, vol. 57, no. 8, pp. 2581-2596, 2010.
- [4] I. Colak, E. Kabalci, and R. Bayindir, "Review of multilevel voltage source inverter topologies and control schemes," *Energy Conversion*, Elsevier, vol. 52, no. 2, pp. 1114-1128, 2011.
- [5] M. Saeedian, J. Adabi and S. M. Hosseini, "Cascaded multilevel inverter based on symmetric-asymmetric DC sources with reduced number of components", *IET Power Electronics*, Vol. 10, No. 12, pp. 1468-1478, 2015.
- [6] A. L. Kouzou, A. Krama, S. S. Refaat and H. Abu-Rub, "Selective harmonic elimination PWM for a cascaded MLI," *International Conference on Industrial Technology*, Argentina, 2016.
- [7] M. S. Sivagama Sundari and D. Periyasamy, "PSO based selective harmonic elimination PWM for cascaded H-bridge MLI," *IOP Conference Series: Material Science and Engineering*, Vol. 1012, 2016.