Sequential Quadratic Programming (SQP) Based Selective Harmonic Elimination for Multilevel Inverter

N.Vinoth kumar, M.Pradish

Abstract: ***Multilevel inverters are most preferable due to it reduced harmonic content and clean waveform. Since the Total Harmonic Distortion (THD) is a major selection criterion for an inverter, the reduction of the same must be most important for power electronics engineer. There are options for reduction of THD, usually filters are employed at output side to reduce THD and harmonic content. Also mathematically, it can be reduced using optimization techniques. The stepped voltage/current waveform of a MLI may synthesis a sinusoidal waveform with reduced THD, if the levels of MLI are increased. Lower order harmonics are dominating in nature which needs to be reduced. This proposed paper brings out a unique technique for suppressing/reducing the lower order harmonics using Selective Harmonic Elimination (SHE) technique. Sequential Quadratic Programming (SQP) algorithm is a optimizing algorithm which is used to find the angles where fifth and seventh harmonic are suppressed in a seven level inverter. SQP based optimized results shows better performance such as reduction of Total Harmonic Distortion (THD) and suppressing of lower order harmonics which is compared with particle swarm optimization (PSO) technique. Simulation results and experimental results proves the proposed concept***

Keywords: ***Multilevel inverter, SHE techniques, SQP, Harmonics elimination***

I. INTRODUCTION

Multilevel inverters (MLI) are widly applied in various applications [1]. MLIs are operating with less switching losses due to the operating switching frequency are selected less. Other significant features are: the waveform with harmonic less, the structure of MLI shall ensure the dynamic voltage sharing, less size, volume and space [2].

There are three main type of MLI which is shown below [3-4].

1.Diode Clamped MLI (DCMLI)
2. Capacitor clamped or Flying Capacitor MLI (FCMLI)
3. Cascaded H-Bridge MLI (CHBMLI) [3-4].

In [5], the main type of modulation and control techiques are addressed to get qulaity in waveform and the are

1. Sinusoidal PWM
2. Space Vector Modulation PWM (SVM-PWM)
3. Selective Harmonic Elimination (SHE).

From literature, SHE techniques are claimed as effective method than others due to less switching losses.

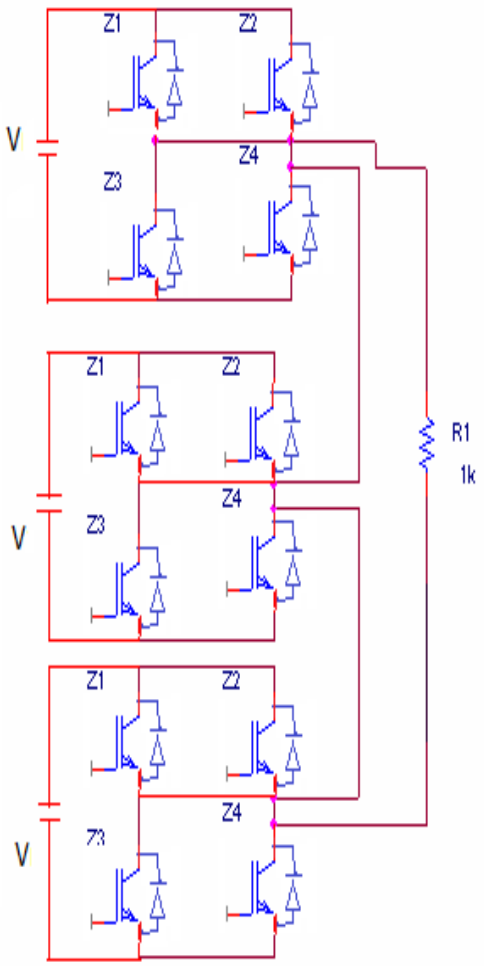

Fig. 1. Seven level CMLI

The lower order harmonics are swiped by SHE method to choose optimum switching angles where the THD also lower. Few algorithms [5-10] are used in this concept which are mentioned below.

1. Bee algorithm
2. Genetic Algorithm (GA)
3. Symmetric Polynomial
4. Resultant Theory

In this work, the section I and II deal about the introduction and CHBMLI. Section III deals about optimization with the SQP for seven level. Section IV more discuss about results where conclusions is provided by section V.

Revised Version Manuscript Received on December, 2018.

N.Vinoth kumar, Assistant professor, Department of Electrical and Electronics Engineering, Kumaraguru College of Technology, Coimbatore, Tamilnadu, India

M.Pradish, Engineering officer, Metering and Utility Automation Division, Central Power Research Institute, Bangalore, Karnataka, India

II. CASCADED MLI (CMLI)

The CHBMLI is making a staircase or stepped output which is obtained by each module's output is seriously connected in cascaded fashion. Here, CMLI consist of several modules in which each of one shall have a DC source with 4 switches that produces the +Vdc, –Vdc & zero voltage. In Fig.1, CHBMLI for seven level is shown. V is a voltage source and Z1,Z2,Z3,Z4 are switches. 3 modules are used for seven level and three voltage shall produce seven level. i.e three voltage in +Ve Vdc and three voltage in -Ve Vdc and 0 Vdc voltage. The magnitude decides the type such as symmetric or asymmetric, the symmetric one has the voltage sources are same that is the magnitude [11-14]. The second one is asymmetric which is claimed as the sources are different in magnitude [15], [16]. The great advantage in the asymmetric is that the voltage level can be made higher with less power switch but reliability need to be taken care. The CHBMLI can be applied in various filed like electric vehicle [17] and direct toque control and solar application [18 -19].

III. PROBLEM FORMATION

The staircase waveform for seven level positive side is shown in figure.2. The amplitude of voltage (V) must be identical for symmetric topology and the angles must be lied between 0 to π/2. Advantage in sine waveform and stepped waveform has equal positive, negative voltage which makes even order harmonics becomes zero because the wave form are symmetry.

Waveform voltage can be expressed using Fourier series by equation (1).

$$V(\omega t) = \begin{cases} 0 & \text{n = even} \\ \dfrac{4V}{n\pi}\sum_{i=1}^{k}\cos(n\alpha_i) & \text{n = odd} \end{cases} \quad (1)$$

n is the harmonic order
k is the no of Dc sources

The THD can be derived using equation 2 and the harmonic order can be given by Vn by equation 3. V1 provides the fundamental voltage which can be derived from equation 4.

$$THD = \sqrt{\sum_{2}^{n} V_n^2} \Big/ V_1 \quad (2)$$

$$V_n = \left(\left(\frac{4V}{\pi}\right)\sum_{2}^{n}\sum_{1}^{k}\frac{Cos(n\alpha_k)}{n}\right) \quad (3)$$

$$V_1 = \left(\left(\frac{4V}{\pi}\alpha_k\right)\sum_{2}^{k} Cos(n\alpha_k)\right) \quad (4)$$

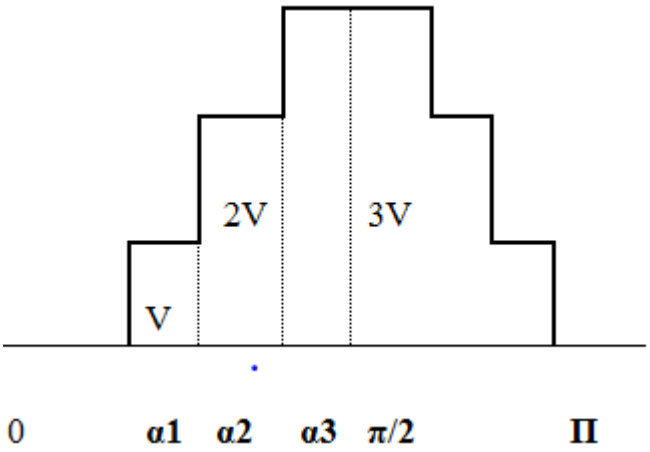

Fig.2 Stepped waveform for seven level

The motive of this work is to dismiss lower harmonics and the balance order of harmonics shall be filtered through the filters. Here, 5th and 7th shall be much dominant harmonics which are lower in orders. Three phase system will not have triplen harmonics which not required to consider. Equation (5) provides the non linear equation of stepped waveform to eliminate the harmonics. Modulation Index (MI) can be provided by equation (6).

$$\begin{cases} (\text{Cos}\,\alpha_1 + \cos\alpha_2 + \cos\alpha_3)/\pi = \text{MI} \\ (\text{Cos}\,5\alpha_1 + \cos 5\alpha_2 + \cos 5\alpha_3) = 0 \\ (\text{Cos}\,7\alpha_1 + \cos 7\alpha_2 + \cos 7\alpha_3) = 0 \end{cases} \quad (5)$$

$$MI = \frac{V_1}{kV_{dc}} \quad (6)$$

The above nonlinear equations can be solved by sequential quadratic programming (SQP) algorithm [20-22].

A. SEQUENTIAL QUADRATIC PROGRAMMING (SQP)

SQP is the method of approximation where the objective function can be made as quadratic form. Here, the constraints are linearized in every iteration. In every iteration the objective function ie. Quadratic problem is solve and the values are updated with new one. Here the iterations can be ends only if there is no improvements further. Trust region method is a technique which is useful to solve quadratic problems. In this approach, a region around has to be evaluated where a quadratic approximation of the function holds. The augmented lagrangian function replaces Lagrangian function. Fig.3 shows the methods to solve the optimization using SQP.

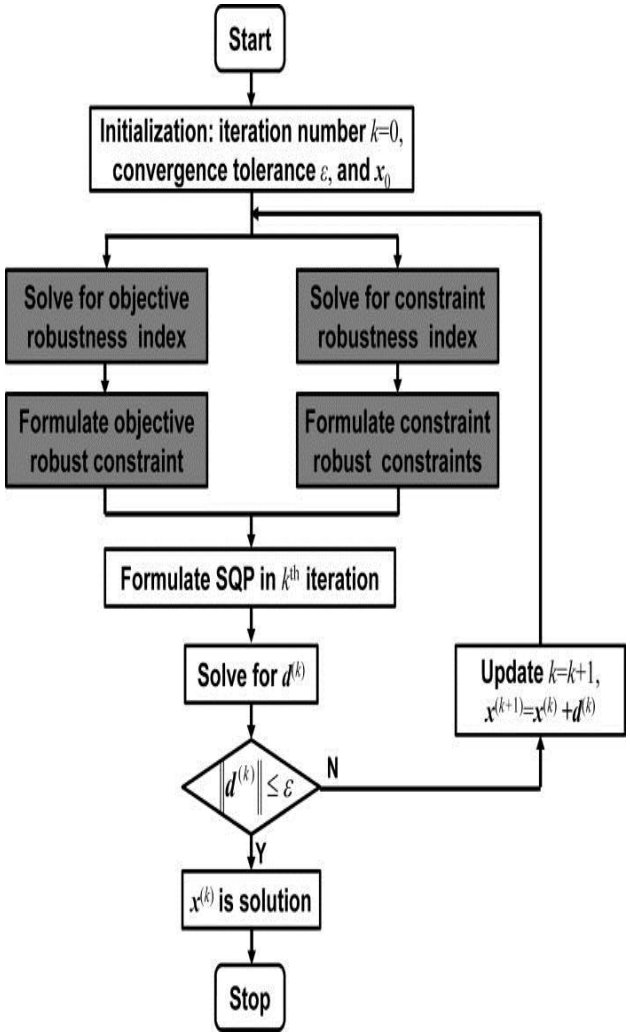

Fig.3. Flowchart: SQP

IV. RESULT AND DISCUSSION

The validation of proposed SQ algorithm is done through Matlab/Simulink. The simulation for cascaded seven level inverter is done and same is verified using hardware. In this work, a symmetric CHB topology is considered. Here, 7 level inverter is developed with 3 symmetrical modules in which the voltage sources are same. The values of each voltage source are 50V.The switching angle of MLI is identified in offline using MATLAB and the values are substituted in arduino board where the firing pulses are generated. The seven level output voltage using hardware model is shown in fig.4. Harmonics spectrum using FFT analysis for seven level waveform for phase voltage and line voltage are shown in the fig. 5 and fig.6. In seven levels, the phase voltage THD is 11.69%. The THD for line voltage is 8.73% at MI equal to 1. In this work, switching frequency of power switches is at fundamental/line frequency which improves the efficiency due to reduction of switching losses. The comparison between PSO and SQP is shown in table 1. It is inferred for table that the SQP is better when compared with PSO for THD and lower harmonics. However the SQP is limited for lower step/level when the level/step increases then the solving problem becomes difficult. Higher order of equations is need to solve the problem which may increase the time. The relationship between MI and angle are shown in fig. 7 and experimental setup of seven level MLI is shown in fig.8.

Optimization techniques used	MI	α1	α 2	α3	Phase voltage THD (%)	Line Voltage THD (%)
		in degree				
Proposed SQP	0.98	12.324	33.666	60.076	13.63	7.83
	1.0	11.69	31.193	58.608	12.47	8.73
	1.02	11.025	24.59	54.331	11.45	8.78
PSO	1.0	11.579	27.63	56.465	12.37	8.65

Table I. Comparison For 7 Level

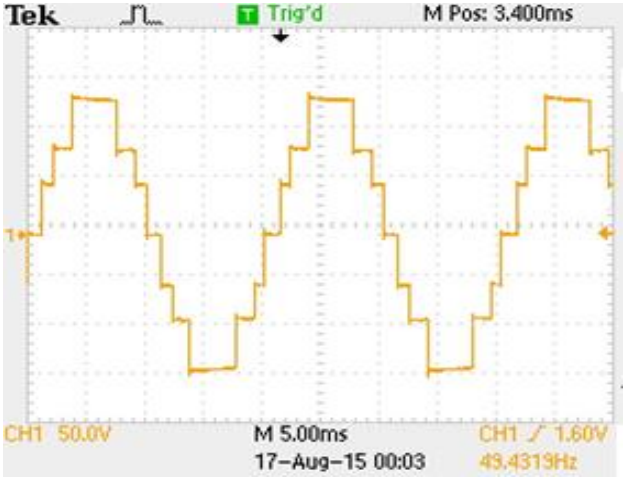

Fig.4. Output of seven level CHB MLI

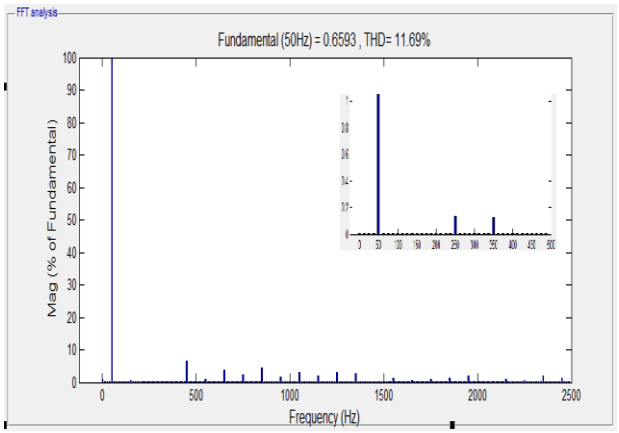

Fig.5. THD analysis for line voltage waveform

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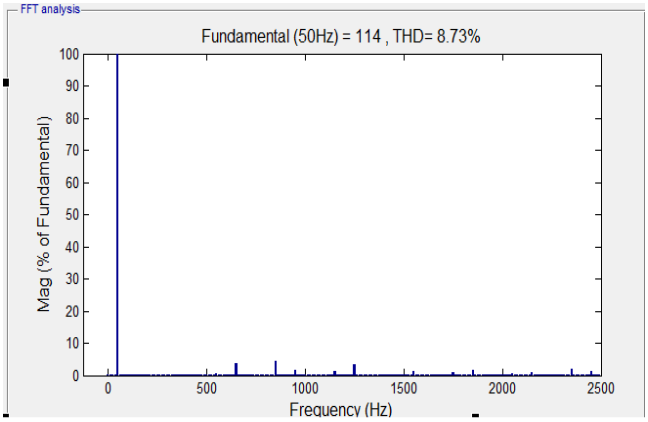

Fig.6 THD analysis for phase voltage waveform

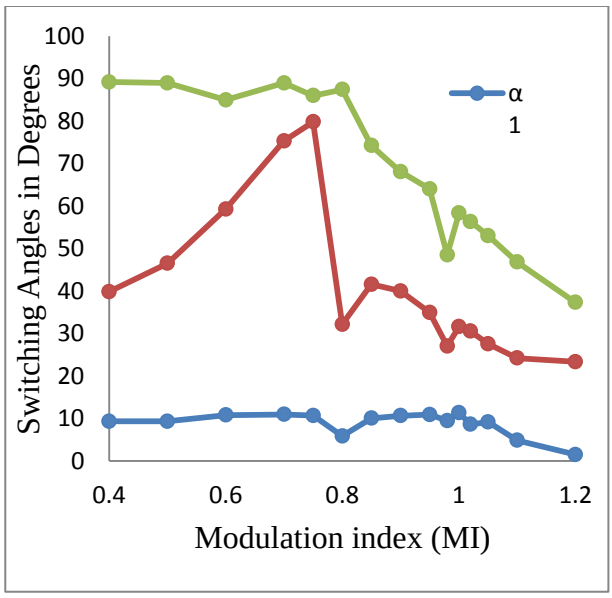

Fig.7 Switching angle Vs MI

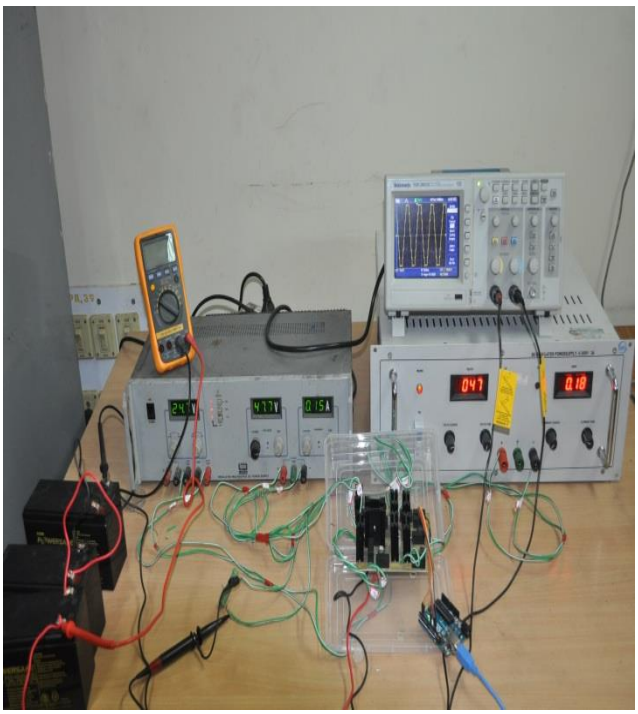

Fig.8 Experimental setup for seven level MLI

V. CONCLUSION

In this paper, the improved waveform for a MLI is obtained using SQP. THD of a MLI output voltage is improved and the switching angles are identified where the lower order harmonic are suppressed. These angles not only diminish the lower order butt also shrinks THD for voltage waveform and current waveform. The experimental results are proving that the proposed work has much closed to simulation result and it can be claimed that the inverter performance and the results are much better due to SQP.

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