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# THD Reduction in Multi-Level Inverter by Solving SHE Equations Using Improved Optimization Technique

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**Abstract**: The multilevel Inverter is used for high power utility applications. To get AC output waveforms with low harmonic content, a set of non- linear transcendental equations known as selective harmonic elimination equationsare solved. Thus lower order harmonics are eliminated and the higher order harmonics are filtered out in SHE techniques .The switching angles are optimized with new proposed optimization technique. Modulation index m, is changed over a range to get required output waveform. THD vary with modulation index values. In this paper, the THDs and output waveform of single phase full-bridge inverter using SHE scheme with varying the modulationindex isobtained

**Index Terms** – Cascaded H-Bridge multilevel inverter, Total Harmonic Distortion-THD, Selective Harmonic Elimination-SHE, Modulation index $m_i$, Optimization techniques.

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## I. INTRODUCTION

**E**xtensive use of renewable resources, has given opportunity for innovations and enhancements in field of inverters.A multilevel converter is used to achieve high power ratings, reduce harmonics, dv/dt stresses, and stresses in the bearings of a motor. Different multilevel converter topologies used are; i) diode clamped, ii) flying capacitors, and iii) cascaded or H-bridge. A cascade multilevel inverter is a power electronic device, which synthesize a desired AC output from several levels of DC inputs. Referring to the literature reviews, the cascaded multilevel inverter (CMI) is the most feasible topology for medium& high power applications due to its modularization and extensibility. Cascaded multilevel inverter is composed of several single phase H-Bridges connected in series, thereforeits often called as, H-bridge cascaded multilevel inverters.It has varies application such as motor drives, renewable energy, active powerfilters, Flexible AC Transmission System (FACTS), HVDC and others[1]. With specific modulation techniques, required harmonics can be eliminated.

Reduction in harmonics is achieved, byfinding optimum switching angels of converters. There are many modulation techniques studied to reduce harmonic contents inthe converters. Different methods emerged: sinusoidal Pulse Width Modulation (PWM), Space Vector PWM, Selective Harmonic Elimination (SHE), and Space Vector Modulation (SVM)[2]. However, PWM techniques do not eliminate low order harmonic.

It is found that SVM and SHE are the most widely used modulation techniques for all the types of multilevel inverters.The popular selective harmonic elimination method is based on the harmonic elimination theory[3],[4].SHE techniques comprises the mathematical modelling of output voltage waveform and solving nonlinear transcendental equations which contain trigonometric terms for switching angles based on the amplitude of the fundamental wave of the output voltage, the order and number of the eliminated harmonics.

The main challenge with SHE technique is to solving the system of nonlinear transcendental equations that contain trigonometric terms which in turn provide multiple sets of solutions. In [5]-[6], numerical iterative techniques have been used to solve the SHE equations producing only one solution set, and a proper initial guess and value of modulation index for which solutions exist are required. In [7], [8], theory of resultants of polynomials and the theory of symmetric polynomials algorithm to solve the polynomial equations obtained from the transcendental equations. The drawback with these approaches is the order of the polynomials become very high with increase in levels, the computations of the solutions of these polynomials is very complex. In [9], Optimization technique based on Genetic Algorithm (GA) is proposed for computing switching angles .This approach requires proper selection of population size, mutation rate etc., thereby for higher levels are become difficult. In [10] ,the most popular Newton-Raphsonmethod for solving these equations is proposed. This method gives optimum result only for proper initial guess.

The new technique proposed in this paper , uses both cauchy (steepest descent )and NR method algorithm for convergence. A 7-level inverter using five H-bridges per phase in series is analysed , and it is shown that for a given range of modulation index , switching angles can be computed. Desired fundamental voltage V1 is obtained, with elimination of 5th, 7th, and 9th, components. The validity of the proposed methods are made by comparing the results with experimental results

## II. SYSTEM DESCRIPTICTION

Cascade Multilevel Inverter (CMLI) is the most popular topology in the group of multilevel inverters and multipulse inverters. It requires less number of components compared to diode-clamped and flying capacitors type multilevel inverters and no transformer is required as compared to multipulse inverter.

### *A. Cascaded H-Bridge Multilevel Inverters (CHB-MLI) topology*

Fig 1,shows cascaded multilevel inverter, it consist of H-bridge modules connected in series.The absence of clamping diodes or voltage balancing capacitors, and easy adjustment of the number of output voltage levels are some advantages of CMLI in comparison with other topology. Switching devices switch ON and OFF once per cycle to overcome the switching loss problem [3].Each H-bridge generates three different voltage: $+V_{dc}$, 0, and $-V_{dc}$. All CMIL produces staircase wave and $2S + 1$ number of output voltage levels are generated, where $S$ is the number of dc sources.

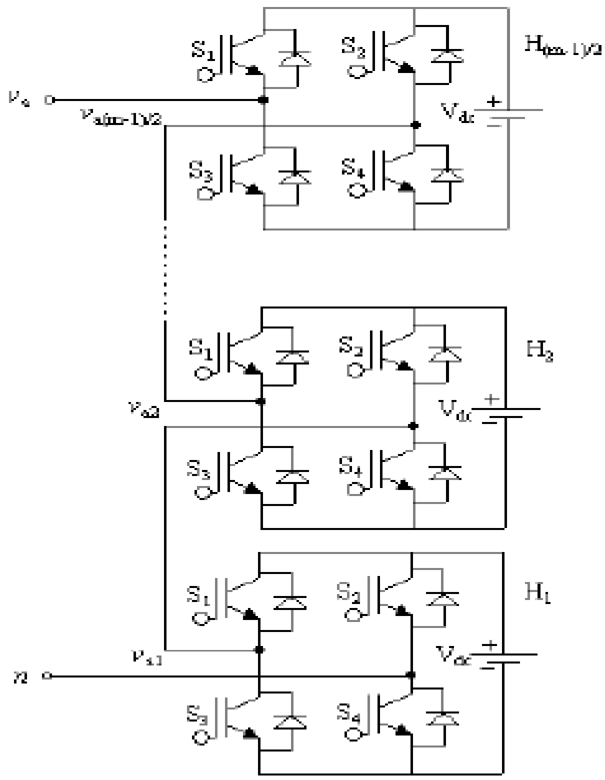


**Fig 1:** Single phase cascaded multilevel H- bridge inverter

Fig 2 and 3, shows circuit and phase voltage waveform of a 5-level cascaded multilevel H-bridge inverter with two dc sources ($S = 2$). Each H-bridge module produce a quasi-square waveform by phase-shifting the switching timings of its positive and negative phase legs. The magnitude of the ac output phase voltage is given by$V_n = V_1+V_2$[2].

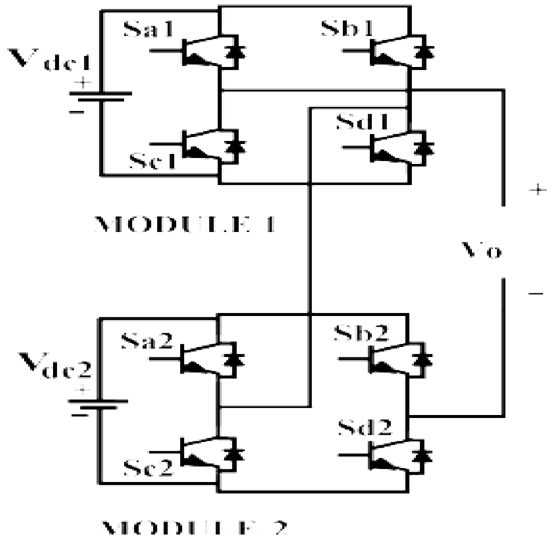


**Fig.2.** 5-level cascaded multilevel inverter

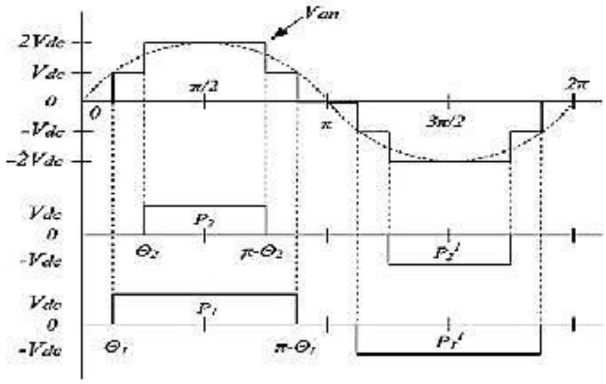

**Fig. 3.**5-level CMLI output voltage waveform.

## III. CASCADED MULTILEVEL H-BRIDGE INVERTER MODELLING USING SHE TECHNIQUE

Fourier series expansion of the staircase wave of CMLI is given as

$$V(wt) = \sum_{n=1}^{\infty} V_n \sin(nwt) \qquad (1)$$

where, $V_n$ is the amplitude of the *n*th harmonic. Switching angles are limited between zero and 90° ($0 \leq x_i < \pi/2$)[11]. Because of odd quarter-wave symmetric characteristic, even order harmonics become zero. Consequently, Vnbecomes

$$f(x) = \begin{cases} \dfrac{4Vdc}{n\pi} \displaystyle\sum_{i=1}^{S} \cos nx_i\,, & for\ odd\ ns \\ 0, & for\ even\ ns \end{cases}$$

(2) where , $V_{dc}$ is the level of dc voltage, S is number of H-bridge

The objective of SHE method is to reduce the lower order harmonics and other remaining harmonics are removed with filter[12].In this paper, a 7-level inverter is chosen for case study and its low-order harmonics (fifth and seventh) are eliminated. Triplen harmonics disappear in three-phase applications.

$$\frac{4Vdc}{\pi}[\cos(x_1) + \cos(x_2) + \cos(x_3)] = V1 \qquad (3)$$

$$\frac{4Vdc}{\pi}[\cos(5x_1)+\cos(5x_2)+\cos(5x_3)]=0 \quad (4)$$

$$\frac{4Vdc}{\pi}[\cos(7x_1)+\cos(7x_2)+\cos(7x_3)]=0 \quad (5)$$

Equation (2) is the expression for the fundamental voltage in terms of switching angles. The modulation index $m_i$ is the ratio of the fundamental output voltage $V_1$ to the maximum obtainable fundamental voltage $V_{max}$[2];.The maximum voltage ,when all the switching angles are zero, $V_{max}={4s\text{Vdc}}/{\pi}$ Therefore the expression for $m_i$ is

$m_i={\pi V1}/{4sVdc}$ (6)

Equation (3) to (5) is non-linear transcendental equation and it is solved for switching angles for the a range of $m_i$(0 to 1)

## IV. PROPOSED OPTIMIZATION TECHNIQUE TO SOLVE SHE EQUATIONS

The negative of the gradient vector as a direction for minimization was first made by Cauchy in 1847 . In this method, initial point of x1 is assumed and iteratively moved along the steepest descent direction ,to reach optimumpoint. The NewtonRaphson method, converges fast when initial guess of **X**i is close to the optimum point **X**∗. The new proposed optimizationmethod is combination of both the steepest descent and NR methods. In this method diagonal elements of the Hessian matrix is modified , [Ji] by multiplying it a positive constant *p.* The value of $p_i$decreases from a large value to zero, the characteristics of the search method change from those of a steepest descent method to those of the NR method.

### *A. Algorithm of proposed optimization technique*

1. Start with an arbitrary initial point $x_1$ and constants $p_1$(highest value),
2. Set the iteration number as i = 1.
3. Compute the gradient of the function, ∇Fi = ∇F (xi).
4. Test for optimality of the point $x_i$ . If $\|\nabla F_i\| = \|\nabla F(xi)\| \le \varepsilon$,
   If, $x_i$ reaches optimum point ,then stop the process. Otherwise, go to step 4.
5. Find the Xi+1 as Xi+1 =Xi − [[Ji]] + pi [I ]]−1 ∇Fi
6. Compare the values of Fi+1 and Fi.
7. If Fi+1 < Fi , go to, step 8
   If Fi+1 ≥ Fi, go to step 9.
8. Set pi+1 = b1*pi, i = i + 1, and go to step 2.
9. Set pi = b2*pi and go to step 4.

By following the above algorithm steps, all possible solution sets, when they exist, can be computed without any computational complexity.

## V. IMPLEMENTING PROPOSED OPTIMIZATION METHOD ON 7-LEVEL INVERTER

### *A. 7-level CHB-MLI driving angles*

Toncalculate the switching angles, the above mentioned proposed optimization technique is programmed using MATLABsoftware. Initial values are guessed. Possible output for nine level inverters iscalculated for different mi values.

**Table 1:** SWITCHING ANGLES CALCULATED for different modulation index of 7 levels inverter

| m | $X_1$ | $X_2$ | $X_3$ |
|---|---|---|---|
| 0.35 | 35.5532 | 54.2994 | 69.3368 |
| 0.387 | 26.4589 | 52.8006 | 64.2048 |
| 0.451 | 13.4068 | 36.3693 | 61.5077 |
| 0.489 | 11.8817 | 25.9052 | 55.4652 |
| 0.501 | 14.038 | 20.9695 | 53.0517 |

| m | $X_1$ | $X_2$ | $X_3$ |
|---|---|---|---|
| 0.303 | 39.4136 | 55.8922 | 79.5333 |
| 0.319 | 39.064 | 54.3992 | 76.3244 |
| 0.346 | 36.2584 | 54.1282 | 70.2651 |

| | | | |
|---|---|---|---|
| 0.412 | 19.994 | 46.2434 | 64.6165 |
| 0.415 | 19.3367 | 45.4369 | 64.5504 |
| 0.441 | 14.7231 | 38.8326 | 62.6869 |

Table 1, shows all the driving angles of 7levels inverter, the same is verified on Simulink. It is observed that the driving angles are not obtained for few modulation indexes.

***B. Harmonic analysis using Simulink inverter model***

SHE technique is used for finding different switching angles that can be used for removing certain harmonic from the output waveform of the CHB-MIL.angles obtained in above proposed optimization technique is validated by simulating CHB-MIL and harmonic analysis is carried out to find the percentage content of selected harmonic in the output waveform The harmonics that are considered for elimination are 5th, $7^{th}$ and $9^{th}$.

**Table 2:** Harmonic Content, THD and Vrms for different Modulation Index of 7-Level MLI

| m | 3rd | $5^{th}$ | $7^{th}$ | 9th | THD | Vrms |
|---|---|---|---|---|---|---|
| 0.5 | 43.58 | 0.74 | 0.75 | 7.44 | 48.32 | 142.7 |
| 0.6 | 40.89 | 0.02 | 0.06 | 1.11 | 43.47 | 170.5 |
| 0.7 | 9.11 | 6.46 | 5.91 | 8.19 | 18.27 | 170.5 |

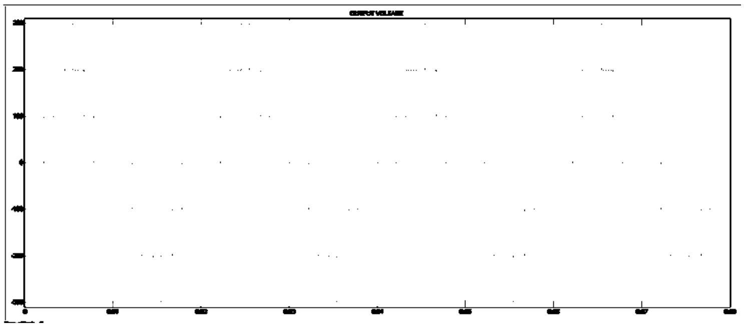

**Fig 4:** Output voltage waveform of 7-level MLI with 0.5 modulation index

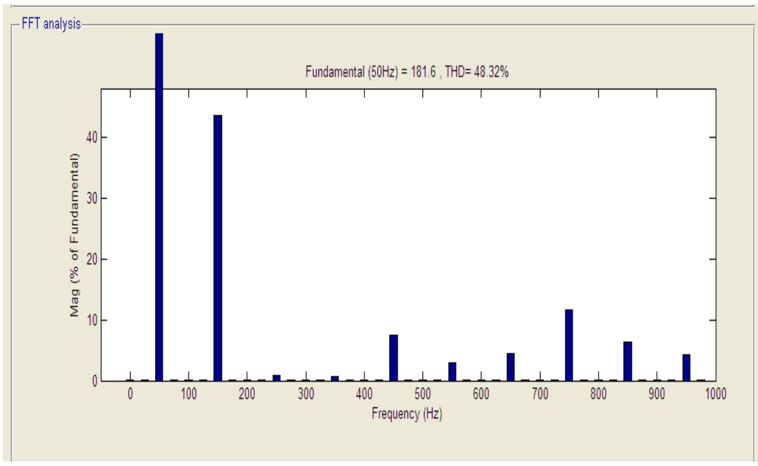


**Fig 5:** Harmonic content in Output voltage waveform of 7-level CHB-MLI with 0.5 modulation index

Figure 4,shows the output waveform of 7level CHM-MLI ,with particular modulation index ,i.e 0.5.Figure 5 shows the harmonic content in output voltage of 7 level CHB-MIL with 0.5 modulation index. It is observed that $5^{th}$, 7th and $9^{th}$ is almost eliminated.

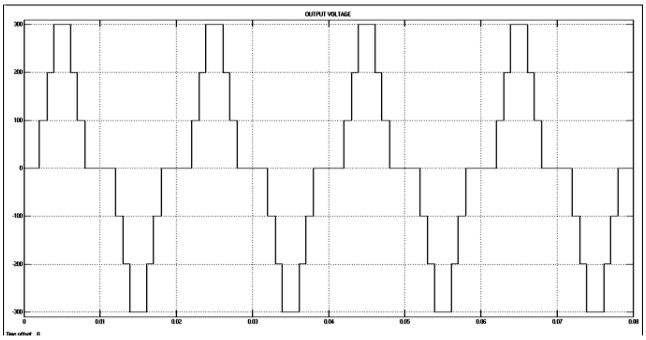

**Fig 6:** Output voltage waveform of 7-level MLI with 0.6 modulation index

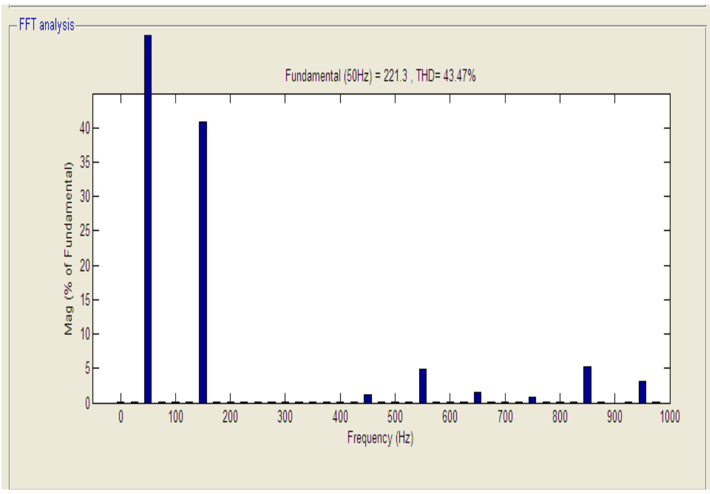


**Fig 7:** Harmonic content in Output voltage waveform of 7-level CHB-MLI with 0.6 modulation index

Figure.7, shows the harmonic content in output voltage of 7 level CHB-MIL with 0.6 modulation index. It is observed that $5^{th}$, 7th and $9^{th}$ is almost eliminated. It is observed that SHE technique successfully removes targeted harmonics from the output voltage waveform of the CHB-MLI. It can successfully calculate the angles where notches are required to remove the targeted harmonics.

## VI. CONCLUSION

The selective harmonic elimination strategy at fundamental has been solved using the proposed optimization technique that produces all possible solution sets of switching angles when they exist. In comparison with other methods, the proposed technique has many advantages such as: it can produce all possible solution sets for any numbers of multilevel inverter without much computational burden; convergencespeed is fast etc. The proposed technique was successfully implemented for computing the driving angles for7level H-Bridge cascaded multilevel inverter. It was observed that $5^{th}$ ,7h and $9^{th}$ harmonics were almost eliminated . A complete analysis for n - level inverter can be made and switching angle which results in lower THD and can be determined.

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