

Thad 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 equations are 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 modulation index is obtained

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

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I. INTRODUCTION

Extensive 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, therefore it is often called as, H-bridge cascaded multilevel inverters. It has various applications such as motor drives, renewable energy, active power filters, Flexible AC Transmission System (FACTS), HVDC and others [1]. With specific modulation techniques, required harmonics can be eliminated.

Reduction in harmonics is achieved, by finding optimum switching angles of converters. There are many modulation techniques studied to reduce harmonic contents in the 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 comprise 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-Raphson method 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 V_1 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 DESCRIPTION

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.

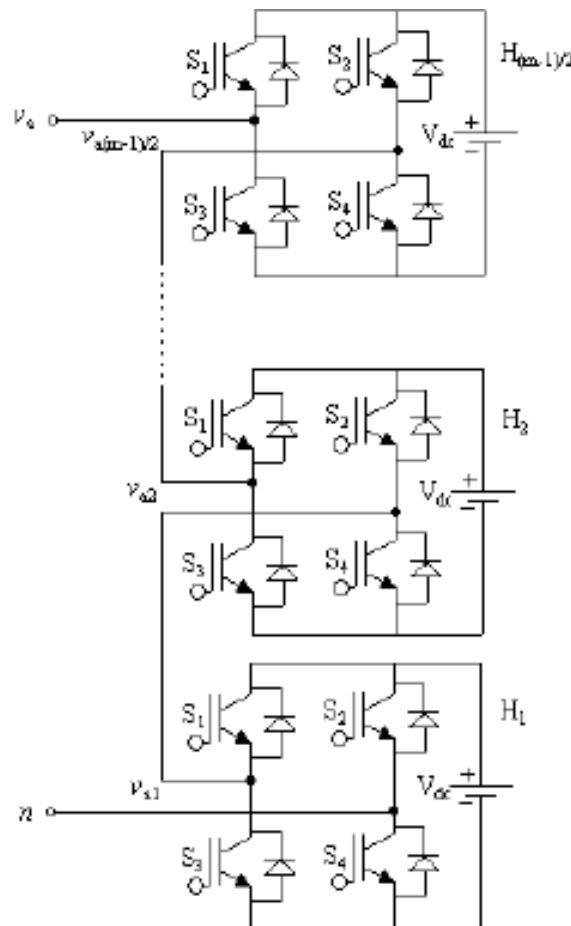


Fig 1: Single phase cascaded multilevel H- bridge inverter

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].

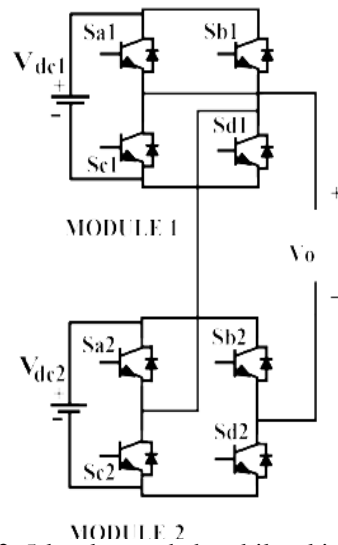


Fig.2. 5-level cascaded multilevel inverter

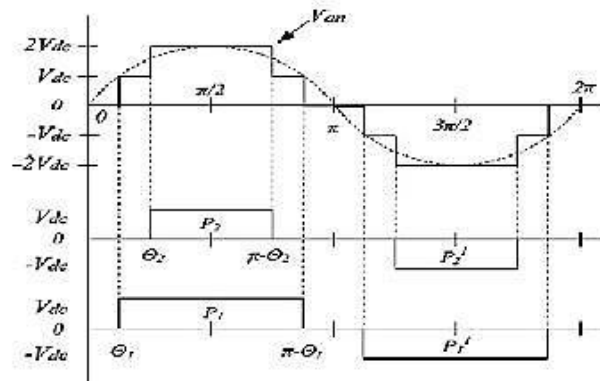


Fig. 3.5-level CMLI output voltage waveform.

III CASCADED MULTILEVEL H-BRIDGE INVERTER MODELLING USING SHE TECHNIQUE

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

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

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, V_n becomes

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

(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.

$$\frac{4V_{dc}}{\pi} [\cos(x_1) + \cos(x_2) + \cos(x_3)] = V_1 \quad (3)$$

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

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

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, $V_{\max} = 4sV_{dc}/\pi$. Therefore the expression for m_i is

$$m_i = \pi V_1 / 4sV_{dc} \quad (6)$$

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)

III. 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 x_1 is assumed and iteratively moved along the steepest descent direction, to reach optimum point. The Newton Raphson method, converges fast when initial guess of X_i is close to the optimum point X^* . The new proposed optimization method is combination of both the steepest descent and NR methods. In this method diagonal elements of the Hessian matrix is modified, $[J_i]$ 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, $\nabla F_i = \nabla F(x_i)$.
4. Test for optimality of the point x_i . If $\|\nabla F_i\| = \|\nabla F(x_i)\| \leq \epsilon$,
If, x_i reaches optimum point, then stop the process.
Otherwise, go to step 4.
5. Find the X_{i+1} as $X_{i+1} = X_i - [[J_i]] + p_i [I]]^{-1} \nabla F_i$
6. Compare the values of F_{i+1} and F_i .
7. If $F_{i+1} < F_i$, go to, step 8
If $F_{i+1} \geq F_i$, go to step 9.
8. Set $p_{i+1} = b_1 * p_i$, $i = i + 1$, and go to step 2.
9. Set $p_i = b_2 * p_i$ 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.

IV. IMPLEMENTING PROPOSED OPTIMIZATION METHOD ON 7-LEVEL INVERTER

A. 7-level CHB-MLI driving angles

To calculate the switching angles, the above mentioned proposed optimization technique is programmed using MATLAB software. Initial values are guessed. Possible output for nine level inverters is calculated for different m_i 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, 7th and 9th.

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

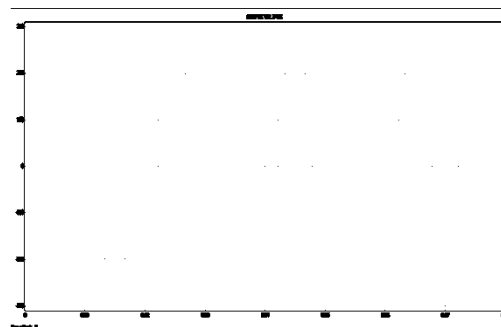


Fig 4: Output voltage waveform of 7-level MLI with 0.5 modulation index

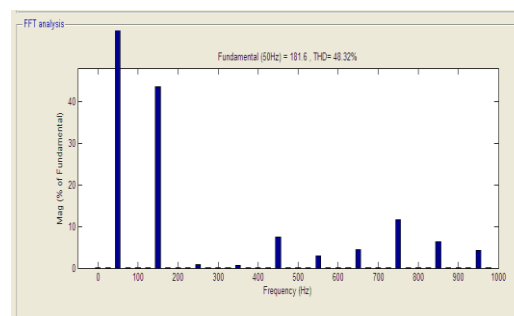


Fig 5: Harmonic content in Output voltage waveform of 7-level CHB-MLI with 0.5 modulation index

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 5th, 7th and 9th is almost eliminated.

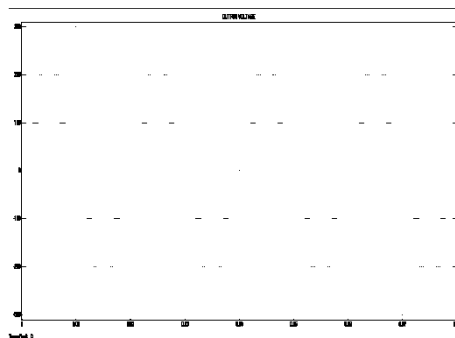


Fig 6: Output voltage waveform of 7-level MLI with 0.6 modulation index

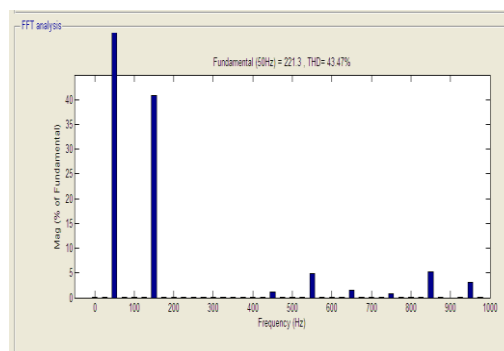


Fig 7: Harmonic content in Output voltage waveform of 7-level CHB-MLI with 0.6 modulation index

Figure.7, shows the harmonic content in output voltage of 7 level CHB-MIL with 0.6 modulation index. It is observed that 5th, 7th and 9th 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.

V.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; convergence speed is fast etc. The proposed technique was successfully implemented for computing the driving angles for 7-level H-Bridge cascaded multilevel inverter. It was observed that 5th, 7th and 9th 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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