Advances in Mathematics: Scientific Journal **10** (2021), no.3, 1311–1317
ISSN: 1857-8365 (printed); 1857-8438 (electronic)
https://doi.org/10.37418/amsj.10.3.18

COMPARATIVE ANALYSIS OF NEWTON RAPHSON AND PARTICLE SWARM OPTIMIZATION TECHNIQUES FOR HARMONIC MINIMIZATION IN CMLI

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ABSTRACT. The work in this paper gives a comparative analysis of two methods applied for modulating Cascaded Multilevel Inverters (CMLI). Selective Harmonic Elimination is employed for 5 and 7-level CMLIs using unequal dc input voltage sources by implementing Newton Raphson (NR) and Particle Swarm Optimization algorithm (PSO). A brief description of these methods is presented with comparison as per the simulation results.

1. INTRODUCTION

Multilevel Inverters (MLIs) are employed in industries for applications with high power and medium voltage requirements and remain under research and development with recent reports of new cost-effective topologies and other contributions [1]. The use of MLI technology has grown tremendously from initially being employed in traction to high voltage (HV) drives, volt-ampere reactive (VAR) compensation, dc (direct current) transmission at HV, renewable energy

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2020 *Mathematics Subject Classification.* 65-02.
Key words and phrases. Harmonic minimization, newton Raphson, particle swarm optimization.
Submitted: 16.02.2021; *Accepted:* 04.03.2021; *Published:* 16.03.2021.

(RE) and stability improvement [1]. CMLIs offer number of advantages including low distortion in output voltage and input current, reduced common mode voltage, and hence they are used in utility and motor drive applications (also regenerative type) [1]. In MLIs as voltage waveform steps at output terminals increase, the harmonic distortion reduces [2]. Popular modulation techniques for MLIs include:

a. sinusoidal pulse width modulation (SPWM);
b. selective harmonic elimination (SHE); and
c. space vector modulation (SVM) [2].

CMLIs comprises of two or more series connected H-bridge inverters, Figure1 [3]. Here 'n' separate dc sources have the same voltage level V_{dc}, the resultant phase voltage waveform would range from $-nV_{dc}$ to $+nV_{dc}$ with 2n+1 levels (or steps).

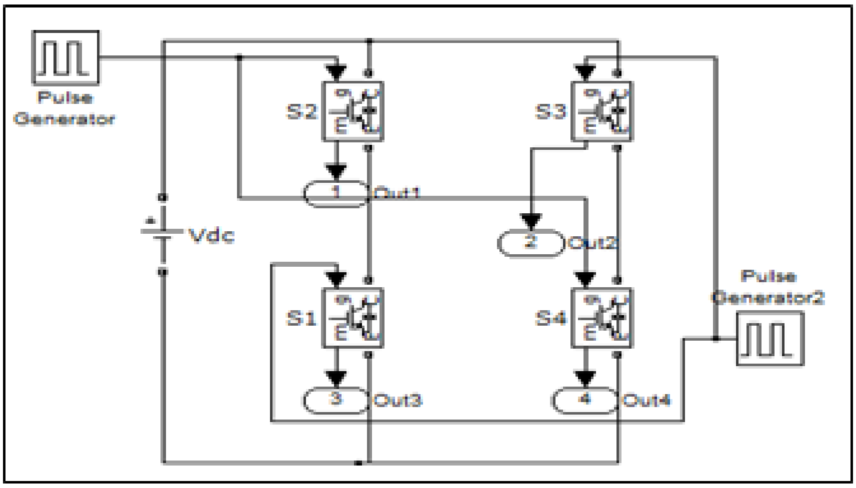

FIGURE 1. Single H-Bridge Inverter Module

2. MODULATION AND CONTROL STRATEGY

SHE-PWM technique is implemented on 5 and 7 level CMLI (unequal input dc voltages) using MATLAB/Simulink. It determine angles for switching the power semiconductor devices to minimize the harmonics in output voltage [4]. This technique, describes harmonic components as functions of switching-angles in trigonometric forms of transcendental equations which are non-linear [4, 5]. Iterative techniques such as NR and PSO can solve these non-linear equations [2]. The output of a CMLI is a staircase voltage waveform and by applying Fourier series analysis, the waveform equation is,

$$V(\omega t) = \sum_{n=1,3,5...}^{\infty} \frac{4V_{dc}}{k\pi}(k1\cos(n\alpha_1) + k2\cos(n\alpha_2) + \cdots + ks\cos(n\alpha_s))\sin(n\omega t),$$

where, n represents the harmonic order, kiV_{dc} represents ith dc voltage, V_{dc} is nominal dc voltage, and α_s is 's'th switching angle. The angles $\alpha_1 - \alpha_s$ values are constrained as $0 < \alpha_1 < \alpha_2 < \alpha_s < pi/2$. Based on above equation, the following set of polynomial equations are obtained to determine 's' angles and eliminate selective harmonics till nth order [5],

$$k1\cos(\alpha_1) + k2\cos(\alpha_2) + \cdots + ks\cos(\alpha_s) = s * M,$$

$$k1\cos(5\alpha_1) + k2\cos(5\alpha_2) + \cdots + ks\cos(5\alpha_s) = 0,$$

$$k1\cos(n\alpha_1) + k2\cos(n\alpha_2) + \cdots + ks\cos(n\alpha_s) = 0.$$

The NR method is a root-finding procedure that necessitates a good preliminary estimate that should be very close to the actual solution and outputs a single solution set for a unique modulation index (M). Additionally, this method is unsuccessful to give solution for a specific range/value of M for which solution exists. This technique although can give satisfactory harmonic content results for inverters with lower output voltage levels. PSO is a stochastic technique, this method draws inspiration from social behaviour of bird flocking or fish schooling [3]. Here initialization is required with a random solutions population and looks for optimum value by apprising generations [3]. This algorithm as implemented on CMLI for SHE needs an objective function, to minimize it and give corresponding variables value where the function has minimum value [4]. The THD equation is taken as the objective function.

$$\%THD = \frac{\sqrt{V_2^2 + V_3^2 + .. + V_n^2}}{V_1} \times 100.$$

3. SIMULINK MODEL: 5-LEVEL AND 7-LEVEL CMLI

A five level CMLI structure consists of two dc sources thereby giving 5 levels of the output voltage waveform (phase) as per the formula 2s + 1 = N. For harmonic analysis, following fundamental and harmonic voltage equations are taken:

$$V(\omega t) = \sum_{n=1,3,5\ldots}^{\infty} \frac{4V_{dc}}{k\pi}(k1\cos(n\alpha_1) + k2\cos(n\alpha_2))\sin(n\omega t),$$

$$k1\cos(\alpha_1) + k2\cos(\alpha_2) = 2M,$$

$$k1\cos(5\alpha_1) + k2\cos(5\alpha_2) = 0,$$

where α_1,α_2 are the switching angles that need to be determined, M is the modulation index and objective function is the harmonic content up to 7th order harmonics [3, 4],

$$k1\cos(\alpha_1) + k2\cos(\alpha_2) + k3\cos(\alpha_3) = 3M,$$

$$k1\cos(7\alpha_1) + k2\cos(7\alpha_2) + k3\cos(7\alpha_3) = 0,$$

$$k1\cos(7\alpha_1) + k2\cos(7\alpha_2) + k3\cos(7\alpha_3) = 0.$$

4. EXPERIMENTAL RESULTS: VOLTAGE WAVEFORM AND THD SPECTRUM

Subsequent sections show harmonic spectrum (figure 2 to figure 5.) for five and seven step CMLI implementing PSO and NR method. The input dc voltage source values used are 90V, 110 V and 100 V for modulation index of 0.75. Table 1. gives the switching angles and modulation index values for both inverter types used in simulation using PSO.

TABLE 1. Switching angles using PSO

Type	Modulation Index	α_1	α_2	α_3
5-level	0.75	18.8554	59.9274	-
7-level	0.75	13.8747	33.2980	58.6087

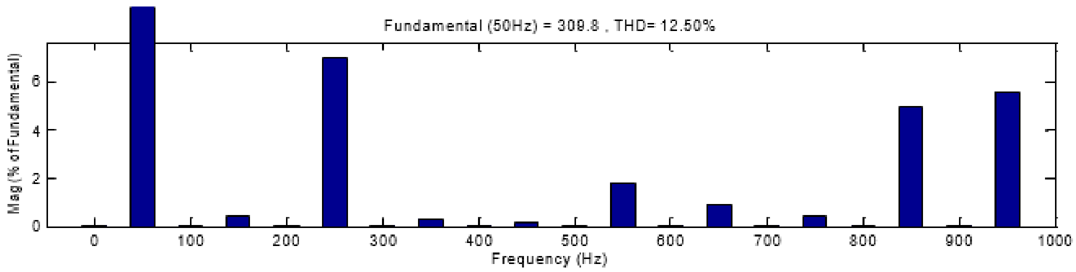

FIGURE 2. Harmonic spectrum of line voltage for 5-level CMLI (THD=12.50%)

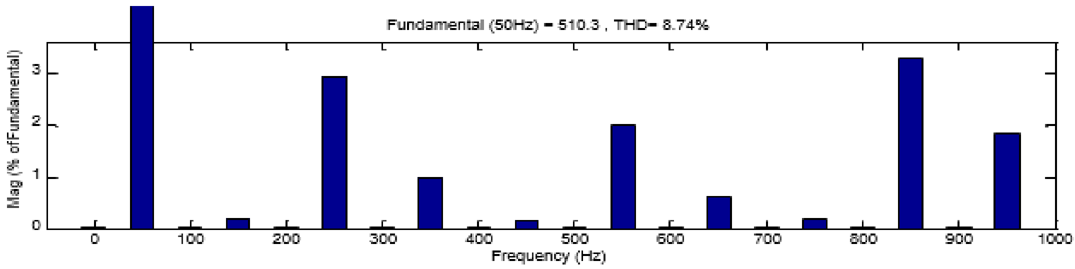

FIGURE 3. Harmonic Spectrum of 7-level unequal sources CMLI (THD=8.74%)

TABLE 2. Switching angles using NR method

Type	Modulation Index	α_1	α_2	α_3
5-level	0.75	18.25	59.21	-
7-level	0.75	14.96	33.688	59.16

Table 2. gives the switching angles and modulation index used in simulation using NR.

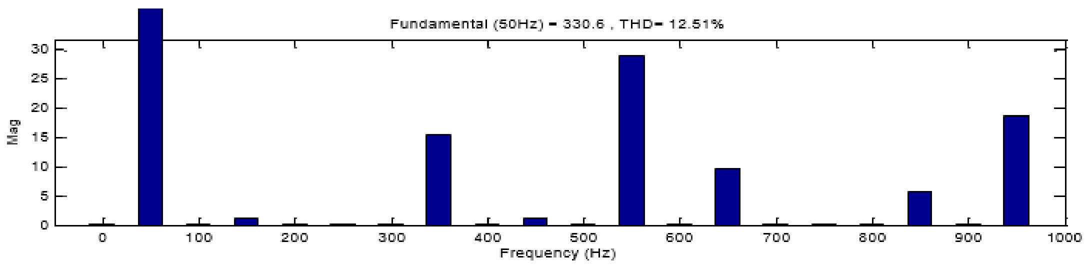

FIGURE 4. Harmonic Spectrum for 5-level equal sources CMLI (THD=12.51%)

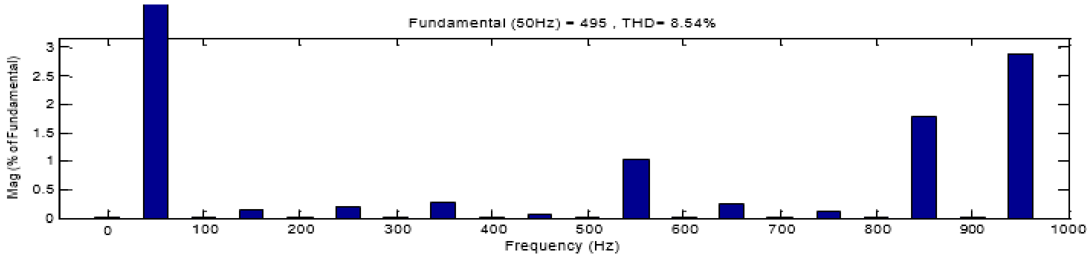

FIGURE 5. Harmonic Spectrum for 7-level equal sources CMLI (THD=8.54%)

5. CONCLUSION

With the results it can be concluded that the a good preliminary guess (closer to actual solution) is needed in NR technique. Additionally, with increase in number of H-bridges the order of the polynomial equations becomes very high hence computations for the solutions become very complex and time consuming also owing to the transcendental nature of equations for unequal dc source MLI, NR method may not be able to give satisfactory solutions due to high degree of equations. However, the PSO method overcomes the challenges faced in NR method, also for small number of firing angles, it lessens the computation load to output ideal solution set.

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