Design and Harmonic Optimization of an IBC-Fed Multilevel Inverter Using Newton–Raphson and Particle Swarm Optimization Algorithms

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Abstract: -

Electric vehicles will be an essential part of any future transportation system for their ability to boost fuel efficiency and energy security for the environment. At the present time, there are two kinds of two-level inverters available in this market. A five-level cascaded H-bridge multilevel inverter for Electric Vehicles application is proposed in this article. The newly suggested one can produce better quality output than the classic 2-level inverter. In general, the H-bridge inverter is used for generating 5 level output from two dc sources, in this work dc sources are replaced with renewable energy sources. Because of its abundant supply that is present in nature. The most used renewable energy system is photovoltaic cells. A constant DC output voltage from PV systems is desired with the proposed Interleaved Boost Converter. This DC-DC converter is used as a replacement of the DC sources in the multilevel inverter. The study of the boost converter and interleaved boost converter also showed the proposed integrated circuit is superior to the performance of EV propulsion and the reduction of EMI of the drive. Gate control logic in the inverter is developed based newton Raphson and particle Swarm optimization (PSO) eliminating the specific harmonic on selective Harmonic Elimination (SHE) PWM control logic is used in CML to even reduce the predominant harmonics and reduce the losses under different loading conditions. The simulation is carried out in MATLAB/SIMULINK considering various values of irradiation and temperature

Keywords: Multilevel Inverters, Cascaded H-Bridge, Dragonfly Algorithm, Selective Harmonic Elimination, Pulse Width Modulation, Total Harmonic Distortion

1. Introduction.

The need for effective power conversion systems is rising in our technologically advanced society. Converters with high efficiency, dependability, and superior performance are desperately needed as electronic devices and energy consumption patterns change. Furthermore, the need for stable and effective DC-DC converters is highlighted by the decline in conventional energy sources. Renewable energy sources like the sun and wind, which vary depending on the environment, are commonly used to generate power. To maintain a consistent and dependable energy supply, this power must be controlled by DC-DC converters. We can lessen our reliance on fossil fuels and make better use of renewable energy by increasing the stability and efficiency of these converters.

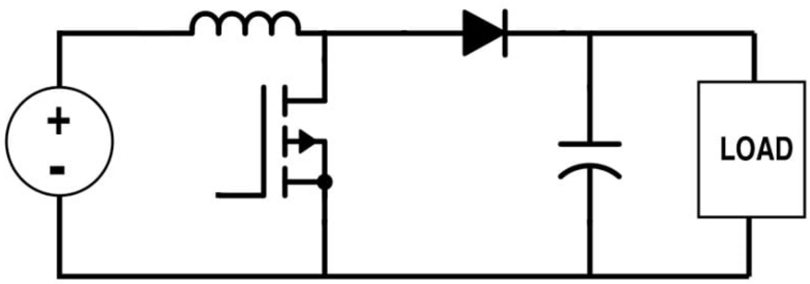
Electrical appliances that use DC-DC converters conventionally usually have higher switching losses, which lowers efficiency and produces unstable voltage outputs. These difficulties may shorten appliances' lifespan. Furthermore, the ongoing depletion of conventional energy sources emphasizes how critical it is to address these problems. The creation of dependable and effective DC-DC converters is necessary to support clean and renewable energy sources. DC-DC converters are essential for supplying loads with variable control and stability and for generating regulated voltages from a variety of sources. Improving their dependability and performance is essential to assisting sustainable energy systems. Three-level inverters are the first inverters to be referred to as multilevel. The introduction of this idea occurred in 1975. The utilization of renewable energy is made possible by a multilevel inverter, which also has a high-power rating and reduces harmonic content. DCMLI, FCMLI, and CHMLI are the three types of MLI. It is important to keep the harmonic content of CHMLI output as low as possible because it can negatively impact appliances. If these problems are not addressed, the device may malfunction and have a shorter lifespan. The most common harmonic among the lowest-order harmonic is the fifth harmonic.

Here, the NR and PSO algorithms are employed to lower harmonics. PSO explains how the swarm particles are moving in the search space in an intelligent manner in search of nourishment. The method begins with a swarm of particles that explore the search space of the problem at random locations and speeds to find the optimal. They update the locations and velocity based on their best local and global solutions. NR can lower THD more than PSO, according to a comparison study between the two. MATLAB/SIMULINK is used to finish the work, and the proposed system operates over CHMLIs at levels 5 and 7.

This Paper presents the integration of interleaved boost converter with cascaded multilevel inverter. The proposed methodology uses MATLAB/Simulink for mathematical modeling and simulation. In contrast to a conventional boost converter, the IBC control topology reduces current imbalances during charging cycles by facilitating current injections through interleaved stage sharing. Further the control logic of the cascaded five level inverter was developed by using the SHE-PWM concept. To solve SHE-PWM Equations N-R and PSO Methodes are proposed. The structure of this research paper is as follows: The suggested system and its modes of operation are explained in Section 2. The outcomes of the simulations are discussed in Section 3. Lastly, the research findings are presented in Section 4.

2. Proposed System:

Fig. 1 shows the block diagram of suggested system. The multi-level inverter (MLI), IBC, and solar PV



system supply power to the EV system. The battery storage system is connected halfway point between IBC and MLI [3]. The system's overall performance is enhanced through the use of IBC. The IBCs are connected between the

Fig. 1: Block diagram of the proposed arrangement.

solar PV panel and the CML to keep the inverter's DC voltage steady regardless of the sun's intensity [1]. These converters are being integrated with motors in EVs. Optimization methods for removing dominant harmonics in integrated circuits are not covered in the literature

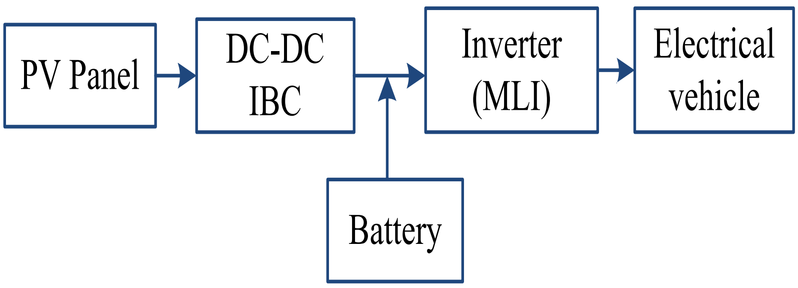


Fig 2. DC-DC boost converter

2.1 Boost converter:

Boost converters, also called step-up converters, are DC-DC converters that lower current while raising input voltage. A switched-mode power supply (SMPS) of this type usually has at least one energy storage component, such as an inductor, capacitor, or occasionally both, and at least two semiconductors, such as a diode and a transistor. Often used as filters on the converter's input (supply side) and output (load side), capacitors reduce voltage ripples

$$V_L = V_{in}$$

$$L\frac{di_L}{dt} = V_{in} \quad \text{--------1}$$

when the switch is close;

$$di_L = \Delta i_L;\ dt = \delta\, T$$

$$(\Delta iL\,)_{\,closed} = \frac{V_{in}\delta\, T}{L}$$

Where δ is duty cycle, V_l *and* I_l are the inductor voltage and current respectively. T is the period of one-cycle, V_{in} is the input voltage

$$(\Delta iL\,)_{open} = \frac{(V_{in}-V_o)(1-\delta\,)T}{L} \quad \text{--------- } \mathbf{2}$$

At Steady-state operation

Where V_o is Output voltage (V).

1.2 Interleaved boost converter.

Interleaved Boost Converter (IBC) is an enhanced version of the Boost Converter (BC) to provide increased voltage gain, while limiting input current ripple, output voltage ripple and size of components. It is composed of several phases of boost converter functioning in parallel with each other and being controlled at 180° phase shift. There are two modes of operation for each phase: inductor charging and energy transfer to the load. The interleaving technique results in a better transient response and requires less filters. The test system parameters are given in Table 1, and the IBC circuit isillustratedinFig.4.

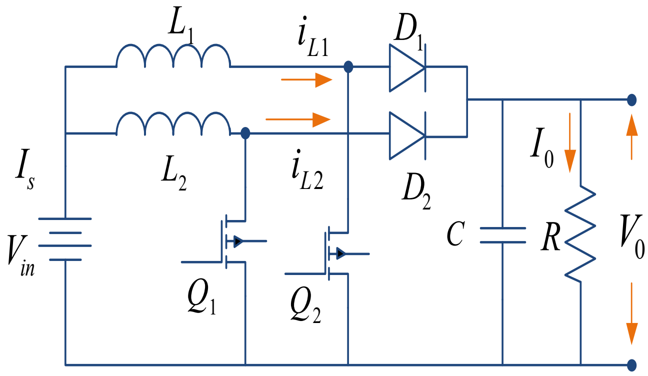


Fig. 4: Proposed interleaved boost converter for EV application

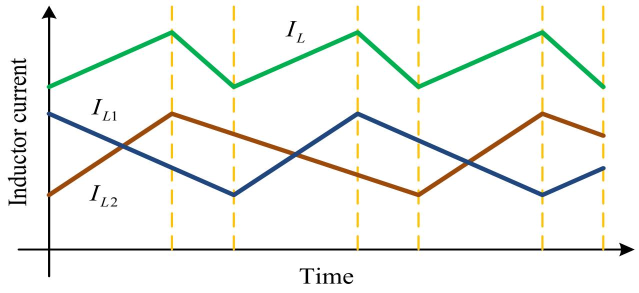


Fig. 5 .. Ideal waveform for the interleaved converter

The performance of IBC under steady-state analysis can be studied with the help of the following parameters

Duty cycle: it can calculate the output voltage at various values of D, with its range lying between 0 to 1.

$$v_0 = \frac{v_{dc}}{1-D} \qquad (3)$$

Here Vo=output voltage, V = input voltage, D = duty ratio.

Input Current: The input current supply is given by equation (3)

$$I_{in} = \frac{P_{in}}{V} \qquad (3)$$

Inductor Current Ripple: The inductor current ripple is the difference between two inductor currents [1]

$$\Delta I_1 I_2 = \frac{V.D}{f.L} \qquad (4)$$

Here the L is the inductance of inductors and f is the input switching frequency

2.3 SHE-PWM TECHNIQUE.

This method is used for removal of lower order harmonics and to lower the THD as much as possible. Lower order harmonics cause vibration or noise in the system and reduces the lifetime with less frequency switching, an efficient output can be obtained. The CHMLI output voltage equation is given below.

$$V(wt) = \sum_{n=1}^{\infty} V\text{nsin}\,(nwt) \qquad \text{----------------}\ 5$$

Where

$$\text{Vn} = \begin{cases} \frac{4Vdc}{n\pi} \sum_{n=1}^{s} cos(n\theta i) & \text{For odd} \end{cases}$$

Vn = 0 for even -

Where n= lower order harmonic component (i.e., n=1, 5, 7,)

Even harmonics is equal to zero (i.e.,Vn=0) because of its quarter wave symmetry . Various Modulation Indices (MI) are used to reduce harmonics which results in less frequency switching.

$$\text{M}=\frac{V1}{12Vdc/_{\pi}} \qquad (0 \le M \le 1) \qquad \text{-------}\ 6$$

MLI are performed with fundamental frequency . Because of nonlinear transcendental nature, result of SHE-PWM equations are complicated. The generated solutions can therefore be used to eliminate the chosen harmonic content.

To solve the above equations N-R and PSO methods are used.

2.3.1 NEWTON RAPHSON:

The Newton-Raphson method or the Newton Method is an effective method of solving nonlinear equations. It is founded on the mere concept of linear approximation. Newton Raphson algorithm of finding the roots of a given equation is an approximation algorithm.

Generally, the system of nonlinear equations with S variables is represented as:

$$F(\alpha) = B \qquad \text{---------} \quad -7$$

Where $F=[f_{1,}f_{2,}f_{3,}]^T$, $B=[b_1,b_2,b_{3,} \dots . b_s]^T$ and $\alpha=[\alpha_{1,}\alpha_{2,}\alpha_{3,} \dots \alpha_s]^T$

F, α, B are Sx1 vectors.

2 5-level cascaded multi-level inverter:

The Fourier series of a 5-level unity DC source is

$$F(t)= f_{\theta 1}(t) + f_{\theta 2}(t)= 2Vdc/\pi \sum_{h=1}^{\infty}[\cos(h\theta 1) + \cos(h\theta 2)]$$

$$=2Vdc/\pi \sum_{h=1}^{\infty}[\sum_{i=1}^{2}(cosh\theta_i)\frac{\sin(hwt)}{h}] \qquad \text{----------} \qquad 8$$

Where:

V_{dc}: Voltage of each voltage source that is unity

θi : The switching angles

h : The harmonic orders

i: No of H-Bridges

In Newton-Raphson method the following matrixes should be created:

1. Switching angles matrix

$$\theta = \begin{bmatrix}\theta_1 \\ \theta_2\end{bmatrix}$$

2. The nonlinear system matrix

$$F = \begin{bmatrix}\cos(\theta_1)+\cos(\theta_2) \\ \cos(5\theta_1)+\cos(5\theta_2)\end{bmatrix}$$

$$dF= \begin{bmatrix}-\sin(\theta_1) & -\sin(\theta_2) \\ -5\sin(5\theta_1) & -5\sin(5\theta_2)\end{bmatrix}$$

3. The answers matrix

$$T= \begin{bmatrix}\frac{\pi}{2} \\ 0\end{bmatrix}$$

$$d'F= \frac{T-F}{dF}$$

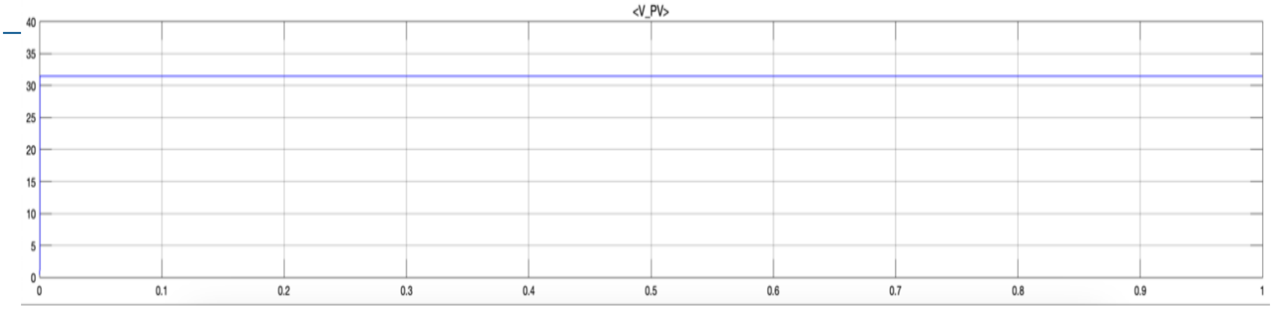
For each iteration loop

$$\theta_{new} = \theta_{old} + d'F$$

By some iteration, the switching angles for a 5-level cascaded H-bridge multilevel inverter are calculated.

2.3.2. PSO

The PSO algorithm's operation and the steps it includes are as follows:



Step1.The swarm (a set of particles) in the search space of SHE problem receives its initialization. According to the equations below, the particle's position and speed are randomly initialized.

$Xi = [Xi1, Xi2, Xi3 \quad XiD]$

$Vi = [Vi1, Vi2, Vi3\ldots\ldots ViD]$, $I = 1,2,3. \quad n$. Where n is the size of the population.

Step 2:The fitness of each particle is determined in each iteration. For a minimization issue, the best fitness is the function's minimal value.

Step 3 : Calculate the pbest and gbest values for each particle in the population.

Step 4: Using the equations, update all of the particles' positions and velocities in each dimension.

$Vij\,(It + 1) = WVij(It) + C1r1\,(Xijp(It) - Xij(It)) + C2r2\,(Xijg(It) - Xij(It))$

$Xij(It + 1) = Xij(It) + Vij(It + 1)$, Where $j = 1,2,3. \quad D$.

C1: Cognitive speed-up factor

C2 : Social acceleration factor

W : weight of Inertia.

r1 & r2 : random values in [0,1]

Xijp : Best position of particle

Xijg : Best position in the total population.

$\sigma = 3s-2$ If s is odd

$\sigma = 3s+1$ if s even.

This above is simplified from SHE technique.

Step 5: Update pbest and gbest, if the present fitness value is lower than the prior fitness value,

Step6 : Until the convergence conditions are satisfied, move on to step 2.

3. Results And Analysis

The simulation results for Interleaved Boost Converter (IBC) are given in this section. The voltage produced by the Solar PV array is fed into the converter. Since the boost converter significantly influences the overall performance of the PV system, its efficiency is crucial. The voltage generated by the PV array is shown in the figure below.

Fig.7. input voltage of boost converter

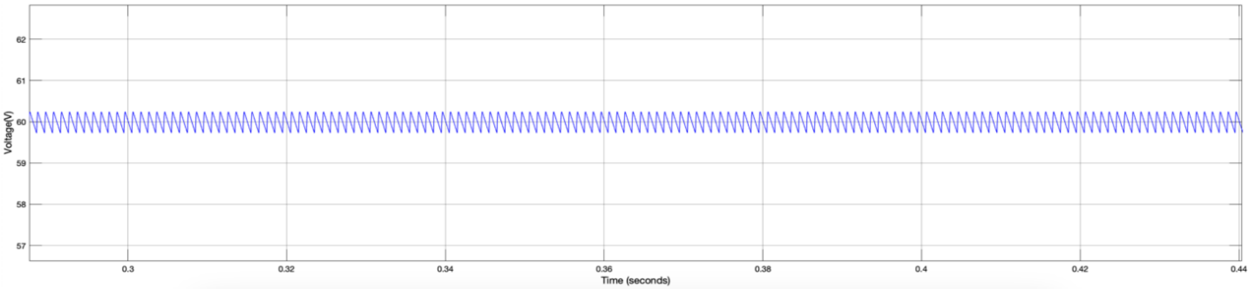


Fig 8. Output voltage of Conventional Boost Converter

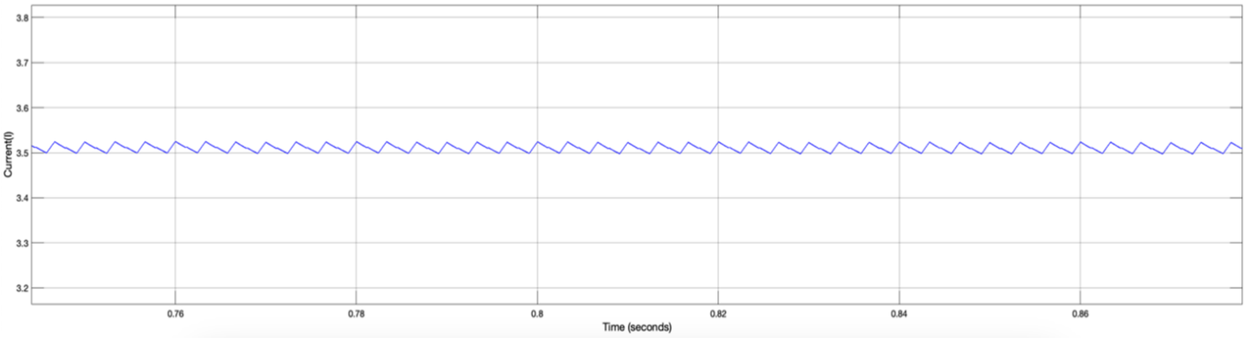


Fig 9. Output current of Conventional Boost Converter

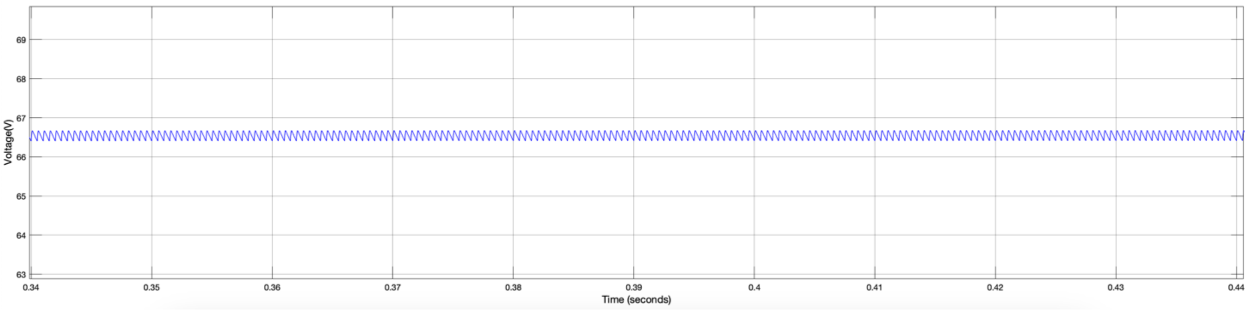
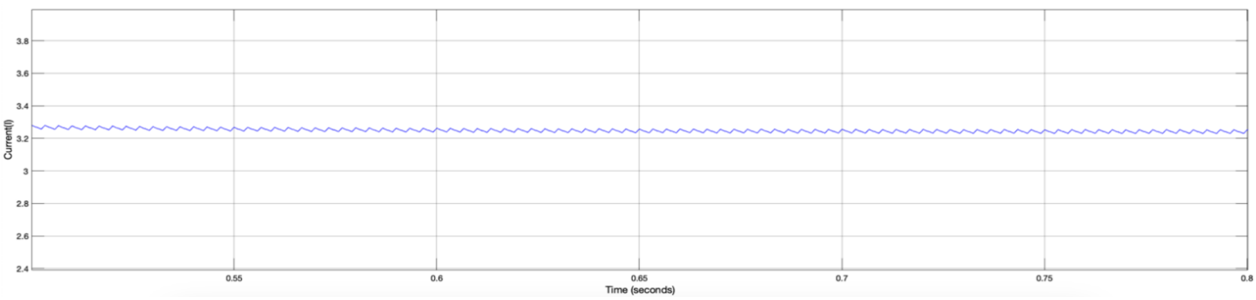


Fig 10: Output Voltage of Interleaved Boost Converter.

Fig 11: Output Current of Interleaved Boost Converter.



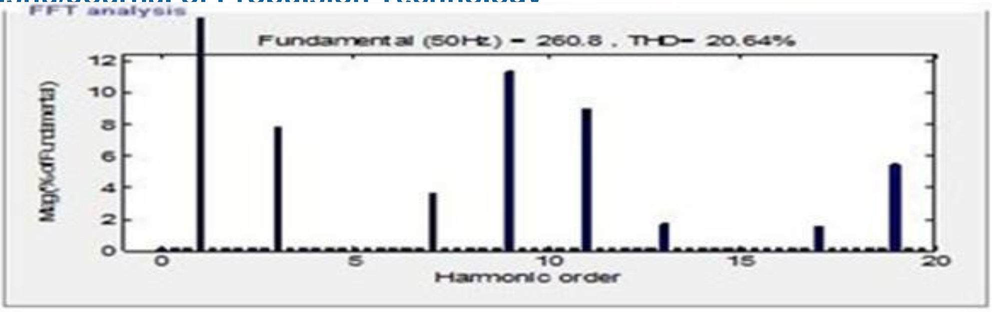


Figure.13. output voltage and current waveform for 5-level inverter using NR, PSO

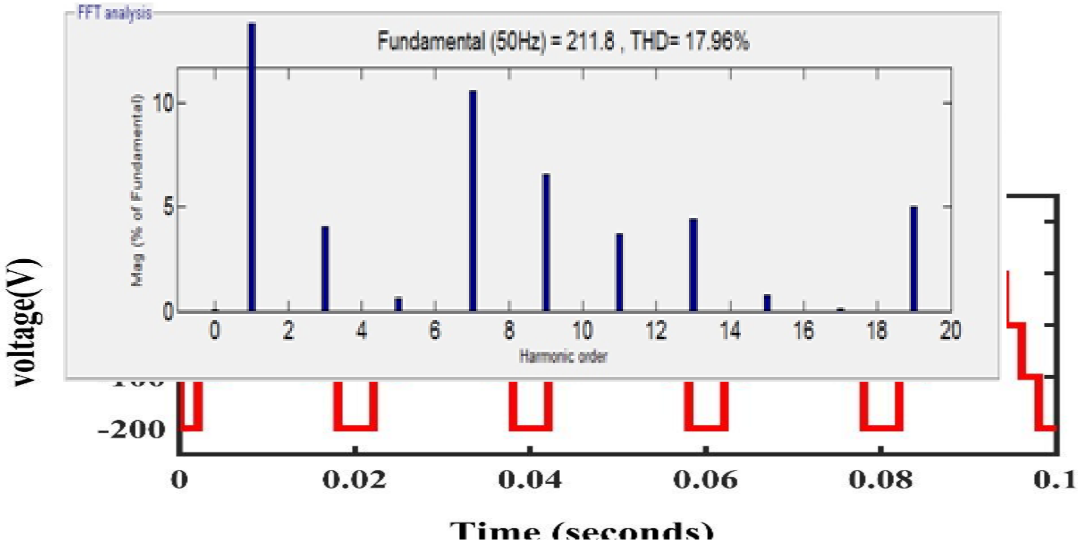


Figure.14.FFT Analysis for 5-level inverter using NR

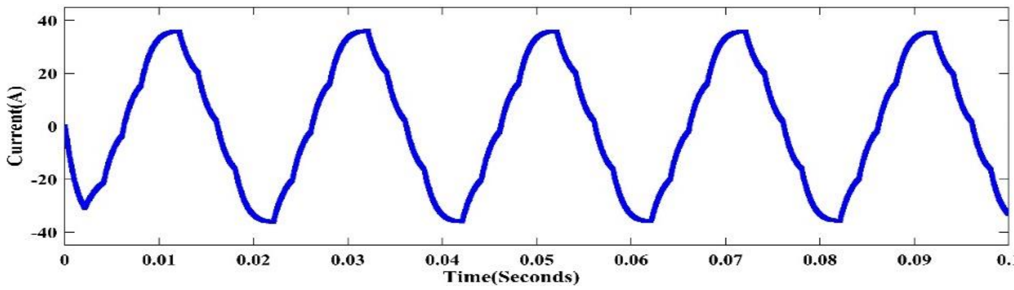


Figure.15.FFT Analysis for 5-level inverter using PSO.

Table.3 deals with the comparison table the THD for proposed algorithm.

S.No	Proposed Method	%THD
1	NR	20.64
2	PSO	17.96

4. Conclusion

The two-phase Interleaved Boost Converter (IBC) with PWM is designed to optimize the efficiency, reliability, power density, ripple current and converter size of the solar PV application. This paper describes the implementation of a solar powered IBC along with a Five Level CHMLI and its control by using SHE-PWM with Newton–Raphson (NR) and Particle Swarm Optimization (PSO) algorithm.The simulation results showed the operation of the system successfully with the elimination of the fifth harmonic and THD value 17.96%. The comparative analysis revealed that PSO technique has a lower THD value and a faster convergence speed than NR technique, and thus PSO is proved to be a better technique for harmonic reduction and power quality improvement in Multilevel inverter system

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