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Simulation of Reduced Switch Nine-Level Multilevel Inverter with SHEPWM using Salp Swarm Algorithm

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ABSTRACT

Harmonic contents in any type of inverter output voltage, particularly at the lower order harmonic, have a significant impact on the operation of various appliances and the system's reliability. The issue in this design is to determine the optimal switching angles for the modulation switching technique which used control the switching devices. Because of the capacity to suppress any single individual harmonic, this system requires the Selective Harmonic Elimination Pulse Width Modulation (SHEPWM) switching mechanism. Due to the efficacy of the metaheuristic optimization algorithm, a recent Bio-inspired Intelligent Algorithms (BIAs), Salp Swarm Algorithm (SSA), will be evaluated for use in the power electronic area as an angle provider for this system. As a result, this work provides a proposed topology with SHEPWM using the SSA. The proposed circuit was modelled and simulated using PSIM software. Total Harmonic Distortion (THD) results will be chosen for modulation 0.56 and 0.83 due to the best global optima performance. The results demonstrate that the fifth, seventh, and eleventh order harmonics have been completely eradicated.

1. Introduction

A significant shift toward the energy utilisation derived from renewable energy sources to cut back on releases of greenhouse gases is an urgently required step toward mitigating the effects of climate change [1,2]. As a consequence of this, renewable sources of energy have received a great deal of attention and development as a result of the fact that they generate efficient electricity with virtually little pollution [3]. To expand this technology's, there is an urgent need from a scientific and technical perspective for upcoming technologies that can give increased conversion efficiency to reduced production costs [4]. These new technologies must be developed as soon as possible.

A multilevel inverter (MLI) has more voltage levels than the common two-level inverters, which typically can be used from medium to high power applications [5,6]. MLIs outperform two-level

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inverters in terms of staged approximately sine wave, reducing the stress from the switch, rejecting the filters and transformers less [7]. For integrating renewable energy sources like wind and solar into the grid, MLI have become a popular option [8].

There are three primary varieties of multilevel inverters, which are referred to as flying capacitor (FC-MLI), diode clamp (DC-MLI), and cascaded H-bridge (CHB-MLI) multilevel inverters [9,10]. The topology of an MLI can be grouped as symmetrical or asymmetrical [11-13]. The asymmetrical MLI generates more levels at the output than the symmetrical MLI. However, asymmetrical MLI topologies are unworkable since they necessitate the addition of a bidirectional switch and numerous separate dc voltage sources of differing magnitudes [14,15]. As a result, this paper focuses on symmetrical MLI. This substance lowers the THD result by eliminating the selected harmonic especially the lower order harmonic [16,17]. When the MLI classification has been determined, one of the primary concerns in calculating the ideal firing angle is the necessity to solve a nonlinear equation while ensuring that the essential component is gratified. This is especially critical to eliminate the lower order harmonic. In reference [18,19], the SHEPWM possesses a number of benefits such as ability to eliminate targeted individual harmonics, and capable to operate in fundamental switching frequency.

This paper presents the SHEPWM approach's SSA algorithm for reduced switch MLI proposed topology. Three objective functions based on the SHE transcendental equation were used to assess the SSA's ability to determine optimal switching angles for a wide modulation index range. Investigation and significance were determined by eliminate the selective individual harmonics and total harmonic distortion better (THD). As conclusion, Objective function 2 reduces selective individual harmonics and total harmonic distortion better than objective function 1 and 3.

2. Proposed Topology and Problem Formulations

In a typical H-bridge inverter, contains 4 switches and have the ability to generate three-level MLI. The modification of this configuration involves with the addition of one supporting power device of unidirectional switch and a diode to complete the circuit. As a result, a single proposed modified H-bridge is now capable of operating a five-level waveform. By cascading the circuit into two bridges similar to Figure 1, it is now possible for the circuit to generate up to nine-level MLI, as shown in Figure 2.

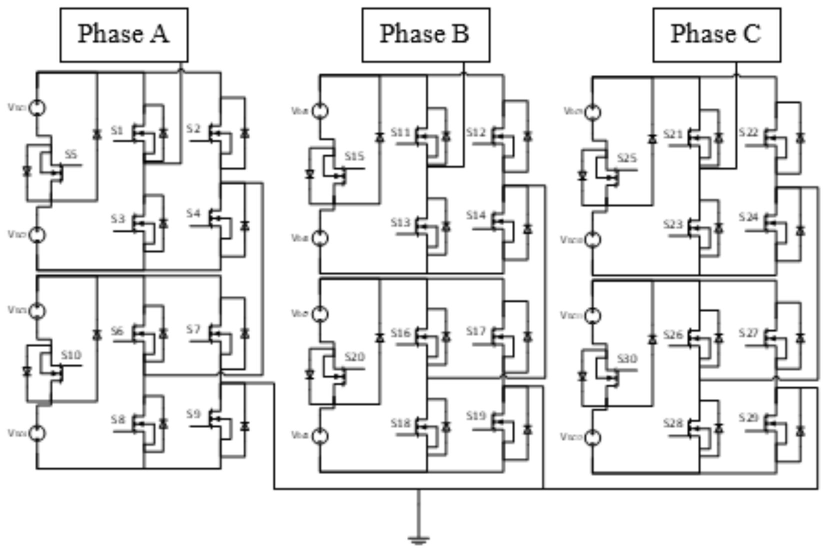


Fig. 1. Proposed three-phase reduced switch nine-level MLI [17]

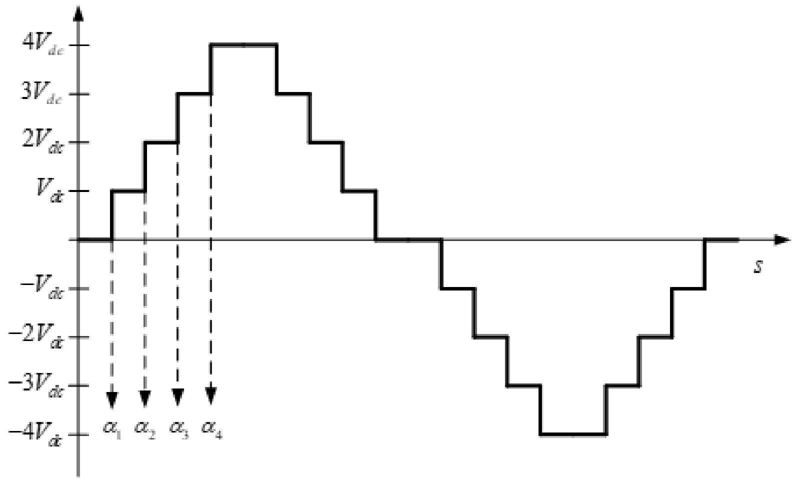


Fig. 2. Typical waveform of nine-level MLI [20]

The staircase waveform shown in Figure 2 has nine-levels and can have four different firing angles, denoted by the notations α_1, α_2, α_3 and α_4. This firing angle should conform to the criteria stated below, as seen in the Eq. (1). The same four switching angles can be utilised for the three-phase system, with each phase delay 1200 respectively. As can be seen in Eq. (2), the angles that are not known are substituted into the Fourier series equation that is used by the multilevel inverter.

$$\alpha_1 < \alpha_2 < \alpha_3 < \alpha_4 < .. < 90° \tag{1}$$

$$V_{AN}(\omega t) = \sum_{n=1,3,5..}^{\infty} \frac{4V_{dc}}{n\pi} \begin{pmatrix} V_{dc1}\cos(n\alpha_1) + V_{dc2}\cos(n\alpha_2) + \\ V_{dc3}\cos(n\alpha_3) + V_{dc4}\cos(n\alpha_4) \end{pmatrix} \tag{2}$$

Figure 1 depicts an equal voltage source, and this source's V_{dc1}, V_{dc2}, V_{dc3}, and V_{dc4} connections all have the same layout. The triplen harmonic, such as the third and ninth, are automatically abolished by the MLI because in a balance three-phase system. Since then, the fifth, seventh, and eleventh harmonic orders have been identified as the following individual harmonics that consume a substantial percentage of harmonics in the spectrum of Fast Furrier Transform (FFT). To eliminate the harmonic, each harmonic order's equation must be set to zero. Consequently, the method may determine the optimal angles that correspond to the closest zero-value solution for each equation, as illustrated in the Eq. (3).

$$\begin{gathered} V_{dc1}\,cos(\alpha_1) + V_{dc2}\,cos(\alpha_2) + V_{dc3}\,cos(\alpha_3) + V_{dc4}\,cos(\alpha_4) = sm_a \\ V_{dc1}\,cos(5\alpha_1) + V_{dc2}\,cos(5\alpha_2) + V_{dc3}\,cos(5\alpha_3) + V_{dc4}\,cos(5\alpha_4) = 0 \\ V_{dc1}\,cos(7\alpha_1) + V_{dc2}\,cos(7\alpha_2) + V_{dc3}\,cos(7\alpha_3) + V_{dc4}\,cos(7\alpha_4) = 0 \\ V_{dc1}\,cos(11\alpha_1) + V_{dc2}\,cos(11\alpha_2) + V_{dc3}\,cos(11\alpha_3) + V_{dc4}\,cos(11\alpha_4) = 0 \end{gathered} \tag{3}$$

In this equation, *s* is the number of H-bridges in each phase, and m_a is the modulation index which can be defined as follows in Eq. (4);

$$m_a = \frac{\pi V_1}{4V_{dc}} \tag{4}$$

In order to find a solution to the Eq. (3) over the full dynamic range of ma, the SSA technique is utilized. It is necessary to have an objective function as part of the optimization process to ensure that the unwanted individual harmonic will be eliminated. As a result, in selecting the most appropriate solution for the nine-level inverter, the three objective functions, OF_1, OF_2, and OF_3, must first be determined. These three objective functions will be compared to evaluate which objective function will produce the best results and solutions. This will help determine which objective function will ensure that the fifth, seventh, and eleventh harmonics are removed while also satisfying the fundamental component, as shown in Eqs. (5)-(7) where V_{ref} is a desire fundamental voltage component, V_1 is the fundamental voltage, s is the number of harmonics, while h_s is the order of viable harmonic, for example (h_2 = 5 and h_3 =7).

$$OF_1 = \left[\left| 100 \frac{V_{ref} - V_1}{V_{ref}} \right|^4 + \sum_{s=2}^{s} \frac{1}{h_s} \left| 50 \frac{V_{hs}}{V_1} \right|^2 \right] \tag{5}$$

$$OF_2 = \left(V_1 - V_{ref} \right)^2 + V_5^2 + V_7^2 + \ldots + V_n^2 \tag{6}$$

$$OF_3 = 100 \times \left(\frac{|V_5| + |V_7| + \ldots + |V_n|}{|V_1|} \right) \tag{7}$$

3. Salp Swarm Algorithms

The SSA is another method used on solving the optimization problems back in 2017 [21]. Salp Swarm functions similarly to a group, with a leader and followers. The Salp at the head of the chain is the leader, while the others are followers. The leader commands the swarm, and its members obey (and the leader, either directly or indirectly).

All Salp coordinates are recorded in a matrix named x. A letter F is a source of a food is considered to represent the swarm's search space objective. The following Eq. (8) shows the current position of the leader:

$$x_j^1 = \begin{cases} F_j + c_1 \left(\left(ub_j - lb_j \right) c_2 + lb_j \right) c_3 \geq 0 \\ F_j - c_1 \left(\left(ub_j - lb_j \right) c_2 + lb_j \right) c_3 < 0 \end{cases} \tag{8}$$

where x_j^1 shows the j^{th} dimension's leader. F_j is the j^{th}-dimensional food supply. lb_j is the dimension's lower bound. Random numbers are c_1, c_2, and c_3. The leader will solely update on food. The random number c_1 will become an important element in SSA due to exploration and exploitation balances and define as Eq. (9).

$$c_1 = 2e^{-\left(\frac{4l}{L} \right)^2} \tag{9}$$

where L denotes the maximum iteration value and l denotes the current iteration. In the range [0,1], the random values that make up the parameters c_2 and c_3 are created in a uniform manner. They also govern whether the subsequent point in the j^{th} dimension should be infinity (positive or negative). The motion of the Newton's law is used to establish the followers' latest position as in Eq. (10).

$$x_j^i = \frac{1}{2}at^2 + v_0 t \tag{10}$$

The value of *i* ≥ 2 and x_j^i shows the position of the i^{th} follower Salp in the j^{th} dimension. The v_0 is the unit used for initial speed while *t* stand for time. The value of a defines as $a = \frac{V_{final}}{V_0}$, $v = \frac{x - x_0}{t}$. The divergence between iterations is equal to 1 because the time in optimization is iteration, and taking v_0 = 0, this equation can be stated in Eq. (11) as follows;

$$x_j^i = \frac{1}{2}x_j^i + x_j^{i-1} \tag{11}$$

where *i* ≥ 2 and x_j^i shows the position of the i^{th} follower salp in the j^{th} dimension.

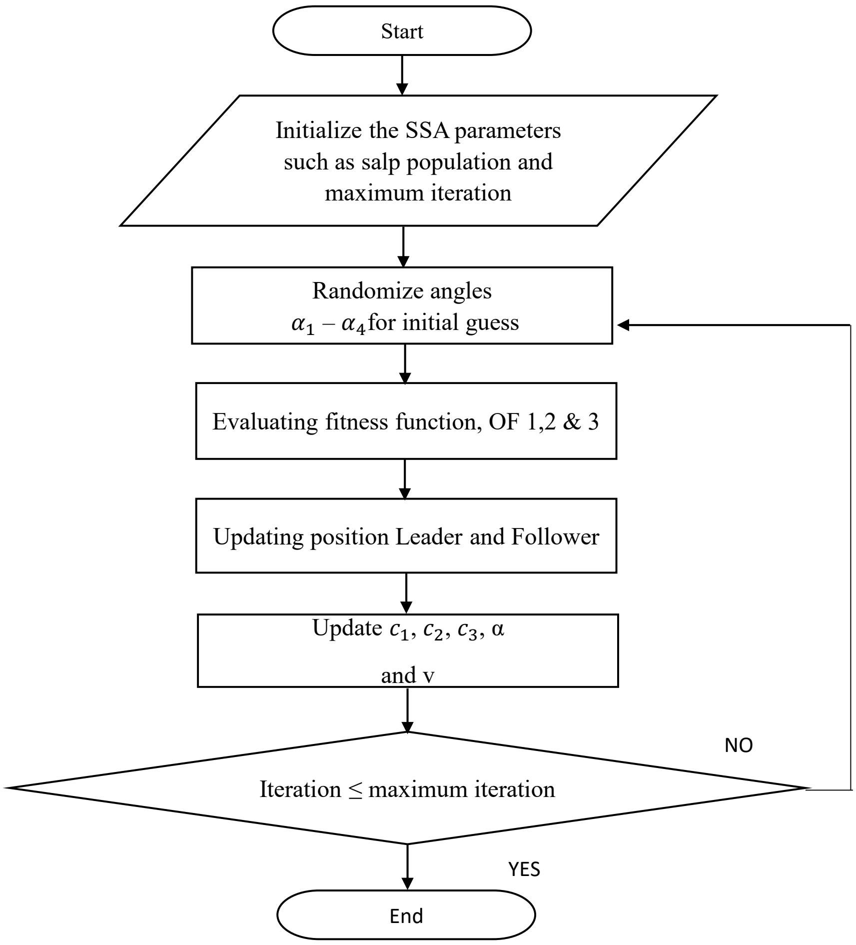


Fig. 3. Flowchart of SSA operation [21]

Table 1 shows the parameter is applied to the proposed MLI to suppress the fifth, seventh, and eleventh harmonics with identical dc sources by using SSA. The objective function values for SSA with equal dc sources are shown in Figure 4. The modulation index is a number between 0 and 1, with each step rising by 0.01. The lowest objective function value for SSA occurs at OF_2 with m_a equal to 0.56. Figure 5 shows the comparison of the Cumulative Distribution Function (CDF) between OF_1, OF_2

and OF_3 for SSA with equal dc sources. It shows that the possibility of obtaining the result below 10^{-5} for OF_1 is 25%, OF_2 is slightly higher than OF_1 with 28% and OF_3 is 22%. This clearly indicates the probability of OF_2 is reaching global optimal is more than OF_1 and OF_3. Figure 6 demonstrates that the V_1 will always follow V_{ref} for almost entire modulation index range and it conclude that by using SSA, the fundamental component is satisfied.

Table 1
Parameter for Salp Swarm algorithm

Parameter	OF_1	OF_2	OF_3
Size of population	200	200	200
Iterations	300	300	300
Total number of runs	10	10	10

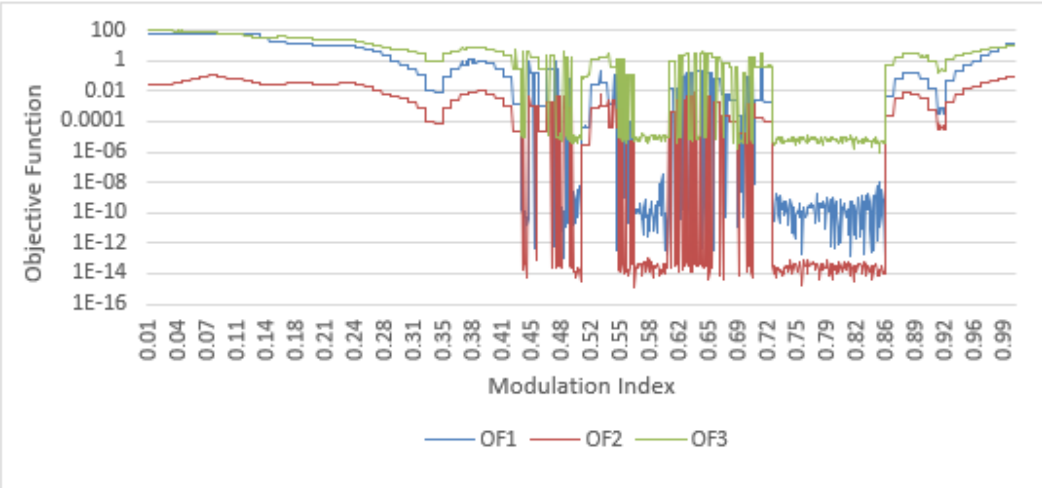


Fig. 4. Comparison of objective function value for SSA with equal dc sources versus modulation index

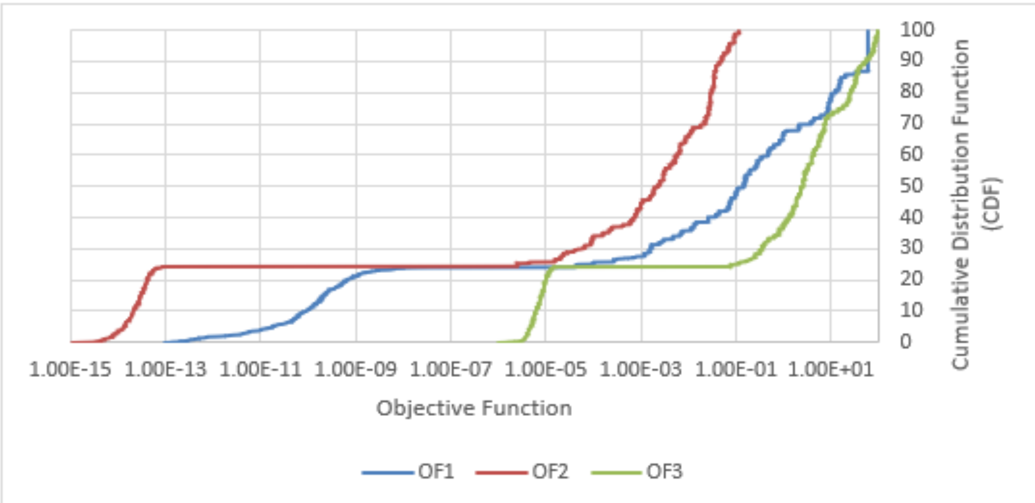


Fig. 5. Comparison of CDF curve for SSA with different objective function

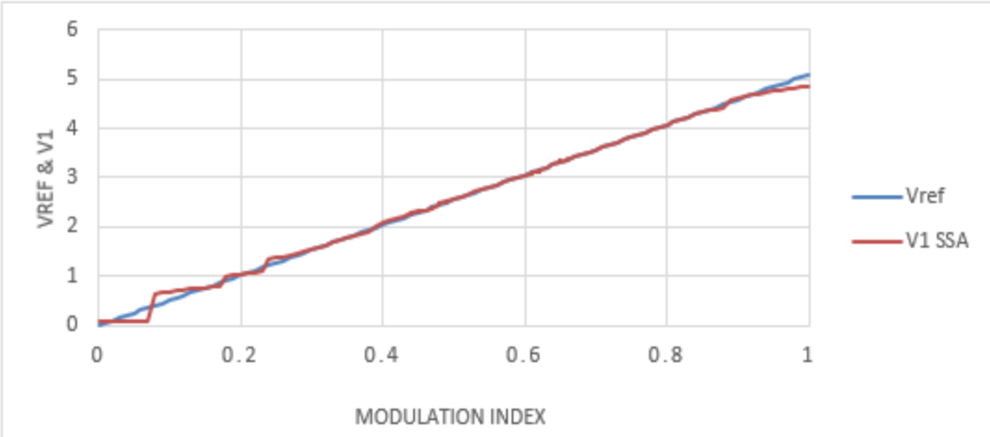
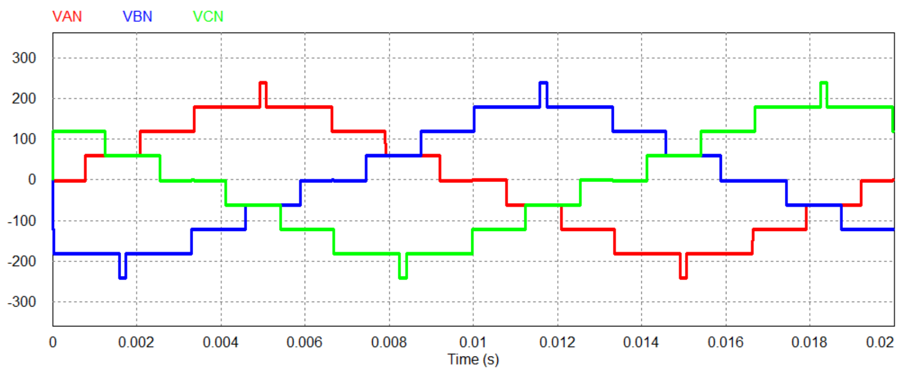


Fig. 6. Comparison V_1 and V_{ref} against modulation index for OF_2 of SSA

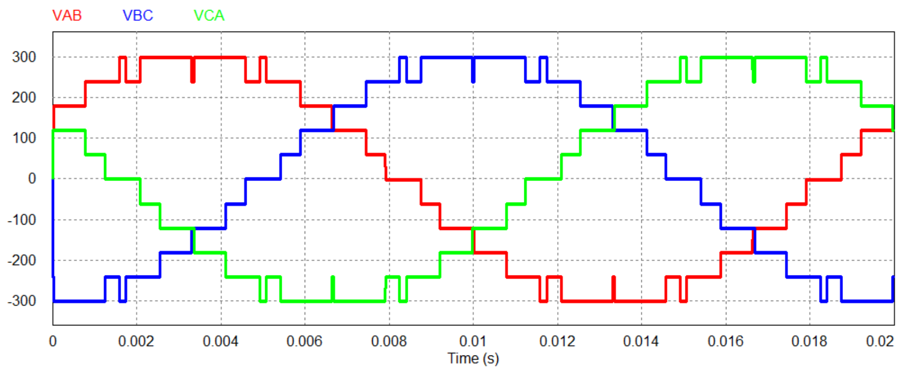
4. Simulation Results

The computed angles were put through a circuit simulation that was carried out with the help of the PSIM software. To demonstrate the usefulness of the proposed system, modulation index of 0.56 and 0.83 were chosen as the solutions that are closest to zero or allow for the fulfilment of the global optimal outcome, as shown in Figure 4.

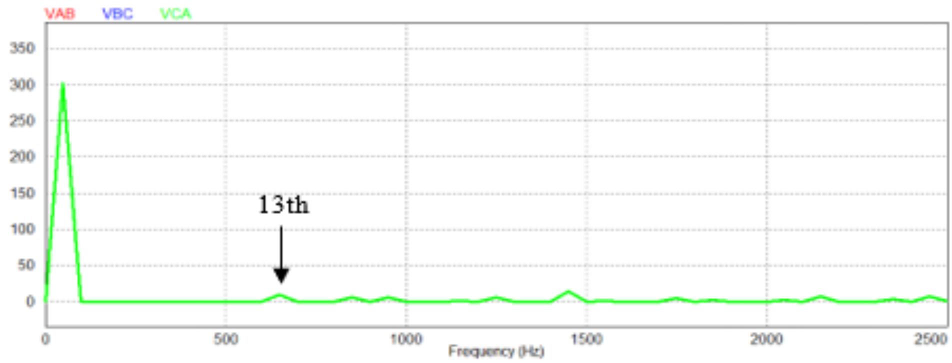
Figure 7(a) shows the phase voltage and Figure 7(b) shows the line-to-line voltage. As a result, with the balance of a three-phase system, triplen harmonics which mean the third, ninth, and up to the fiftieth, are automatically eliminated. As a result of the computation and as was to be predicted, the individual harmonics at the fifth, seventh, and eleventh positions were removed, and they began to rise again at the 13th position, as depicted in Figure 7(c).



(a)



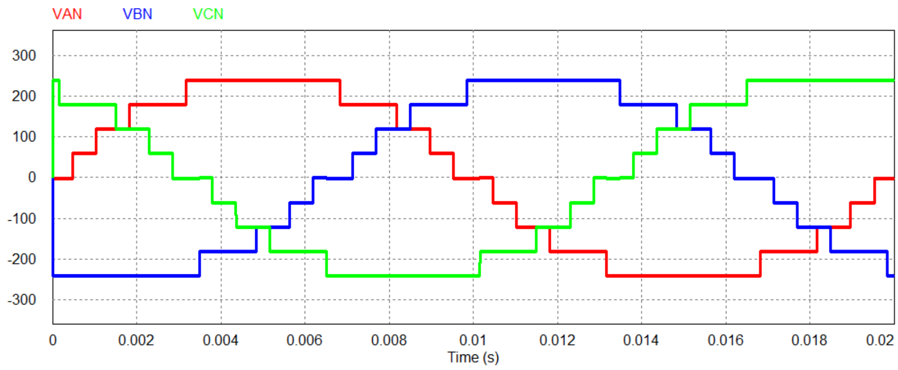
(b)



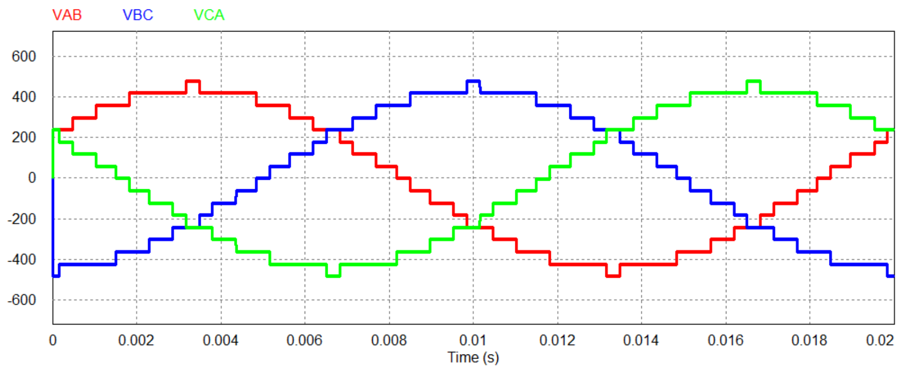
(c)

Fig. 7. Result of simulation of 0.56 modulation index (a) voltage in phase waveform (b) voltage in line-to-line waveform (c) line-to-line fft waveform

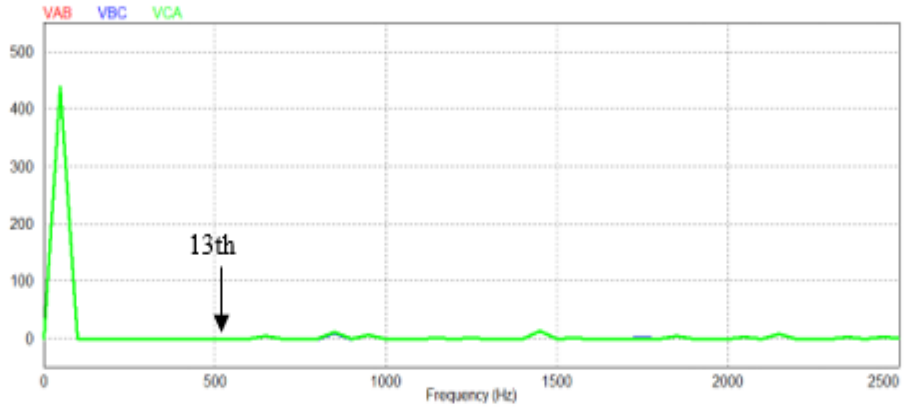
Figure 8(a) and (b) exhibit, respectively, the voltage in phase and voltage in line-to-line waveform for a modulation index of 0.83. As was described in Figure 7(c), Figure 8(c) depicts the same behaviour with the triplen harmonics. This behaviour includes how the third and ninth harmonics up until the fiftieth harmonic are automatically suppressed on their own as a result of the balance provided by the three-phase system. In addition, the fifth, seventh, and eleventh harmonic order positions are dropped, only to be reinstated at the 13th harmonic position. The comprehensive results of the simulation for the proposed MLI are presented in Table 2.



(a)



(b)



(c)

Fig. 8. Result of simulation of 0.83 modulation index (a) voltage in phase waveform (b) voltage in line-to-line waveform (c) line-to-line fft waveform

Table 2
Comparison of Simulation of THD Result

Modulation	THD (%) Simulation
0.56	8.38%
0.83	6.01%

5. Conclusion

In conclusion, this research illustrates that a proposed three-phase MLI is successfully generated by employing the reduced switch approach topology. The operation of the three-phase multilevel inverter demonstrates that the triplen harmonic will be automatically eliminated from a system that is in balance. The findings of the simulation also demonstrate that the lower order harmonic can be regulated so that it is removed entirely by employing SHEPWM as a solution to the nonlinear equation. The suppression of lower order harmonics for the fifth, seventh, and eleventh harmonics was explored, and the SSA can effectively determine the optimal angles, as illustrated for modulation index 0.56 and 0.83. The presented results, which are based on simulation data, are consistent across all of the scenarios that were investigated for this research, and they satisfy the fundamental component.

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