PSO Based Selective Harmonic Elimination PWM for Cascaded H-Bridge Multilevel Inverter

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Abstract. A Single phase Cascaded H-bridge multilevel inverter topology fed by Photovoltaic source for the reduction of harmonics is proposed in this paper. Selective Harmonic Elimination technique is employed for elimination of 5th, 7th, 11th and 13th lower order harmonics and the particle swarm optimization algorithm is employed for estimating the switching angles. As a novelty, in order to maintain the power balance among the various sources, a cyclic selection procedure is adopted that over a period of operation also the sources equally contribute for the output power. MATLAB software is used for optimization and the results show the effectiveness of the proposed algorithm. The performance of the Particle Swarm Optimization Algorithm has been compared against the performance of the Genetic Algorithm.

Keywords: multilevel inverter, cascaded h-bridge multilevel inverter, total harmonic distortion, selective harmonic elimination-pulse width modulation, particle swarm optimization

1. Introduction

In recent years, electrical energy consumption is increasing rapidly due to the increasing demand of energy in the world. As a result of this, numerous fossil fuel sources and other resources which have great contribution in global warming due to greenhouse gases emission are largely consumed. Due to these negative impacts caused by these resources, a rapid progress in finding an alternative and renewable energy has attained a significant interest in the area of researches to eliminate the shortage of fossil fuels and reduce the global warming concern. In the last three decades, renewable energy has become a challenging field and many researchers have made renewable energy the main focus in order to create new sustainable, natural abundance and environmental friendly nature energy resources. This interest of environmentally friendly power will proceed in future in light of the fact that the creation of sustainable power sources are required to fulfill 20% and half of the absolute energy needs in 2020 and 2050 separately. In 2015, worldwide last energy utilization which originated from environmentally friendly power sources is around 22.8% and the portion of environmentally friendly power sources incorporating hydro power in power age is about 28%. Because of the chance of giving energy less reliance on the petroleum products, various types of renewable energy resources such as solar, wind, tidal, waves, geothermal heat, hydropower, especially solar photovoltaic conversion have gained increased acceptance and growth in recent times[1]. Significant advantages of PV panels include clean and reliable energy production and suitability for distributed generation. In addition, the
prices for Photovoltaic modules are drastically decreasing. In fact, it is expected that the PV global installed capacity can reach up to 3000GW, approximately 11% of the global electricity production by 2050. [2]

An inverter is an important component used to convert DC power into AC power from the PV panels in the PV system which is to be given to the grid. PV inverters types have been introduced and explained [3-6]. The cascaded H-bridge multilevel inverter needed a separate DC source for individual H-bridge and have been used for high power and high voltage applications. Also this topology is suitable for medium and large grid-connected PV systems [7-10]. In addition to that, isolated dc sources in the multilevel inverter circuit make their own voltage control. At the same time, the cascaded h-bridge multilevel inverter has given great care due to its simplicity of control and modularity and as a suitable candidate for the forthcoming generation of reliable grid-connected PV system. In solar photovoltaic fed fifteen level Cascaded Multilevel Inverter(CMLI) [11], an optimized harmonic stepped waveform technique is introduced to eliminate lower order harmonics. In eleven level inverter[12], optimum relevance has been found out between switching angles and dc voltages to achieve minimum total harmonic distortion.

In this paper, the PSO algorithm is employed to minimize lower order harmonics and fundamental component is to be satisfied. The performance of the PSO Algorithm has been compared against the performance of the Genetic Algorithm. The novelty uses an automatic sequential scheme such that the total energy delivered the state of charge of the batteries and the terminal voltages are all equal in all the DC sources.

2. Cascaded H-bridge multilevel Inverter topology

The block diagram of proposed topology contains PV source from solar panel, boost converter, multilevel inverter, battery and a filter is shown in figure.1. Multi-string technology with PV modules is employed. The PV array string is linked together to a boost converter with maximum power point tracking. The power produced by the PV modules is continuously changing due to weather conditions, since the irradiance is not constant during the whole day. By using the Perturb and Observe P & O algorithm, maximum power is extracted from the PV array. The eleven level inverter output is AC voltage which is linked together with the load.

![Figure 1. Block diagram of the proposed topology.](image_url)

The proposed topology is shown in figure.2. Five H-bridge inverters are connected in series to form a single-phase 11-level inverter. The H-bridge inverter output voltage gives vHT with 5 levels by providing PV panels with equal dc link voltage.
3. Particle Swarm Optimization Algorithm

The particle swarm optimization (PSO) algorithm was employed for estimating the switching angles $\theta_1$, $\theta_2$, $\theta_3$, $\theta_4$ and $\theta_5$ which will result to the lower order harmonics 5th, 7th, 11th and 13th elimination in a multilevel inverter. An objective function uses the set of five trigonometric transcendental equations for harmonics elimination.

Figure 2. Solar fed Cascaded h-bridge inverter topology
4. Selective Harmonic Elimination Pulse Width Modulation

To eliminate 5th, 7th, 11th and 13th lower order harmonics, mathematical methods are used in SHE PWM technique. This technique is employed to find out the switching angles such as \( \theta_1, \theta_2, \theta_3, \ldots, \theta_N \) so that amplitude of fundamental voltage is satisfied and (\( N-1 \)) odd harmonics can be minimized. The harmonic components in the multilevel waveform are as follows:

- amplitude of dc component is equal to zero
- amplitude of fundamental component, \( n = 1 \), and odd harmonics amplitude are as follows:
  \[
  h_1 = \frac{4V_{dc}}{\pi} \cos \theta_k k = 1, \quad \text{and}
  
  h_n = \frac{4V_{dc}}{n\pi} \cos n\theta_k k = 1
  \]
- amplitude of all even harmonics are equal to zero

In the quarter-wave waveform of symmetrical multilevel inverter, only odd harmonics is to be minimized. To control the amplitude of fundamental component and to minimize 5th, 7th, 11th and 13th lower order harmonics, switching angles \( \theta_1, \theta_2, \theta_3, \theta_4 \) and \( \theta_5 \) are calculated for a particular modulation index to reduce the harmonics and the nonlinear transcendental equations must be calculated.

\[
\cos \theta_1 + \cos \theta_2 + \cos \theta_3 + \cos \theta_4 + \cos \theta_5 = \frac{3\pi M}{4} \tag{1}
\]
\[
\cos 5\theta_1 + \cos 5\theta_2 + \cos 5\theta_3 + \cos 5\theta_4 + \cos 5\theta_5 = 0 \tag{2}
\]
\[
\cos 7\theta_1 + \cos 7\theta_2 + \cos 7\theta_3 + \cos 7\theta_4 + \cos 7\theta_5 = 0 \tag{3}
\]
\[
\cos 11\theta_1 + \cos 11\theta_2 + \cos 11\theta_3 + \cos 11\theta_4 + \cos 11\theta_5 = 0 \tag{4}
\]
\[
\cos 13\theta_1 + \cos 13\theta_2 + \cos 13\theta_3 + \cos 13\theta_4 + \cos 13\theta_5 = 0 \tag{5}
\]

The modulation index is given by

\[
M = h_1 S V \tag{6}
\]

Where, \( h_1 \) is the amplitude of fundamental component. By changing the modulation index from equation (6), the amplitude of fundamental component is controlled.

5. Power balance between the H-Bridge Inverters

In a cascaded h-bridge multilevel inverter operated with a number of isolated PV sources, with step modulation there is a possibility that the individual PV sources and the corresponding inverter units are not equally loaded. This may cause the sources that deliver more power to get more burdened. In order to avoid this situation a cyclic change over system was employed. Also the five H-bridge units were cyclically shifted periodically over every cycle so that fairly uniform loading could be affected on each inverter unit and the corresponding power supply.

6. Simulation Studies

The performance of the SHE PWM based cascaded h-bridge inverter topology with isolated PV dc sources is determined through MATLAB/SIMULINK software. The simulation elements and the parameters are given in Table 1.

The simulink model of the proposed system is shown in figure 3. The simulation circuit contains five H-bridges and PWM block contain parameters as pulse width period, phase delay and amplitude. The obtained output voltage is eleven level stepped waveform and reduces the harmonics.

| Parameters of the Cascaded H-Bridge Inverter |
|---------------------------------------------|
| Parameters                       | Values |
|---------------------------------|--------|
| No. of H-Bridge levels          | 5      |
| No. of Switches                 | 20     |
| PV source voltage for individual H-bridge | 20 V   |
| Fundamental frequency           | 50Hz   |
| Load resistor                   | 100 Ohm|
| Load Inductor                   | 40mH   |
The results are taken for modulation index $M = 0.71$ in MATLAB software. The Output voltage and current waveform of Cascaded h-bridge eleven level inverter are shown in figure 4 & 5.

**Figure 3.** Simulation model of cascaded h-bridge eleven level inverter topology

**Figure 4.** Output voltage waveform

**Figure 5.** Output current waveform

THD is the summation of all consonant parts of the current or voltage waveform. The quantity of music to be diminished is equivalent to the quantity of exchanging points - 1 are acquired.
Figure 6. Harmonic spectrum of the inverter output current

From the above harmonic analysis shown in figure 6, lower order harmonics such as 5th, 7th, 11th, and 13th magnitudes are very small. Furthermore, the solar panel parameters are listed in Table 2.

| Parameters             | Values      |
|------------------------|-------------|
| DC Side                |             |
| MPP voltage            | 17.7V       |
| MPP current            | 6.5A        |
| Open circuit voltage   | 22.2V       |
| Short circuit current  | 7.97A       |
| Temperature            | 25°C        |
| Solar Irradiance       | 1000W/m²    |
| AC Side                |             |
| Rated grid voltage     | 230V        |
| Rated grid current     | 0.5A        |
| Switching frequency    | 20Khz       |
| Inductor filter        | 0.9µH       |

Table 3. Comparison of output current THD

| Modulation Index M | Switching angles in terms of radians | THD(%)         |
|--------------------|-------------------------------------|----------------|
|                    | θ₁       | θ₂       | θ₃       | θ₄       | θ₅       | Simulation | Theoretical |
| 0.51               | 0.79     | 0.89     | 1.06     | 1.26     | 1.34     | 6.54       | 6.02        |
| 0.63               | 0.60     | 0.66     | 0.87     | 1.03     | 1.12     | 4.22       | 4.08        |
| 0.67               | 0.44     | 0.56     | 0.75     | 0.98     | 1.08     | 2.25       | 2.05        |
| 0.71               | 0.25     | 0.42     | 0.66     | 0.94     | 1.02     | 0.72       | 0.62        |

The comparison of output current THD for various modulation indices are indicated in Table 3. The performance of the PSO Algorithm has been compared against the performance of the Genetic Algorithm. For the same modulation index the results obtained in PSO are compared with that obtained with GA in Table 4.
Table 4. Comparison of output current THD (proposed algorithm with existing algorithm)

| Modulation Index M | THD (%) PSO Simulation | THD (%) PSO Theoretical | THD (%) GA Simulation | THD (%) GA Theoretical |
|--------------------|------------------------|-------------------------|-----------------------|------------------------|
| 0.51               | 6.54                   | 6.02                    | 7.78                  | 7.12                   |
| 0.63               | 4.22                   | 4.08                    | 6.04                  | 5.25                   |
| 0.67               | 2.25                   | 2.05                    | 4.68                  | 4.01                   |
| 0.71               | 0.72                   | 0.62                    | 3.02                  | 2.55                   |

The versatility of the proposed logic is that it can be easily extended for multi-level inverters of any size. For example, the same procedure can be used if the proposed idea is design a 15 level inverter or more or a 9 level inverter or less. The only issue will be to formulate the objective function with the required number of variables that influence the removal of harmonics. If the requirement is a 9 level inverter then the number of H bridges will be 4 and 4 switching angles will have to be determined. For the purpose of eliminating three harmonics and to ensure the magnitude of the fundamental to the required level four equations will be formulated to describe the SHE system. Then these four equations will be used to find the four switching angles.

Similarly a 15 level inverter can be constructed using 7 numbers of H bridges and 7 number of switching angles will have to estimate. An objective function incorporating the seven switching angles as the variables to be estimated will be formed.

7. Conclusions
In this paper, elimination of fifth, seventh, eleventh and thirteenth lower request music utilizing SHEPWM system is examined. To tackle the SHE issue and to discover the exchanging points, PSO algorithm is employed with equal dc sources in cascaded H-bridge multilevel inverters. Using an automatic sequential scheme, with the equally distributed fall of state of charge of the batteries, the batteries would exhibit the same terminal voltage thus the switching angle estimation would not be affected. Simulation results are introduced for an eleven-level H-connect inverter to affirm the specific hypothetical results. The selected area of work opens up new avenues for further research. The different directions of research include usage of unequal DC sources for the cascaded H bridges, asymmetrical operation of the bridges with voltage ratios in the order of 1:3:9:81 or 1:2:4:8 etc. for minimal switch operation, enhancement of levels of the inverter and implementation of much modern search algorithms. Besides since most of the applications require real-time control of modulation index the avenues for research in this direction are also open. Proposed topology produces high quality output voltage and gives better current total harmonic distortion.

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