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Asymmetric Multilevel DC Link Inverter for Reducing THD using a Meta-Heuristic Algorithm

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ABSTRACT- Multilevel inverters are essential for increasing power quality, boosting efficiency, and lowering harmonic distortion in the field of power electronics. This research presents a new method using the Pelican optimization algorithm (POA) to create pulse patterns in multilevel inverters. The work focuses on deploying a 125-level asymmetric multi-level inverter that is powered by solar panels through a DC-DC converter in order to address power quality difficulties. In order to get better performance in multilevel inverter systems, the Pelican optimization algorithm is used to create pulse patterns that are modeled after the hunting strategies of pelicans. The Distributed Static Synchronous Compensator, is a leading device that uses power electronic components to control power flow and improve power quality in power grids. It is one of the many specialized power devices available. The primary objective is to enhance reactive power to ensure the stability of voltage within the power system and the aim of this research is to maintain voltage stability. Using the pelican optimization algorithm, the method entails creating and deploying a DSTATCOM based on a 125-level asymmetric multi-level inverter.

Keywords: Multilevel Inverter, Dstatcom, Pelicon Optimization Algorithm, Total Harmonic Distortion.

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1. INTRODUCTION

Due to the increasing prevalence of non-direct, unbalanced, and inductive loads in the distribution system, a multitude of power quality issues arise [1]. Ensuring a stable power supply to meet consumption demands necessitates the use of power electronic converters. While generators generate a consistent sinusoidal voltage, the connected loads draw distorted and imbalanced currents, impacting the feeder voltage and disrupting the operation of other connected loads on the same feeder. To tackle these challenges, various custom power devices (CPDs) have been deployed [2], [3]. Among these CPDs, Distribution Static Compensators (DSTATCOMs) are commonly utilized to mitigate power quality issues stemming from current variations. Due to the escalating reliance on conventional energy sources, there is a pressing need to integrate unconventional resources into a wide array of applications, given their plentiful and eco-friendly characteristics [4]. Solar energy, recognized as a leading and promising energy source, is frequently regarded as a viable solution for fulfilling energy needs. The conversion of solar energy into electrical energy is accomplished through the utilization of Photovoltaic (PV) cells.

PV panels, when integrated with DSTATCOM, can partially offset the electricity demand of the load. Renewable energy sources have long been hailed for their accessibility and environmental benefits. This research utilizes solar energy captured by PV panels to generate direct current (DC) voltage for RSC-AMLC. Through a Bidirectional Converter, the voltage from the solar panels is adjusted to meet the desired level. However, the energy output from PV panels fluctuates due to changing environmental conditions and time. Integration of PV with DSTATCOM can be activated depending on the irradiation availability.

This study seeks to improve the efficiency and performance of multilevel inverters by optimizing pulse patterns through the Pelican Optimization Algorithm. Utilizing this algorithm enables targeted harmonic elimination, allowing for precise control over the output of the voltage source converter.

2. PROPOSED METHOD: RSC-AMLDCL

This study introduces an asymmetric multilevel DC-link (AMLDCL) within the cascaded h-bridge inverter that employs a reduced quantity of switches. The configuration involves a series of "n" half-bridge units, each comprising dual switches and a solitary dc source, as noted in sources [5] and [6]. These interconnected components, referred to as level-production components, enable the creation of a voltage waveform with steps in DC voltage. By manipulating the output voltage's polarity, the H-bridge can produce a full multilevel AC waveform. Leveraging the MLDCL topology with a compact numeral of semiconductor switches enables the production of various output voltage levels. The single-phase full-bridge inverter receives a DC-bus voltage in the shape of a staircase from the MLDCL, which is produced by the half-bridge cells. The inverter then reverses the voltage polarity to produce an AC voltage.

Figure 1 illustrates the MLDCL inverter topology, comprising six DC sources. The stage responsible for generating levels produces zero and positive level of voltage waveform in the shape of a stair-step. Conversely, the polarity generating stage, based on an H-Bridge, intermittently reverses every other half-cycle associated with the waveform produced by the stage of level production, resulting in adverse levels. As a result, the output imitates a sine wave [8]. Utilizing an asymmetrical arrangement of DC sources, the topology in *figure 2* yields 125 levels of output voltage. Employing the binary technique, the DC sources are determined for the 125 output levels using geometric progression as described in the subsequent text [9].

$V_6=2V_5=2V4 = 2V3 = 2V2 = 2V$

Differing from the symmetrical configuration, the count of levels and switches necessary for an asymmetrical MLDCL inverter can be extended as stated in [10]. The principal aim of this investigation is to minimize the number of switches while cumulative the levels of the output voltage. This research introduces a novel topology based on an asymmetrical multilevel inverter (AMLI), illustrated in the single-phase model is represented in *fig. 1*, which is extended for three-phase configuration and its output is shown in *fig. 2*. It necessitates six dissimilar sources of voltage (V_1, V_2, V_3, V_4, V_5, and V_6) and twelve unidirectional switches (S1, S2, S3, S4...S12), combining IGBTs with antiparallel diodes to generate the 125-Level natural waveforms.

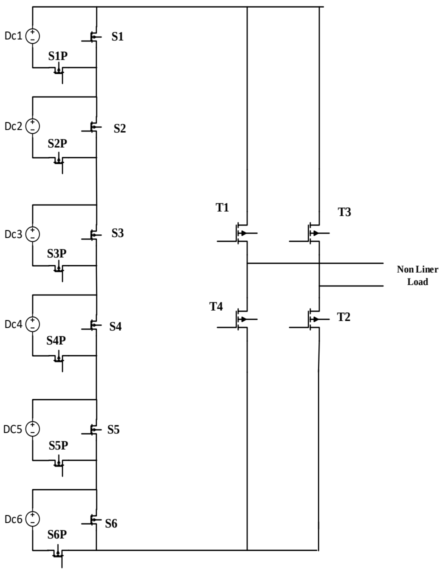

Figure 1. Proposed 125 level AMLDCL Inverter

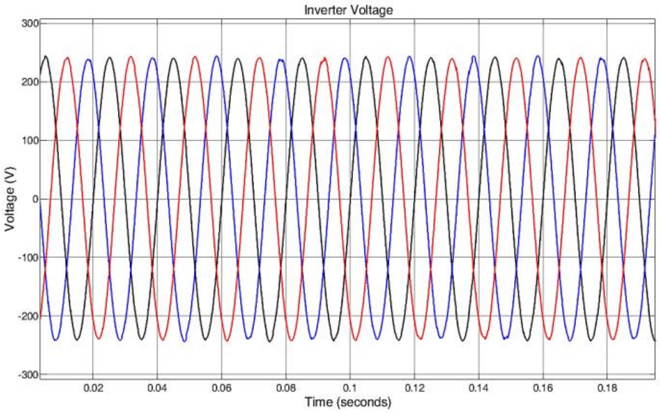

Figure 2. Proposed Inverter Three phase output voltage

3. PV-DSTATCOM OPERATION

Multiple approaches of operation for the solar panel with RSC-MLI are available depending on the availability of irradiation. Throughout the daytime, PV panels generate the highest level of actual power. Consequently, the batteries have the potential to be charged, and they can also offer real power assistance. Conversely, during the night, Insufficient irradiation prevents PV panels from producing actual power. In such scenarios, reactive power's dc-link voltage will be sustained with help from the batteries and compensating for harmonics.

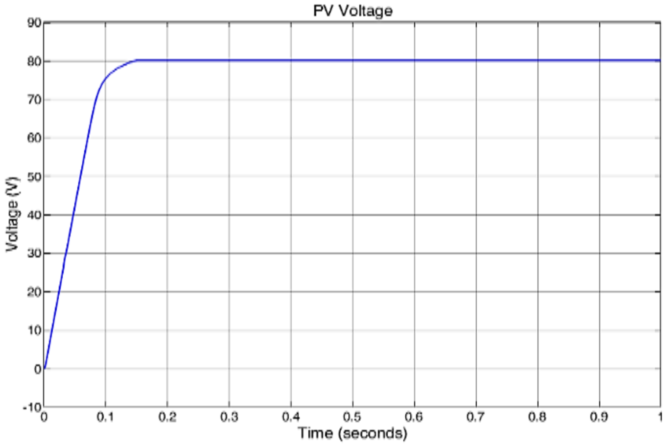

Figure 3. PV Output Voltage

The distribution of actual power can be intelligently managed in accordance with the availability of irradiation and the energy demand, *figure 3* represents the PV panel output voltage.

Since PV panels can immediately replace the segregated DC sources, the MLDCL inverter is optimal for PV system integration. PV panels and inverters can be interfaced with a Bidirectional dc-dc converter shown in *figure 4*. To ensure that the output level is suitable, it is imperative that the output generated by DC- DC converter be, set prior to the inverter in this procedure. PV panel performance, however, is depending upon solar irradiance and ambient temperature, both of which change with time [11].

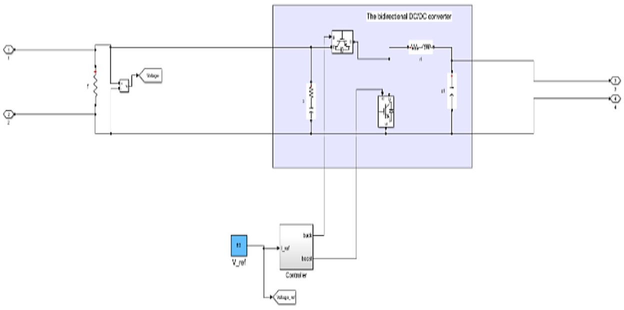

Figure 4. DC-DC Bidirectional Converter

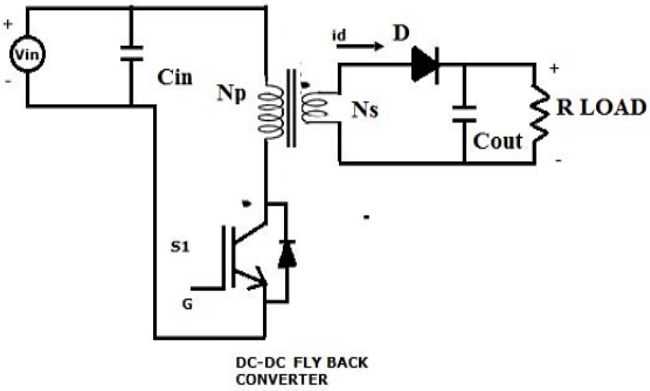

Figure 5. DC-DC Flyback Converter

Bidirectional Dc-Dc Converter enhances the output voltage of the PV panels in such a way that it supplies to AMLI in different voltages from V1 to V6 through Dc-Dc Flyback converter. The flyback converter (FBC) and switch mode dc power supply (SMPS) with a *R* load are shown in *fig. 5*. This FBC operates on the idea that insistence is provided from the necessary polarization inductance to the optional charging inductance connected to the output side when the switch that controls it is turned on. Because the energy retained by the fundamental magnetic inductance does not pass through the discretionary side, snubber circuits are connected in conjunction with switches to lessen voltage spikes that happen when the switch is turned off [12]. Enhancement of the flyback DC-DC converter with various output of Asymmetric voltages shown in *figure 6* are supplied to the Inverter. These different magnitudes of voltages act as the DC link modules to series connected half bridge units. It may occasionally be necessary to use a snubber circuit to reduce the peak voltage and reach a safe level that is within the maximum voltage rating [13]. For the generation of pulses to inverter through Pelican Optimization Algorithm which is inspired by nature.

4. PELICAN OPTIMIZATION ALGORITHM

Nature-inspired optimization techniques are algorithms that mimic natural processes to solve complex optimization problems. These techniques draw inspiration from various biological, ecological, and physical phenomena [14][15]. This section presents suggested swarm-based Pelican Optimization Algorithm (POA). Grounded on the social behavior of pelicans, the Pelican Optimization Algorithm (POA) is an optimization algorithm inspired by nature. Numerous optimization issues, including those involving engineering design, data clustering, picture processing, and other challenging optimization tasks, are resolved using this approach. The Pelican Optimization Algorithm is inspired by pelican hunting behavior and simulates the teamwork and cooperation of pelicans in hunting situations [16]. Pelicans increase the yield rate of their hunts by cooperating to encircle and catch fish. This is known as group hunting. The Pelican Optimization Algorithm is developed on the basis of this cooperative behavior. For multilevel inverters to provide superior output voltage waveforms and reduce harmonic distortion, the right gate pulses must be generated.

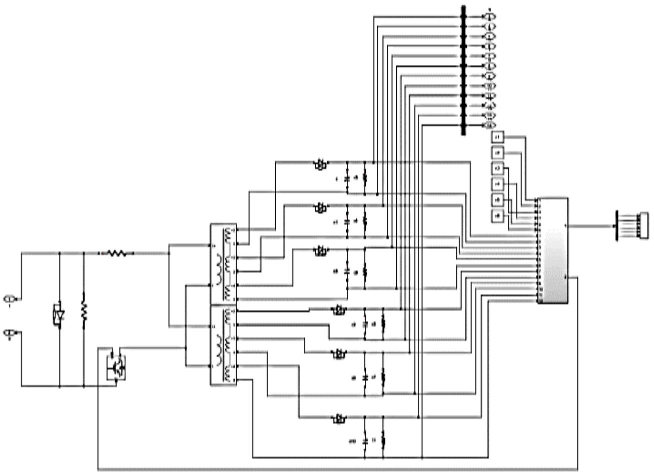

Figure 6. DC-DC Flyback converter with Multi output

These can be produced using the Pelican Optimization Algorithm (POA). The POA can be used to maximize power conversion efficiency, reduce the voltage's overall harmonic distortion (THD) at the output, and minimize the overall number of switching transitions by optimizing the multilevel inverter's switching patterns. The POA can assist in figuring out the best switching angles and patterns for the multilevel inverter's different voltage levels. The suggested POA mimics the tactics and behavior of pelicans throughout hunting and attack. The simulation of this hunting tactic involves two steps:

i. Approaching the prey (the phase of exploration).
ii. On the water's surface, flying (exploitation phase)
Phase i: Approaching the prey (the phase of exploration)

In the *first phase*, the pelicans find the prey and head toward it. Checking the search space and the proposed POA's capacity for exploration in locating various search space regions are made possible by modeling this pelican's approach. The fact that the prey's location is randomly generated inside the search region is crucial to POA. This strengthens POA's capability to explore indeed inside the problem-solving domain. *Equation (1)* represents a mathematical simulating the concepts discussed above and the pelican's tactic to the prey's location.

$$X_{i,j}^{P_1} = \begin{cases} x_{i,j} + \mathrm{rand} \cdot (P_j - I \cdot x_{i,j}), & F_p < F_{i,} \\ x_{i,j} + \mathrm{rand} \cdot (x_{i,j} - P_j), & \mathrm{else}, \end{cases} \tag{1}$$

where P_j is the prey's position in the jth dimension, F_p is the value of its objective function, and $X_{i,j}^{P_1}$ is the ith pelican's new status in the dimension of *j* based on phase-1. *I* is a random number which is equal to 1 or 2. A numeral that can arbitrarily equivalent either 1 or 2 is the parameter I. For every member and iteration, a random parameter is chosen. This parameter's value of two causes a member to be further displaced, which may take them into previously unexplored regions of the hunt space. As a result, constraint *I* influences the POA's ability to explore space accurately.

If the price of the function that defines the objective is improved in the new location for a pelican in the recommended POA, then the position is accepted. This kind of updating, referred to as effective updating, keeps the algorithm from traveling in non-optimal directions. Equation is used to model this process *eq. (2)*

$$X_i = \begin{cases} X_i^{P_1}, F_i^{P_1} < F_i, \\ X_i, \quad else, \end{cases} \tag{2}$$

where $F_i^{P_1}$ is the pelican's function's objective value defined by phase 1 and $X_i^{P_1}$ is its new status.

Phase ii: On the surface of the water, flying (exploitation phase) In the following phase, when the pelicans get closer to the water's surface, they stretch their wings to push the fish higher and then gather the food into their pouch at the neck. This tactic helps pelicans clasp extra seafood in the attacked region. As a result of modeling this pelican behavior, the suggested POA converges to more advantageous locations inside the stalking area. This process increases the exploitation and efficacy of local searches. From a mathematical perspective, for the algorithm to converge to an optimal solution, it must look at the points surrounding the pelican position. *Equation (3)* simulates the hunting behavior of pelicans mathematically.

$$x_{i,j}^{P_2} = x_{i,j} + R \cdot \left(1 - \frac{t}{T}\right) \cdot (2 \cdot \text{rand} - 1) \cdot x_{i,j}, \tag{3}$$

where R is a constant, equivalent to 0.2, $x_{i,j}^{P_2}$ is the *i*th Phase-2 data determines the new position of pelicans in the second dimension, t is the duration of the repetition clock, and T represents the maximum numeral of iterations. The surrounding region extent $x_{i,j}$ is denoted by $R \cdot (1 - t/T)$. The perimeter of the population's surrounding area for locating each member remotely to come up with a better solution is represented by the coefficient "$R \cdot (1 - t/T)$". This coefficient performs effectively on the POA exploitation power to get closer to the optimal global solution.

Since this coefficient has a high value in the first iterations, each member's immediate surroundings are taken into account. The coefficient "$R \cdot (1 - t/T)$" diminishes as the process replicates more, giving each member's neighborhood a smaller radius. In order for we can use smaller, more accurate steps to scan the area encircling every member of the quantity by allowing the POA to narrow down to responses that are nearer to the universal (and even perfectly global) ideal based on the usage notion. *Equation (4)* models the newly adopted pelican positions, which has likewise received approval or criticism at this stage by effective updating.

$$X_i = \begin{cases} X_i^{P_2}, F_i^{P_2} < F_i, \\ X_i, \ else, \end{cases} \tag{4}$$

where $F_i^{P_2}$ is the pelican's objective function value determined by phase-2, and $X_i^{P_2}$ is its new status. The most suitable candidate solution up to this point will be updated once every member of the population has been updated with respect to the initial and subsequent stages, the population's new status, and the parameters of the goal function. Lastly, a virtual-optimal response to the certain issue is offered using the most effective solution found during the algorithm iterations.

Algorithm 1. Pseudo-code of POA.

```
Start POA.
Input the optimization problem information.
Determine the POA population size (N) and the number of iterations (T).
Initialization of the position of pelicans and calculate the objective function.
For t = 1:T
    Generate the position of the prey at random.
    For I = 1:N
    Phase 1: Moving towards prey (exploration phase).
        For j = 1:m
            Calculate new status of the jth dimension using Equation (4).
        End.
        Update the ith population member using Equation (5).
    Phase 2: Winging on the water surface (exploitation phase).
        For j = 1:m.
            Calculate new status of the jth dimension using Equation (6).
        End.
        Update the ith population member using Equation (7).
    End.
    Update best candidate solution.
End.
Output best candidate solution obtained by POA.
End POA.
```

5. RESULTS AND DISCUSSIONS

The proposed Pelican Optimization Algorithm (POA) technique is utilized to analyze switching angles in this study. POA is specifically tailored to evaluate an objective function aimed at effectively managing the Multilevel Inverter (MLI) by identifying optimal switching angles devoid of solution discontinuities. The POA algorithm is executed using MATLAB 2022b software, successfully generating the required switching angles. The depicted 125-level Asymmetric Multilevel DC-Link (AMLDCL) inverter acting as DSTATCOM, is developed using MATLAB as shown in *fig. 7.* To achieve a 125-level output, six DC sources are utilized with voltage values of V1=3.8V, V2=7.6 V, V3=15.2 V, V4=30.4 V, V5=60.8 V, and V6=121.6 V. The nominal output frequency considered is 50 hertz.

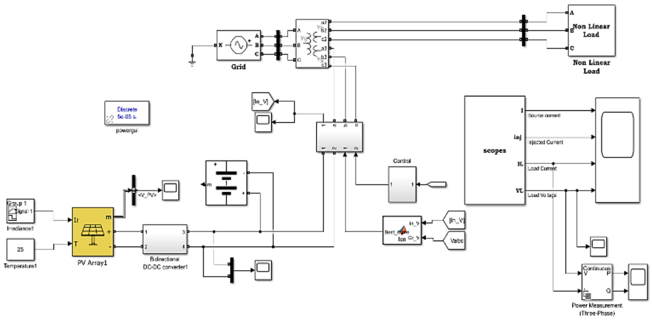

Figure 7. Simulation of proposed AMLI model as DSTATCOM

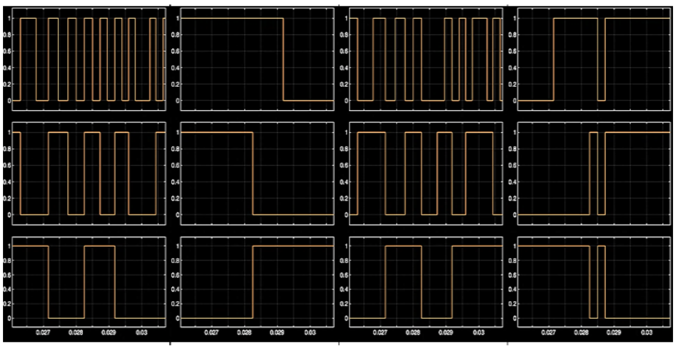

Figure 8. Gate Pulses to AMLDCL Inverter

To facilitate gate pulses for the Insulated Gate Bipolar Transistor (IGBT) switches, the POA algorithm is coded and executed on the identical platform. The resultant switching pulses are depicted in *figure 8*.

The magnitude of these pulses is set at 1V. Simulation is conducted to validate the reduction in harmonics in the final output voltage (Vo) of the proposed AMLDCL MLI. The corresponding load voltage, load current, and injected current are displayed in *figure 9*.

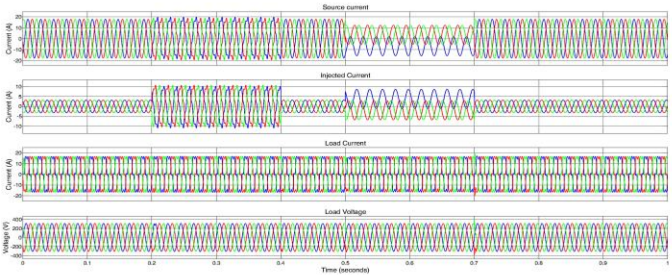

Figure 9. (a) Source Current, (b) Injected Current, (c) Load Current and d) Load Voltage Waveforms

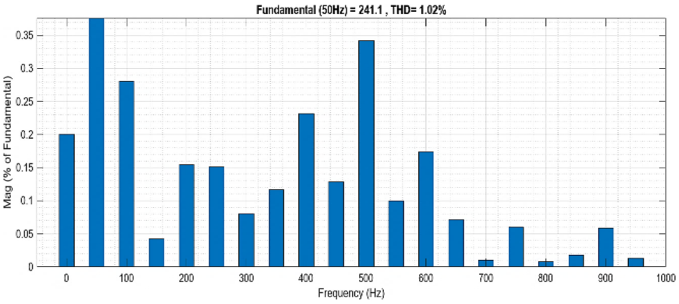

Figure 10. THD Analysis of Inverter Voltage

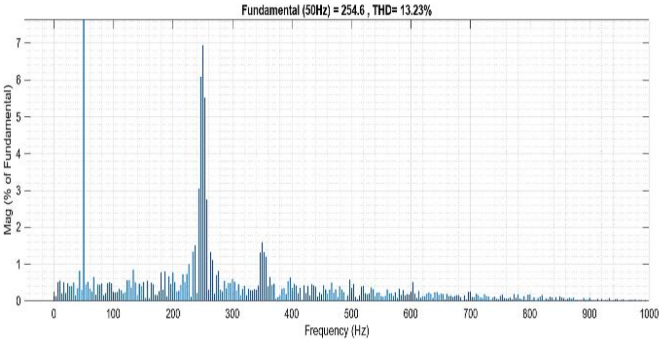

Figure 11. THD Analysis without Compensation

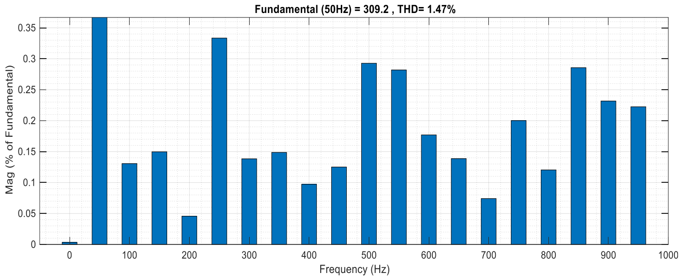

Figure 12. THD Analysis during Compensation

Table 1. Comparison table for THD Analysis

Parameters	THD
THD Analysis of Inverter Voltage	1.02%
THD Analysis without Compensation	13.23%
THD Analysis with Compensation	1.47%

The inverter's output voltage harmonic content is depicted in *figure 10*, measuring at 1.02%, aligning with the tolerance limits outlined by the IEEE 519 standard for harmonics. A voltage sag of 127V occurred between 0.5 and 0.7 seconds, while a 320V voltage swell was observed between 0.2 and 0.4 seconds. During these events, injection current is introduced to the line, effectively correcting the system current. The system voltage returns to nominal levels with the aid of compensated current from the DSTATCOM, which is integrated with the suggested inverter. As illustrated in *fig. 11*, the Total Harmonic Distortion (THD) analysis without compensation measures at 13.23%, whereas with the proposed Asymmetric Multilevel Dc Link Inverter (AMLDCL) functioning as DSTATCOM, utilizing the Pelican Optimization Algorithm, the THD is notably reduced to 1.47% in *fig. 12*. This highlights the effectiveness of the proposed solution in compensating for voltage swells and sags in grid-connected power systems.

6. CONCLUSIONS

This paper introduces a novel AMLDCL inverter architecture featuring a reduced number of switches, comprising only 12 switches for level generation and 4 switches for polarity generation *via* a DC-DC flyback converter tailored for solar PV systems. The proposed AMLDCL inverter module can produce 125 levels at the output, achieving a Total Harmonic Distortion (THD) of 1.02%. Consequently, this suggested topology proves to be a promising alternative to the widely used CHB MLI across various applications. Simulation-based verification demonstrates the functionality of the 125-level MLI as a DSTATCOM, utilizing the Pelicon optimization algorithm inspired by nature to control the switches during level generation. Simulation results demonstrate the DSTATCOM's superior voltage regulation capabilities with minimal Total Harmonic Distortion (THD). Additionally, it is observed that the rating of the DC storage device affects the DSTATCOM's ability to regulate voltage and provide power compensation. The presented simulation results exhibit high accuracy, confirming the effectiveness of the proposed approach.

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