SSRG International Journal of Electrical and Electronics Engineering
ISSN: 2348-8379/ https://doi.org/10.14445/23488379/IJEEE-V10I8P105

Volume 10 Issue 8, 51-61, August 2023

Original Article

Integrating MPPT and Artificial Neural Networks for Efficient DC-DC and DC-AC Conversion in Photovoltaic Applications

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Received: 05 June 2023 Revised: 09 July 2023 Accepted: 06 August 2023 Published: 31 August 2023

Abstract - *This paper describes integrating Maximum Power Point Tracking (MPPT) algorithms and Artificial Neural Networks (ANNs) to optimize DC-DC and DC-AC transformation in photovoltaic applications. By continuously adjusting the operating point to the maximum power point of the PV module, MPPT techniques are frequently used to maximise the power output from PV systems. However, environmental changes and system configurations impact the extent to which conventional MPPT methods perform. An ANN-based MPPT approach is proposed to address this problem, and it uses ANNs' capacity for learning to track the maximum power point under various circumstances adaptively. The simulation results confirm that the integrated system outperforms traditional MPPT techniques regarding power extraction effectiveness. The proposed approach improves the stability and reliability of monitoring the maximum power point, enabling optimal energy collection from PV systems. The efficacy of the integrated system has been exhibited through extensive modelling, highlighting its potential for practical implementation in real-world PV applications.*

Keywords - *Artificial Neural Networks, Boost converter, MPPT, Multilevel inverter, Photovoltaic system, Power efficiency.*

1. Introduction

The use of solar power has received an abundance of attention recently due to its potential as a sustainable and renewable energy source. PV systems convert sunlight directly into electricity and are becoming increasingly common in various settings, from residential rooftops to massive solar power plants.

However, the complicated and unpredictable characteristics of solar irradiation significantly impact the effectiveness of PV systems. For a PV system to operate more efficiently overall, its power output has to be maximised. Incremental conductance and other well-known standard methods for MPPT, like Perturb and Observe (P&O), have an established history of fulfilment. However, these methods frequently exhibit slow convergence and poor accuracy, significantly when irradiance changes quickly.

Artificial Neural Networks (ANNs) have come to light as an intriguing approach to improving MPPT algorithm effectiveness in the past few years. ANNs are mathematical models which can acquire intricate patterns and make accurate forecasts. The neural networks have influenced them in the brain of an individual. ANNs can be effectively developed using historical PV system data to respond to changing atmospheric conditions while offering real-time MPPT control.

Furthermore, the integration of MPPT algorithms with ANNs enables efficient DC-DC and DC-AC conversions of power in solar energy systems. The voltage levels between the PV array and the load are adjusted using DC-DC converters to guarantee optimal power transfer. The DC power generated by the PV array is converted into AC power by DC-AC inverters, which is appropriate for integrating into the grid or supplying AC appliances [1-4].

2. Literature Review

The use of MPPT techniques is crucial for increasing the effectiveness of PV systems. Variable weather, partial shading, and rapidly changing irradiance levels make it difficult to track accurately and present integration challenges. The need for real-time algorithms, the complexity of the hardware, and financial considerations also bring implementation difficulties. Maintaining reliability and performance while ensuring seamless communication and compatibility between the MPPT controller and the PV modules is essential. To maximise the overall generation of the PV system and achieve optimal power in the extraction process, such issues must be resolved by the system's developers [5-9].

The use of photovoltaic energy systems as a renewable and sustainable energy source has increased. For PV systems to operate as efficiently as possible, the optimum power point of the solar panels is needed to be precisely observed. To extract the most power from the PV system, the operating point is dynamically altered using MPPT techniques. It also discusses current studies to enhance the P&O algorithm's performance and robustness. The INC is another popular MPPT method that uses the PV array's incremental conductance to calculate the MPP. Adaptive and fuzzy logic-based INC algorithms are just two examples of recent developments in the INC technique [10-13].

ANNs can adapt to shifting environmental conditions and learn complex relationships between inputs and outputs. In addition to discussing the backpropagation algorithm used to train the network, the investigation looks at the input, hidden, and output layers of ANNs. ANNs can be integrated with MPPT algorithms due to their benefits, such as their capacity to handle non-linearities and uncertainties. The use of ANNs as an additional tool to improve the effectiveness, accuracy, and robustness of MPPT algorithms has been investigated in several studies. The survey emphasises the advantages of ANN-based MPPT, including decreased reliance on precise system models, improved tracking under partial shading conditions, and faster response times [14-18].

The accessibility and calibre of data are the main obstacles to ANN implementation for inverter-fed PV systems. For ANNs to be trained effectively, accurate and representative data are necessary. Due to factors like limited access to comprehensive datasets, the variability of weather, and the requirement for long-term measurements, obtaining such data can be complex. Making accurate predictions also requires ensuring data quality, which includes removing outliers and accounting for missing data. Several variables, such as inverter-fed PV systems, influence complex nonlinear systems, such as temperature, shading, and ageing.

Creating ANNs that can accurately capture these complexities and generalise well to unexplored data is challenging. Predictions may be inaccurate due to overly simplistic ANN models failing to capture the complex dynamics of the system. A critical aspect that must be carefully focused on is balancing the complexity of the ANN model with its generalisation capability. ANNs are frequently regarded as black-box models, making them difficult to interpret. Although they can make precise predictions, it becomes difficult to comprehend the logic behind it. Interpretability is crucial for monitoring, diagnostics, and control in inverter-fed PV systems. When dealing with large-scale inverter-fed PV systems, the computational complexity and training time of ANNs can be a constraint.

Large amounts of training data and computational resources are needed for complex ANN architectures. Efficient algorithms and parallel computing methods are being investigated to lessen this difficulty. Furthermore, the growing interest in acceleration devices and specialised neural network architectures can aid in improving training efficiency [19-21].

DC-DC boost converters are critical components of PV systems because they convert the low voltage from PV panels to the required voltage for battery charging or grid connection. Researchers have suggested several techniques to increase the effectiveness of DC-DC boost converters. Utilising MPPT algorithms is one strategy because it allows PV panels to produce the most power possible by dynamically adjusting the operating point [22-23].

Zero-Voltage Switching (ZVS) and Zero-Current Switching (ZCS), two soft-switching techniques, reduce switching losses and raise the converter's overall efficiency. Several soft-switching topologies for PV applications have been proposed and examined, including resonant and soft-switching boost converters. DC-DC boost converters and DC-AC inverters are crucial parts of PV systems because they transform DC energy from the panels or batteries into AC power compatible with the grid or power for AC loads.

Researchers have tried to improve the efficiency and performance of DC-AC inverters using various methods. One approach is to use cutting-edge modulation techniques, like Pulse Width Modulation (PWM) and Space Vector Modulation (SVM), to regulate the switching of power devices in the inverter. These methods reduce switching losses, minimise harmonics, and raise the inverter's efficiency [24-28].

Due to their capacity to enhance overall system efficiency, reduce harmonic distortion, and improve power quality, efficient five-level multilevel inverters have attracted much attention in Photovoltaic (PV) applications. Due to its ability to effectively integrate renewable energy sources into the grid, multilevel inverters are used more frequently in PV systems. The five-level configuration has emerged as a promising option among the various multilevel inverter topologies because of its delicate balance between complexity and performance.

Efficiency optimisation is another critical component of five-level multilevel inverters in PV systems. Researchers have put forth several methods to increase overall efficiency, including creating sophisticated control algorithms, enhanced methods for heat dissipation, and the best possible selection of inductor and capacitor values. When used with an inverter, Battery Energy Storage Systems (BESS) or supercapacitors can reduce output variations from solar panels, enhance voltage stability, and offer backup power during grid outages. Numerous studies have examined the best control methods and energy storage system sizes for multilevel inverter performance in PV applications [29-36].

In order to combine PV with the MPPT-fed ANN approach, this investigation entails designing and analysing a five-level multilevel inverter. The proposed system has to implement into account the forthcoming crucial factors for applications involving renewable energy:

- Examine the performance assessment of conventional DC-DC converters in solar-power systems.
- Investigate the efficacy of MPPT computations in enhancing energy extraction from PV panels.
- Assess artificial neural networks' positive and negative aspects when modelling and improving the MPPT method.
- Develop a novel integrated system that combines MPPT algorithms with ANNs for efficient DC-DC conversion in photovoltaic applications.
- Evaluate the integrated system's overall performance concerning energy conservation and power output.
- Determine the DC to AC converter's efficacy and the effects of various modulation methods, such as pulse width modulation, on the system's overall efficiency.
- Examine the interactions of the MPPT algorithm with the DC-DC and DC-AC converters, and evaluate the overall system effectiveness and power quality.

3. Proposed PV Integrated Grid System

In order to successfully integrate PV power into the electrical grid, a comprehensive solution called the PV Integrated Grid System has been proposed. It seeks to optimise PV panel power generation, control DC voltage, transform it into usable AC power, and ensure seamless grid integration. The first component of the system is PV panels, which convert sunlight into direct current power.

The power output is optimised using an MPPT algorithm based on the P&O technique. A DC regulator is employed to maintain a constant DC voltage level coming from the PV panels. It ensures that the power delivered to the inverter is consistent and within the specified range. The system's main component is the modular five-level inverter, which transforms DC power into high-quality AC power. This specific type of inverter offers greater efficiency and less harmonic distortion than conventional inverters. This lets it precisely control the output voltage and frequency, ensuring grid compatibility.

The ANN optimises the inverter's control parameters by learning from the system's historical data. This adaptive control strategy improves the system's effectiveness and capability to react to changing grid conditions. A filter reduces harmonics and noise in the output power, ensuring the grid receives a clean and dependable power supply.

The electrical grid is then connected to the system, enabling the distributed injection and distribution of the generated power throughout the grid infrastructure. Combining these elements yields the PV Integrated Grid System, which contributes to a more environmentally friendly and sustainable power generation system by offering an effective and dependable solution for integrating renewable solar energy into the current electrical grid. The PV-integrated grid system is shown in Figure 1.

The input-output pairs that comprise the training data are vectors of attributes as the inputs and corresponding target values as the outputs. The network is taught to map inputs to outputs using these pairs. The gradient descent algorithm optimises the weights of the Radial Basis Function Network (RBFN). With random initial weights, it iteratively updates them by computing the gradient of the error function concerning the weights and moving in the opposite direction of the gradient to minimise the error.

The weights are updated by deducting the learning rate multiplied by the gradient of the error function concerning each weight. This update govern assists the network in determining a set of weights that minimises error. One kind of activation function used in RBFNs is the radial basis function. Calculating the Euclidean distance between an input vector and a prototype vector determines how similar the two are.

These similarity values are weighted together and output by the RBFN. The error is calculated by comparing the RBFN's predicted outputs with the training data's target outputs. The mean squared error, which measures the typical squared difference between predicted and target outputs, is a standard error metric. The ANN approach with supervised learning of RBFN is shown in Figure 2.

In order to maximise power production, photovoltaic systems use the Perturb and Observe and maximum power point tracking algorithms in combination with an artificial neural network. Multiple solar panels connected in series or parallel form the PV array, transforming solar energy into electrical energy. PV voltage denotes the electrical potential difference across the solar panels, whereas PV current refers to the current flow generated by the panels.

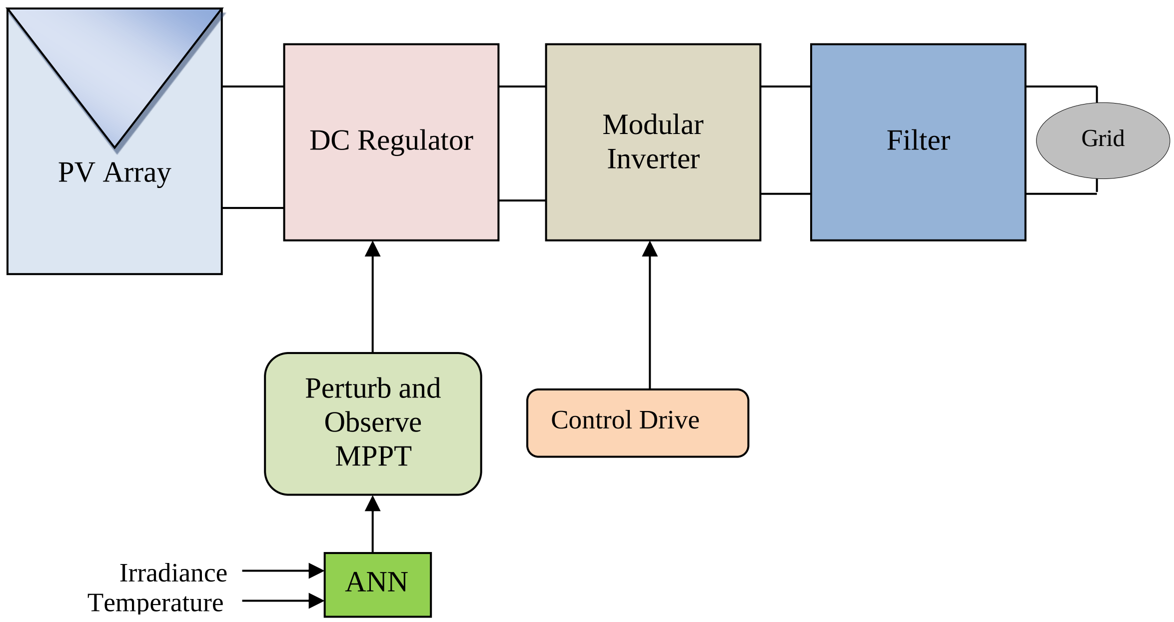

Fig. 1 PV integrated grid connected system

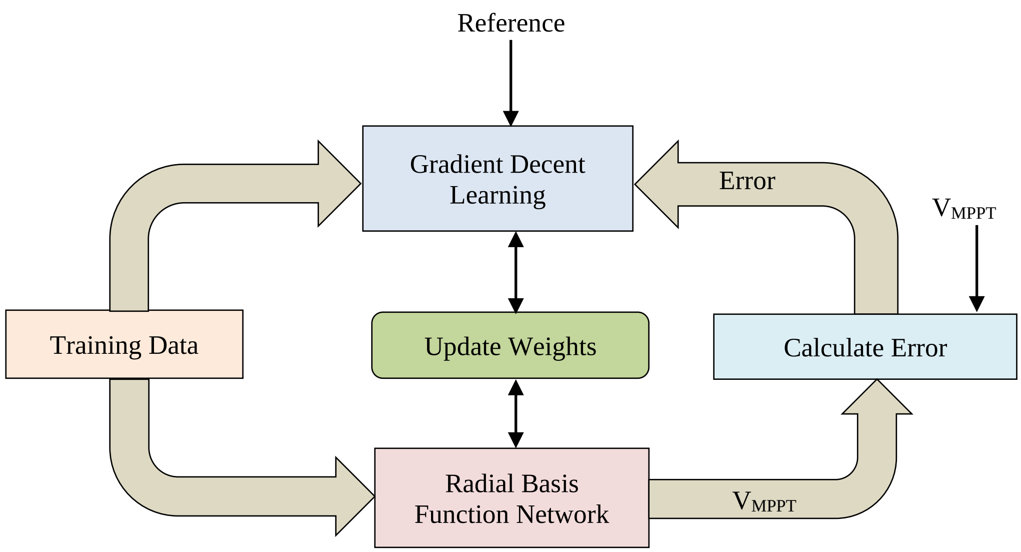

Fig. 2 ANN approach with supervised learning of RBFN

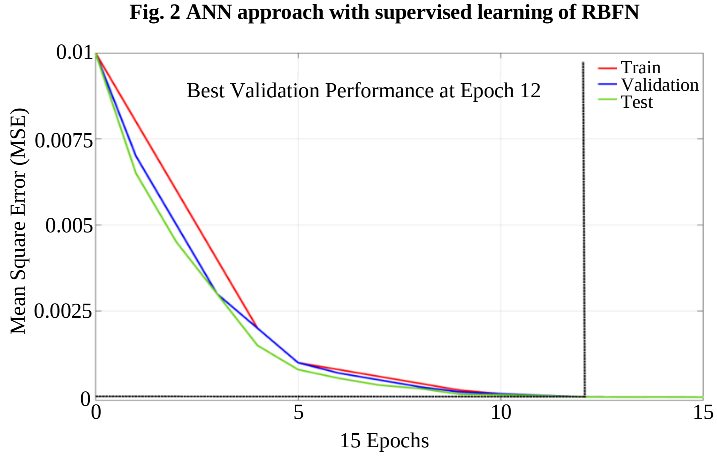

Fig. 3 Validating MSE and epochs using RBFN

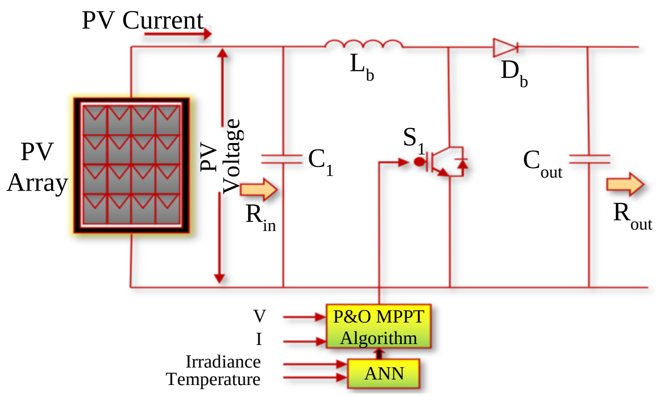

Fig. 4 P&O MPPT with ANN of boost regulator

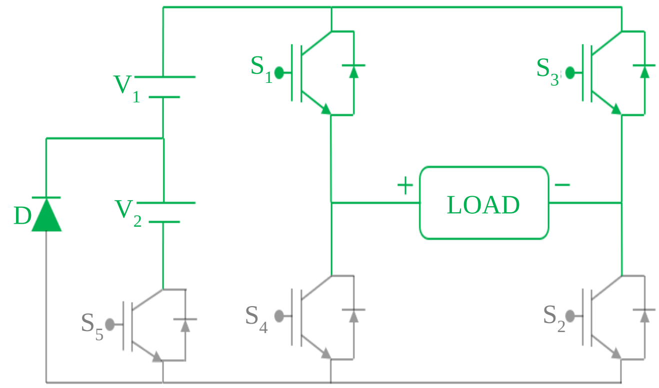

Fig. 8 Proposed modular MLI output voltage of 0Vdc

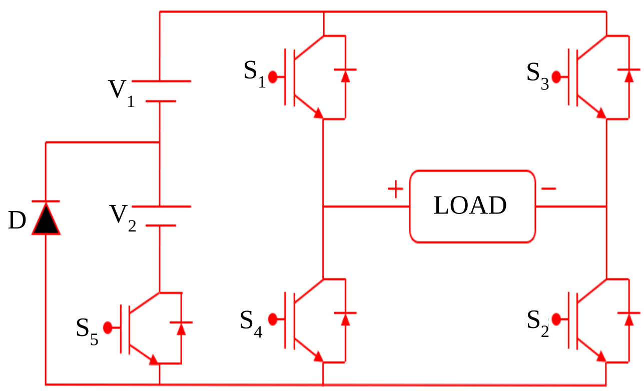

Fig. 5 Proposed modular five-level multilevel inverter

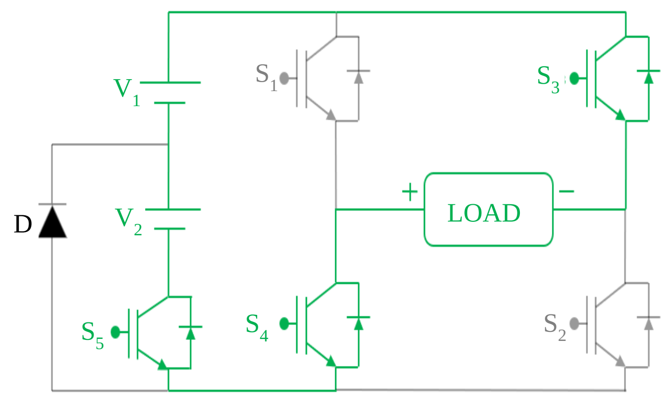

Fig. 9 Proposed modular MLI output voltage of -Vdc

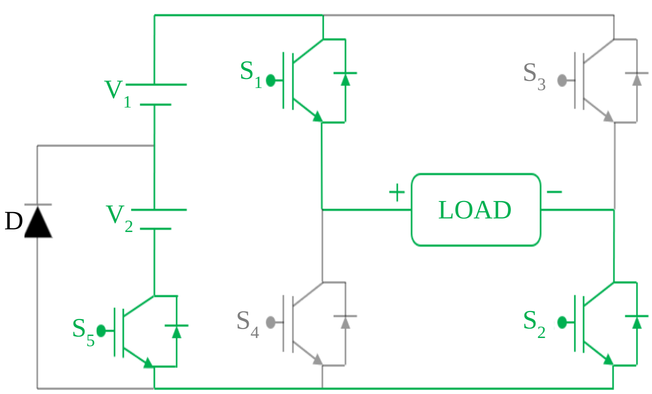

Fig. 6 Proposed modular MLI output voltage of +2Vdc

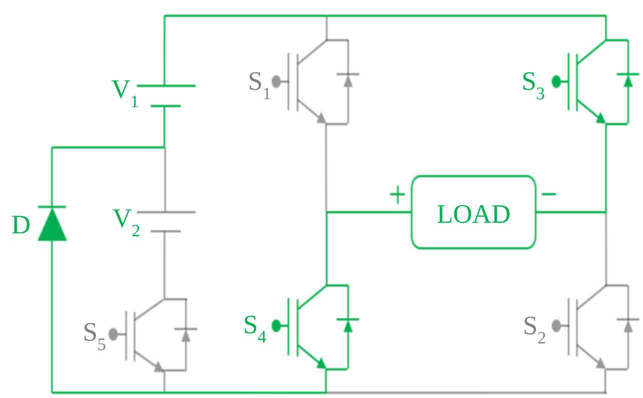

Fig. 10 Proposed modular MLI output voltage of -2Vdc

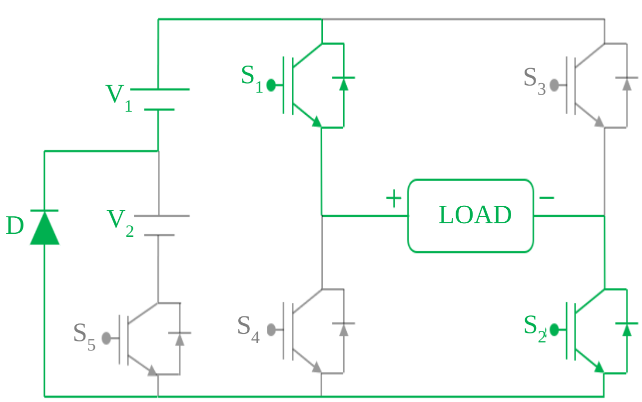

Fig. 7 Proposed modular MLI output voltage of +Vdc

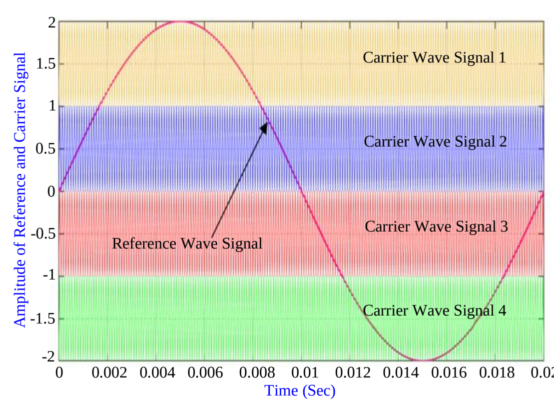

Fig. 11 Pulse width modulation signal to inverter switches

By slightly altering the operating voltage or current, it disturbs the system and tracks any resulting change in power output. The ANN predicts the subsequent perturbation necessary to approach the PV array's maximum power point in light of this recent finding. The P&O MPPT algorithm enables the PV system to successfully track the MPP, ensuring that the solar panels can produce their maximum power. It accomplishes this by repeatedly modifying the operating parameters per the predictions made by the ANN.

The system's performance and overall energy conversion efficiency are improved by this optimisation process, allowing more power generation from the PV array. Figure 4 depicts the boost regulator with MPPT and ANN controller based on temperature and irradiance. The RBFN metric Mean Squared Error (MSE) assesses the model's accuracy throughout learning. The number of times the model iterates using the initial data set is expressed in epochs.

An amount of 12 epochs indicates that the model was trained using all of the data points 12 times. The training, validation, and test values display the degree to which the model performed on the training, validation, and test datasets. Figure 3 displays the top confirmation performance information at 12.

4. Modular Multilevel Inverter

A modular five-level multilevel inverter is a modern power electronic device which transforms to AC with multiple voltage levels. It uses a modular design made up of capacitors and power semiconductor switches. The inverter can generate five distinct voltage levels, zero, positive, and negative, by combining these parts in a specific configuration. The proposed five-level MLI with five switches is shown in Figure 5. Switching operation, MLI is shown in Figures 6 - 10 with output voltages of +2Vdc, +Vdc, 0Vdc,-Vdc and -2Vdc, respectively.

Pulse width modulation is an approach to regulate the switches in a five-level inverter. Changing the pulse width in the control signal achieves this technique's intended voltage output levels. The switches are turned on and off at specified times by adjusting the pulse width, producing various voltage waveforms.

The switches in a five-level inverter are controlled to allow the output voltage to have five discrete levels, allowing for a higher resolution and smoother output waveform. Figure 11 displays the pulse width modulation signal for five-level inverter switches.

5. Results and Discussion

The proposed MLI is implemented using MATLAB/simulink software. The modified multilevel inverter used to create the output voltage of a five-level inverter for a three-phase system with an RMS voltage of 220V is shown in Figure 12. A multilevel inverter is a power electronic device that combines different voltage levels to produce the desired output voltage waveform. An inverter with five levels can produce five different voltage levels.

This suggests a three-phase system's phases can have five different voltage levels. The multilevel inverter closely modulates the voltage levels to generate an output voltage of 220V and a current of 5A. It produces the required waveform by altering the operating assets of its power electronic switches.

Figure 13 shows a three-phase system with a resistive load's five-level output voltage and current. Figure 14 displays the five-level variation of the output current under resistive load, ranging from 2A to 4.5A. Figure 15 displays the five-level output voltage with an output current change from RL to R load of 2A to 3A. As a result of the load change, Figure 16 displays the five-level output current with RL load.

Figure 17 shows the load current's THD value for various modulation index values. According to the observation, the first indicated topology's modulation index value results in a THD value of 7.12%. Figure 18 shows the relationship between output power and efficiency for various multilevel inverters.

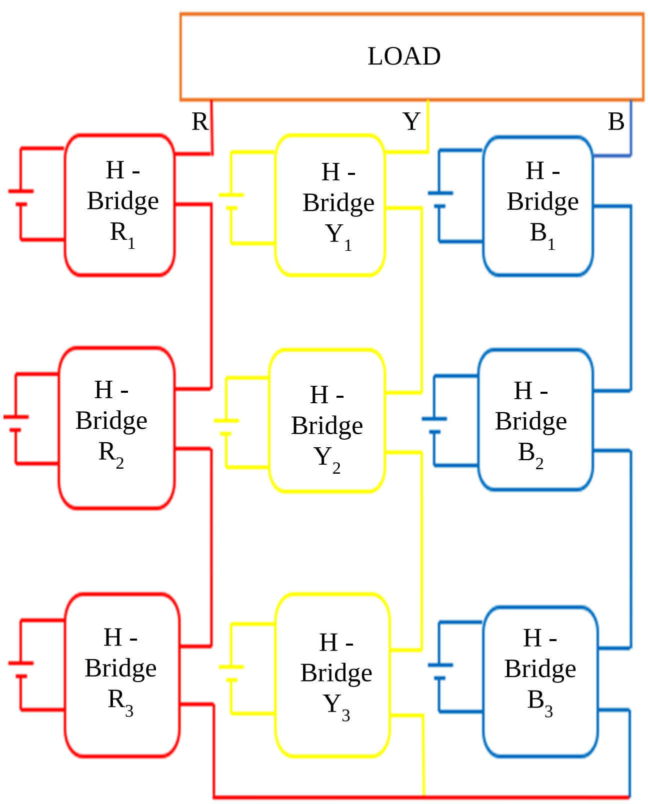

Fig. 12 Five-level output voltage with a three-phase system

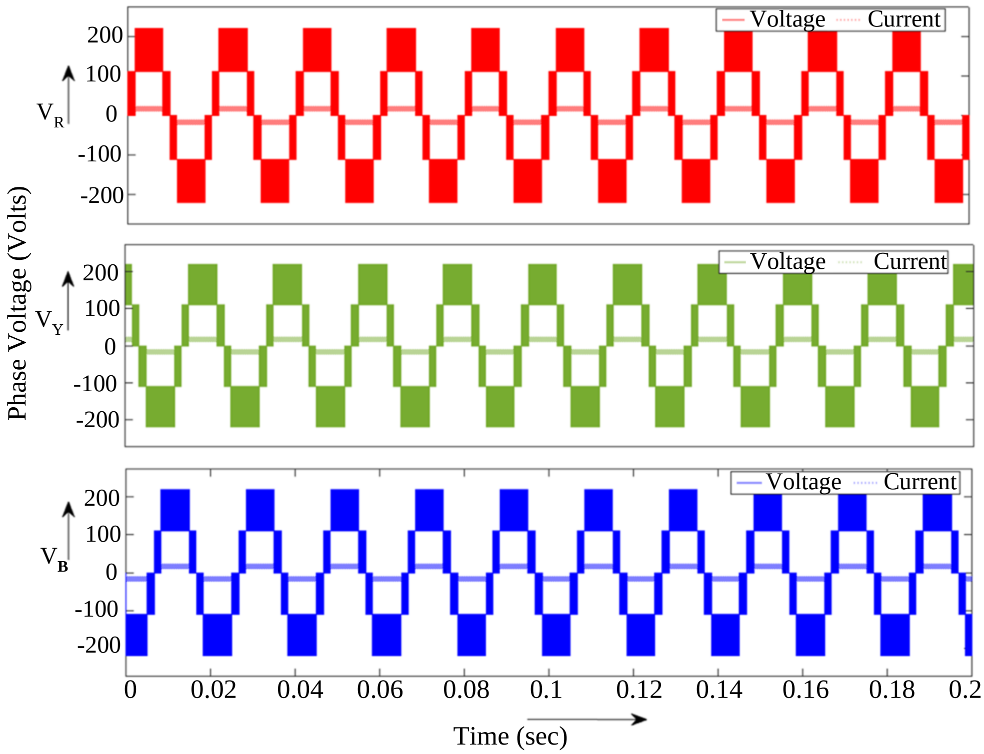

Fig. 13 Five-level output voltage and current of the three-phase system during resistive load

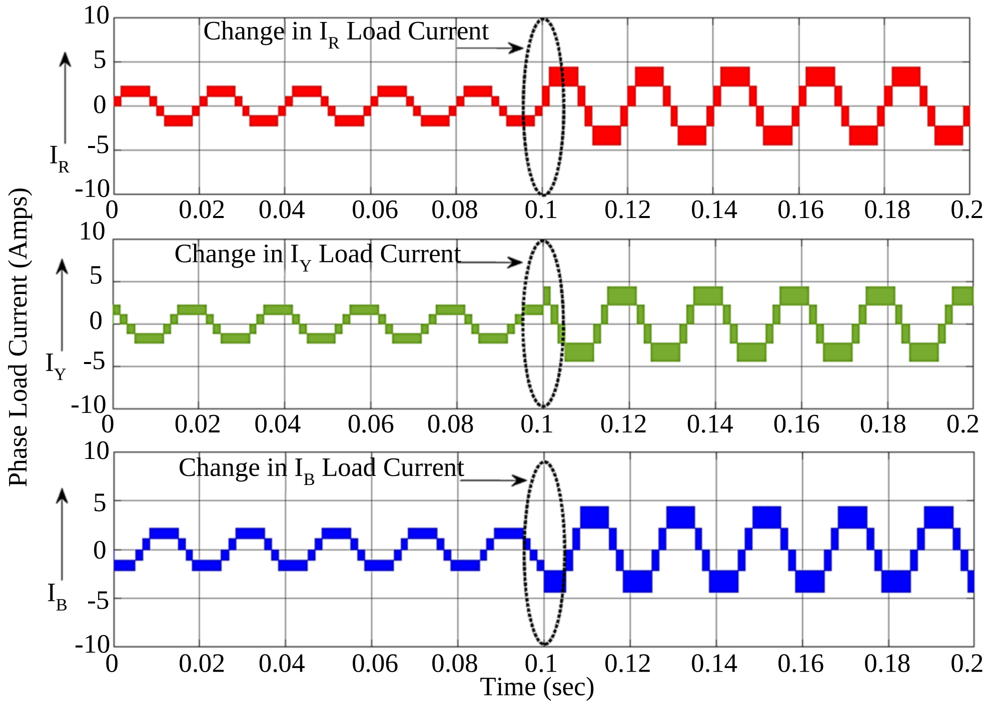

Fig. 14 Five-level change in output current during resistive load

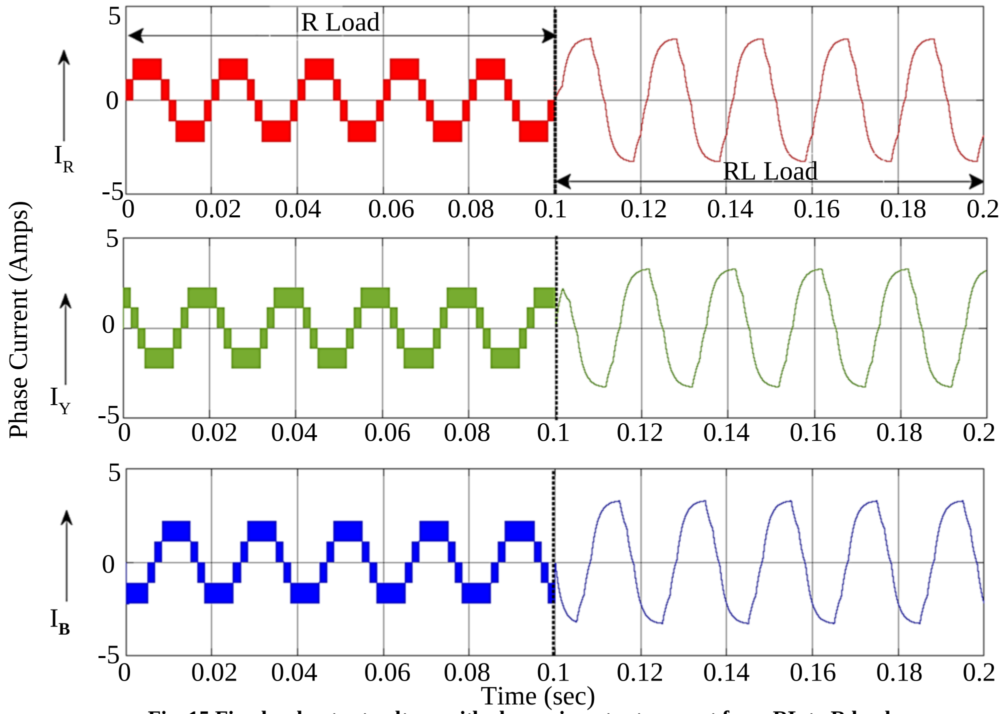

Fig. 15 Five-level output voltage with change in output current from RL to R load

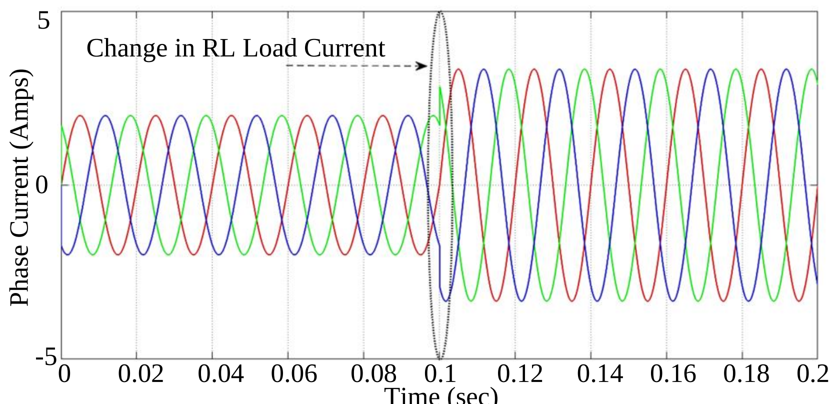

Fig. 16 Five-level change in output current with RL load

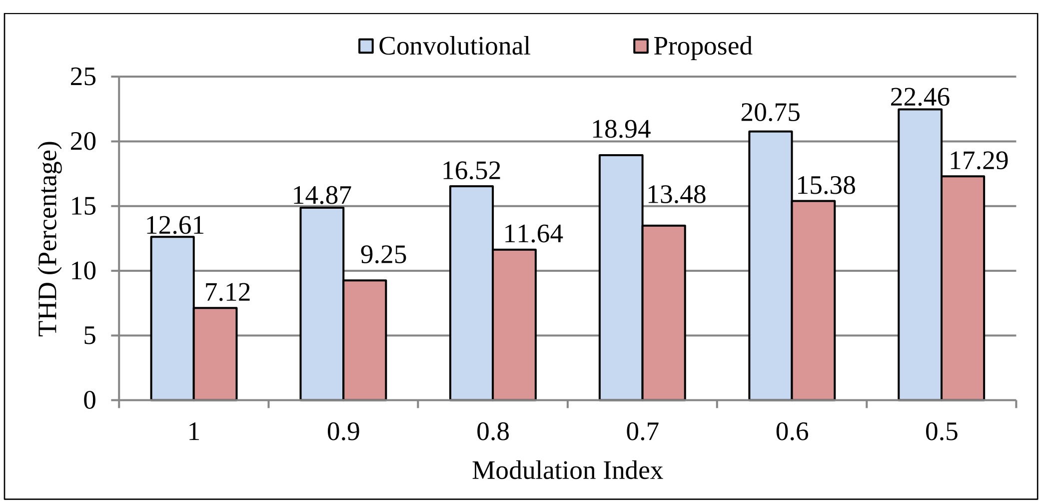

Fig. 17 Five-level output voltage with change in output current during RL load

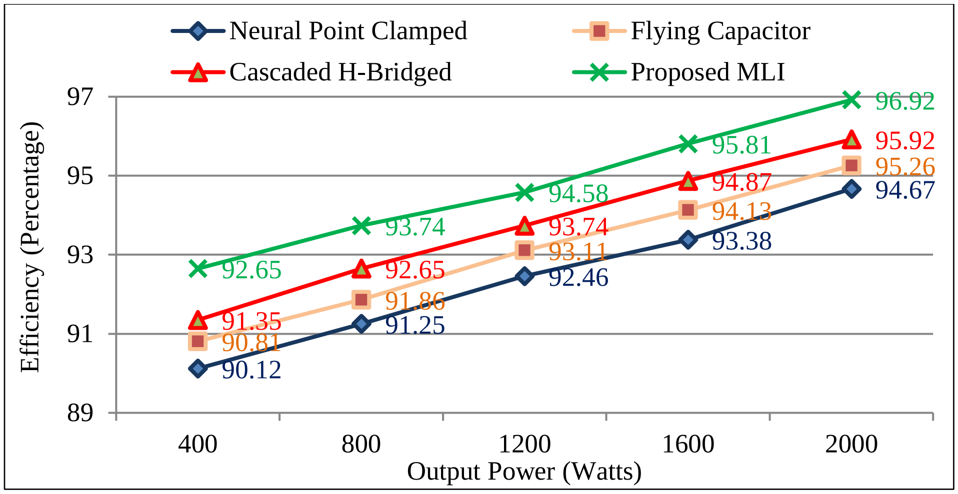

Fig. 18 Output power Vs Efficiency

6. Conclusion

The combination of maximum power point tracking algorithms and artificial neural networks has proven to be a promising approach for increasing the efficiency of DC-DC and DC-AC conversion in photovoltaic applications. Through simulation investigations, it has been shown that using MPPT techniques and ANNs together can significantly enhance the overall performance of PV systems by precisely tracking the solar panel's maximum power point and effectively converting the DC power harvested into AC power for grid integration. The application and verification of the proposed integrated system in actual PV systems are the future emphasise of the present investigation. Additional information on the practical performance of the MPPT-ANN system under various operating conditions and system configurations can be gleaned from experimental studies. To improve the system's capacity for learning and adaption, optimisation of ANN architectures and training algorithms can also be investigated. In order to create comprehensive and effective solutions for PV applications, it is also possible to investigate the integration of other innovative control techniques and energy storage systems.

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