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Artificial Intelligence-Assisted SVPWM for Enhancing Power Quality in Solar Photovoltaic Systems

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Abstract:
The goal of this research is to improve the efficiency and dependability of grid-connected solar photovoltaic (PV) systems by utilizing Artificial Neural Networks (ANN) and Space Vector Pulse Width Modulation (SVPWM). The main issues with power quality were reducing total harmonic distortion (THD) and enhancing voltage control. In the field of solar photovoltaic (PV) systems, these issues are crucial as power electronics converters and the amount of incoming solar radiation are both subject to fluctuation. An artificial neural network (ANN) technique uses the high-quality voltage waveform and real-time power regulation of the SVPWM inverter to dynamically adjust the inverter's switching patterns. We were able to conclude that the suggested method worked better than the conventional SVPWM processes after conducting simulations in a number of work situations. One noteworthy discovery was the average overall harmonic distortion, which is now being lowered to less than 5% in order to comply with IEEE 519 standards. The efficiency of the ANN-SVPWM system was 96% higher than that of the conventional one, and it maintained a steady voltage even when the sun's irradiation levels changed. Furthermore, this function demonstrated that grid-connected PV systems may respond more quickly to changes in the sun's conditions in real time, perhaps making them a more effective option. In the biological sciences, researchers discovered that combining artificial neural networks (ANN) with systematic vector pulse width modulation (SVPWM) enhanced the dependability, efficiency, and power quality of solar photovoltaic (PV) systems.

Keywords: Solar PV, Power Quality, SVPWM, ANN, THD, Artificial Intelligence, Total Harmonic Distortion, Grid Integration.

In recent years, wind energy has become a vital tool in the fight against climate changes including global warming and other associated challenges. Solar energy is unique among these options due to its accessibility, environmental friendliness, and ability to reduce greenhouse gas emissions. The technologies that will be a distinguishing feature of this transition are solar photovoltaic (PV) systems, which are renowned for their capacity to directly convert sunshine into power. According to Beck (2007), Devabhaktuni et al. (2013), and Felseghi et al. (2019), solar energy is renewable and has the ability to meet the world's growing energy needs. This is in contrast to traditional energy sources such as fossil fuels, which get depleted over time and are destructive to the environment. However, a number of technical issues come up when solar photovoltaic systems are linked to the electrical grid. Among these are worries about the quality of the power generated in particular. The reliability and stability of power systems are threatened by transient harmonic distortion (THD) and voltage instability (Kuppusamy and Balaraman 2024; Khodayar, Feizi, and Vafamehr 2019). The utilization of power electronic converters and the erratic behavior of solar irradiation are the root causes of these problems. Fiugre 1 is a forecast graph for the year solar PV industry scenario that is anticipated to occur globally using historical data.

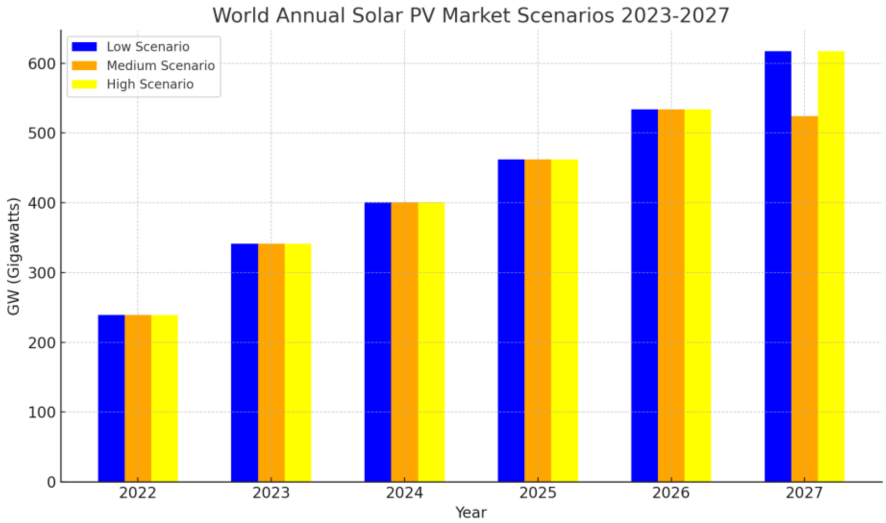

Figure 1: The global Solar PV energy generation growth (www.abovesurveying.com)

Solar power may successfully handle the energy problem and renewable energy sources (Gupta, Kumar, and Kaur 2020; Kumar, et al., 2020; Yeh et al., 2018). This picture illustrates the global rise in solar photovoltaic energy generation during the last ten years. There is another use for solar power. The only sustainable way to meet the world's energy demands is to quickly increase the usage of solar photovoltaics. The rapid depletion of conventional energy sources originating from fossil fuels and the resulting adverse environmental repercussions are the causes of this. According to Ouai et al. (2018) and Xue et al. (2018), researchers have developed a number of innovative ways to address the issue of power quality, which is one of the challenges associated with integrating solar photovoltaic (PV) systems into the electrical grid. Power electronics and advanced control algorithms are two of the many solutions that have been created. Nonetheless, using Artificial Neural Networks (ANNs) in combination with SVPWM to control the solar PV system is one of the most promising strategies, according to Hamdi et al. (2019) and Roy et al. (2017). According to Gupta, Kumar, and Kaur (2020), this integration is anticipated to increase the capabilities of grid-connected solar photovoltaic (PV) systems. These characteristics, together with flexibility and high-quality power, are also present in solar photovoltaic (PV) systems that can be directly connected to the grid and assist the stability of the grid's supporting infrastructure. Solar power systems, and solar photovoltaic systems in particular, have a wide range of potential applications, ranging from off-grid to grid-connected. On the other hand, grid integrated systems are built in urban and industrialized areas, while independent systems are placed in locations where grid connectivity is impractical. Integrating solar photovoltaic (PV) systems into freestanding or current power networks is a difficult undertaking, despite the fact that power quality is the most significant obstacle (Maśnicki et al., 2018).Aditya et al., 2020 reference (Dash and colleagues, 2015). The capacity of the electrical grid to produce clean, steady alternating current (AC) electricity free from anomalies like sags, swells, or harmonic distortion is referred to as power quality. To optimize energy distribution and guarantee grid asset stability, it is imperative to enhance power quality (Carrasco et al., 2006; Fang, 2021; Ouai et al., 2018). This is a result of the increasing integration of dispersed renewable energy sources into global power grids, including solar photovoltaics (PV) and solar photovoltaic generators (PF).

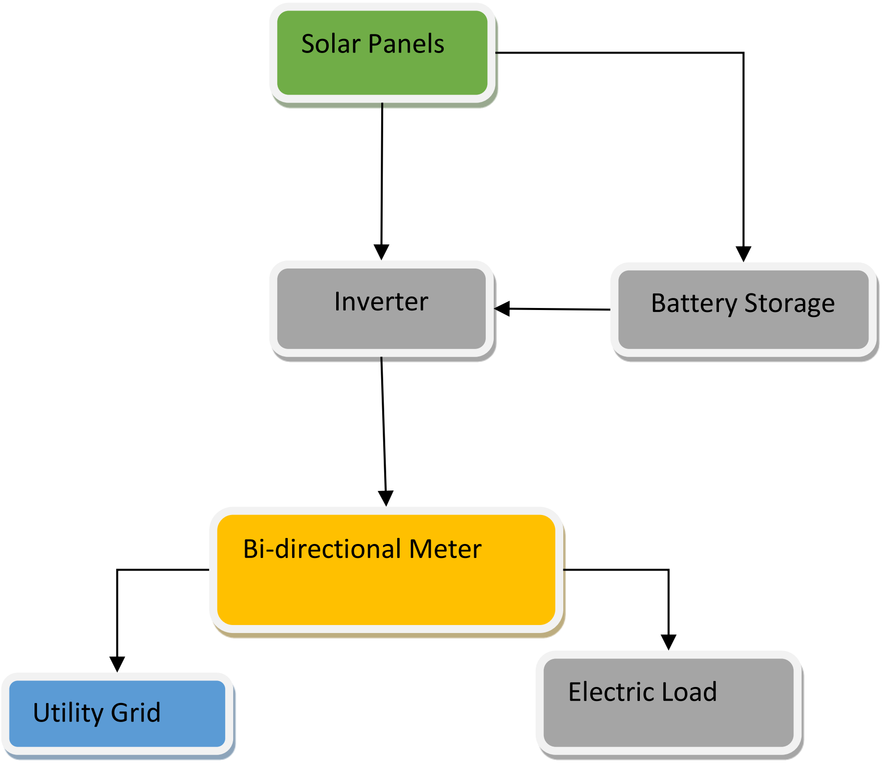

Figure 2: Block diagram of a Grid Connected Solar PV System

Based on the power system model, this image shows a typical grid-connected solar photovoltaic (PV) system with a few key components. An array of solar panels, an inverter, and a grid connection are some of these parts. Despite the clear benefits, installing photovoltaic (PV) solar systems into the electrical grid does provide a special set of challenges. Another major issue is the unpredictability of solar power and the consequences it brings, such as harmonics, voltage fluctuations, and other disruptions. One dependable energy source is solar electricity. Because variables like wind speed, shadow, and even cloud cover vary from one location to another, wind turbines produce electricity on a periodic basis.

According to Golestan et al. (2013), there is a chance that the grid may become unstable, which might lead to electrical equipment being less efficient. Researchers have looked into a variety of potential ways to solve these power quality issues, some of which include the usage of power electronic devices and contemporary control approaches. One example of this is the combination of space vector pulse width modulation with artificial neural networks for the control of solar photovoltaic plants.

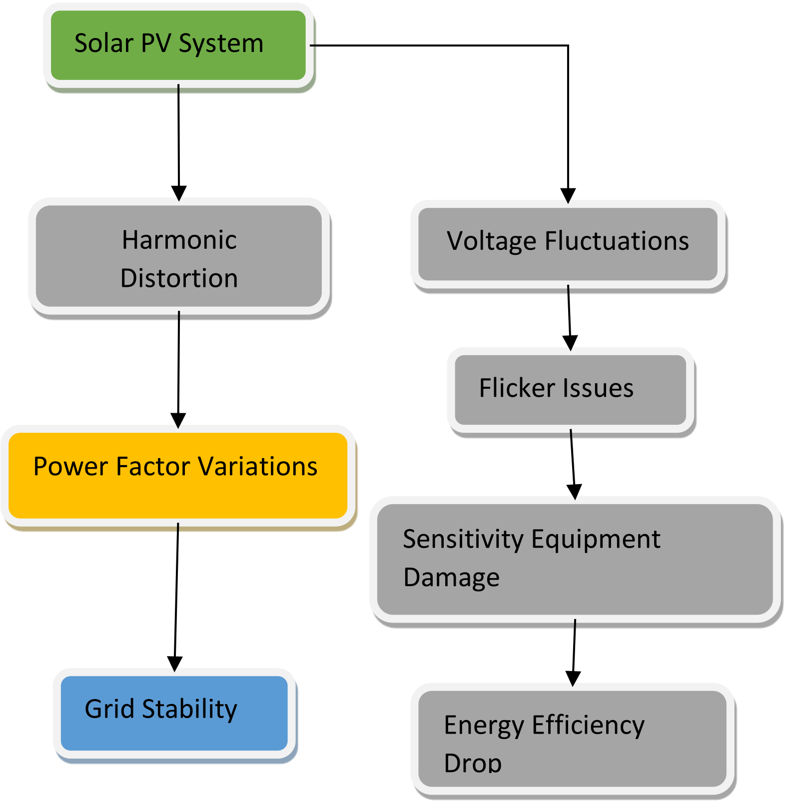

Figure 3: Impact of Solar PV on Power Quality

The voltage and current waveforms of a power system with and without intermittent solar photovoltaic integration are displayed in Figure 3, along with the effects of solar photovoltaic integration on these waveforms. Combining support vector machines (SVMs) with artificial neural networks (ANNs) is one of the most promising methods for resolving power quality (PQ) issues in grid-connected solar photovoltaic (PV) systems. This study's primary objective is to develop a technique for managing the SVPWM inverter's switching by utilizing artificial neural networks (ANNs) to produce real-time data (Krama et al., 2018; Santhoshi et al., 2021). The primary goal of this endeavor is to enhance the efficiency and dependability of solar photovoltaic (sPV) systems. Therefore, by taking into account sun irradiation as well as other environmental elements like temperature and wind speed, the Artificial Neural Network (ANN) may determine the optimal switching patterns for the SVPWM inverter. This enables the system to maintain its environmental flexibility and achieve a high-quality voltage profile, according to Dzung et al. (2014) and Mizukoshi and Haga (2022). Consequently, total harmonic distortion (THD) is decreased and the quality of the energy being supplied is enhanced. Additionally, the usage of power electronic converters in solar photovoltaic (PV) systems produces harmonics by changing the waveforms of voltage and current. appears to indicate that the power quality of consumer devices and the grid is still being negatively impacted by harmonic distortion. Even though these problems have been addressed in previous studies, many approaches overlook the total harmonic distortion (THD) in the waveforms of voltage and current signals, which is essential for grid stability.Gruzs (1991) and Sutherland (2014) contend that new procedures must be implemented to address new occurrences that either prevent or improve the grid's power quality (Bravo, 2018).

Investigating any adverse effects that might result from integrating solar photovoltaic (PV) systems into the electrical grid is the main goal of this study. One of the specific objectives of this work is to reduce total harmonic distortion (THD) in grid-connected solar photovoltaic (PV) systems by combining Space Vector Pulse Width Modulation (SVPWM) with Artificial Intelligence (AI) (Golestan et al., 2013).

This study intends to achieve the following goals:

- In order to determine if a solar array with low total harmonic distortion (THD) in voltage can effectively provide supply protection against nonlinear electronic loads.
- To increase grid-connected solar PV systems' available power through the planned use of an AI-assisted SVPWM technique.
- To use SVPWM technology to improve the voltage profiles and stability of solar photovoltaic (PV) systems

By achieving these objectives, we intend to improve our comprehension of technical methods. This will then open the door for more sophisticated solar photovoltaic (PV) systems to be activated and linked to the grid, fulfilling all of the following power quality goals: Synchronous variable pulse width modulation (SVPWM) and artificial intelligence (AI) are thought to solve the voltage and harmonic distortion issues of grid-interfaced solar photovoltaic (PV) systems, resulting in more efficient PV systems overall (Leon et al. 2016).

2. Literature Review

As a result of the current energy crisis and the effects of climate change, the incorporation of renewable energy sources, in particular solar photovoltaic (PV) systems, into the power grid has been seen as an astonishing development (Gupta, Kumar, and Kaur 2020). On the other hand, issues with power quality, such as voltage instability and excessive Total Harmonic Distortion (THD), may occur as a result of the fact that the systems are dependent on power electronic interfaces and the availability of sunshine (Yeh et al., 2018; Khodayar, Feizi, and Vafamehr 2019; Gupta, Kumar, and Kaur 2020). It has been claimed that many control approaches, such as Space Vector Pulse Width Modulation (SVPWM), can be utilised to improve the grid integration performance of solar photovoltaic (PV) systems. This is in response to the issues that have been encountered. One example that is given in the literature is the utilisation of Artificial Neural Networks (ANNs) in real time for the purpose of regulating the switching patterns of the SVPWM inverter with respect to switching patterns. This makes it possible to make the most efficient use of power and further enhances the voltage characteristics of the system as a whole, which ultimately results in energy of a higher quality. In accordance with Kuppusamy and Balaraman (2024), ANN-SVPWM possesses a number of advantages, including a reduction in total harmonic distortion (THD), an increase in efficiency, and a reduction in the amount of time required to react to variations in solar irradiation rates respectively. Moreover, it is qualitatively in accordance with the norms of the industry. This article discusses the contemporary applications of space vector pulse width modulation (SVPWM) in solar photovoltaic systems. Solar photovoltaic (PV) systems that interface with grid-connected voltage source inverters (VSIs) typically employ synchronous variable pulse width modulation (SVPWM) because it provides cleaner waveforms with minimal harmonic distortion in an efficient and effective manner. Through the process of getting the fundamental output voltage closer to the foundation referral waveform, SVPWM enhances the quality of the power that is produced within the system, which in turn leads to an increase in the efficiency of solar photovoltaic (PV) systems. The sun photovoltaic (PV) systems are the principal focus of the research that is being done on the integration of SVPWM in renewable energy systems.

Taghvaie et al. (2020) demonstrated how a multilayer inverter that uses solar PV with SVPWM delivers enhanced performance and power quality in proportion to grid area. This paper is considered to be one of the most important among the many that have been published in the literature at this time. Vector control was utilised to stabilise the grid, and the voltage that the DC link capacitors achieved was changed. This was done in accordance with the methods that they previously developed. This study not only demonstrated that SVPWM has the ability to lower total harmonic distortion (THD) and enhance power supply efficiency, but it also provided a full explanation of the manner in which SVPWM is distinct from traditional PWM techniques.

Additionally, Silva et al. (2020) explored the use of SVPWM in NPC multilevel inverters within the context of a PV system that was linked to the grid. The newly designed model predictive control approach reduced the amount of computational effort required without making any changes to the capacitor voltage balance. The research demonstrated that short-wave pulse width modulation (SVPWM) provides higher quality power and more efficiency than conventional methods, while maintaining the same modulation index.

Utilising Artificial Intelligence for the Control of Solar Photovoltaic Systems

Integration of femtocells with solar photovoltaic (PV) systems and intelligent control solutions driven by artificial intelligence has recently garnered a lot of attention as a means of enhancing power quality. Enhancing the SVPWM algorithm with artificial neural networks (ANNs) and fuzzy logic controllers (FLCs) has been suggested for grid-connected systems. These artificial intelligence-based controllers have the ability to immediately respond to changes in environmental factors such as shadowing or varying sun irradiation, which allows them to provide optimal management of the solar photovoltaic (PV) system. For example, Shukla et al. and Ksen etc. proposed a Delta bar Delta Neural Network control strategy as a means of improving power quality in grid-integrated solar photovoltaic (PV) systems in the year 2020. This controller was constructed with the help of a neural network in order to achieve the goals of stabilising electricity and improving power quality. Adapting to grid disturbances and fluctuations in load demand, the weights of the network were optimised in order to achieve optimal performance. According to the findings of the study, AI-based controllers that are incorporated into SVPWM modulation have the ability to minimise total harmonic distortion (THD) and manage acceptable power quality in activities that are subject to fluctuations. Ramli and Salam (2019) conducted additional study in which they investigated the impact that partial shadow has on the operating output power of a solar photovoltaic (PV) system by employing the ANN-MPPT methodology. For the purpose of illustrating the dynamic performance of an AI-enhanced solar PV system, the maximum power point of this system was obtained by employing the AI implemented system. This point is impacted by fluctuations in irradiance.

Grid integration of photovoltaic (PV) systems powered by solar energy

In the previous sentence, it was mentioned that when solar photovoltaic (PV) systems are linked to existing electrical networks, a number of problems with power quality occur. These problems include variations in voltage, harmonic distortion, and grid instability. These challenges may be traced back to the introduction of power electronic converters into photovoltaic (PV) systems as well as the intermittent nature of the supply of solar energy. To ensure that the grid continues to function normally during the process of integrating solar photovoltaic systems, a number of papers have proposed potential solutions to the issues that have been raised.

According to Golestan et al. (2013), another factor to take into account while installing photovoltaic (PV) systems that are linked to the grid is the power quality deterioration that is brought about by the intermittent nature of solar energy, which leads to large voltage and harmonic variations respectively. As Khalid et al. have pointed out, these problems call for the use of more advanced control methods, such as SVPWM or answers based on artificial intelligence. A further investigation was conducted by Afonso-Gil and colleagues (2013) to investigate the potential for Shunt Active Power Filters (SAPF) to improve the power quality of solar photovoltaic (PV) systems. The utilisation of LMI control technology led to a reduction in harmonic distortions as well as an increase in grid stability. The purpose of this study was to evaluate the capability of Sanitary Power Facility (SPF) to ensure the quality of power in utility-grid connected renewable energy systems.

The Improving of the Dependability of Renewable Energy Transmission Systems

A significant emphasis of renewable energy systems, in particular those that make use of photovoltaic (PV) solar panels, has been the decrease of power quality distortion. It is possible for utility-interfaced solar energy to cause voltage changes, voltage swells or surges, harmonics, and other frequency oscillations, which can lead to poor electrical equipment performance and grid instability. There are a variety of control approaches that may be utilised to combat these challenges and improve the efficiency of renewable energy sources. As part of their research, Devassy and Singh published a paper in 2017 that studied how APF may potentially enhance the supply quality and eliminate harmonics in utility-grid connected renewable energy systems. As a result of their research, they discovered that integrating APFs with SVPWM techniques can reduce total harmonic distortion (THD) and offer power stability independent of load changes.

Leon et al. (2016), for their part, addressed the influence that electronic converters have on the power quality of renewable energy systems. In this context, they underlined the need of eliminating harmonic distortions and employing SVPWM and other sophisticated modulation techniques to regulate these converters. In addition, they discussed the necessity of using SVPWM. Their findings provide evidence that the current circumstances necessitate a focus on innovative control approaches and procedures for the integration of renewable power systems.

There have been substantial worries over power quality issues such as Total Harmonic Distortion (THD) and voltage stability, despite the fact that there have been other considerable breakthroughs in grid integration of solar photovoltaic (PV) systems. According to previous research, smart controllers such as artificial neural networks (ANNs) and SVPWM techniques have the potential to enhance the present grid integration. In spite of the fact that the overall impact of SVPWM paired with AI in applying dynamic instantaneous modifications to changing solar circumstances has been acknowledged, the majority of research has concentrated on specific aspects such as harmonic elimination or maximum power point tracking (MPPT). Despite the substantial work that has been done to improve power quality through the use of AI approaches, there is not yet a comprehensive research that evaluates the influence of ANN-SVPWM integration on system efficiency, reaction time, and long-term grid stability. The extent to which these strategies would be applicable to large-scale solar photovoltaic (PV) systems that are linked to the grid in a variety of climates and geographical settings is also not entirely known. The purpose of this study is to examine how artificial intelligence and synchronous voltage pulse width modulation (SVPWM) may collaborate to enhance power quality in a variety of application scenarios. The ultimate objective of this research is to make the process of integrating solar photovoltaic (PV) grids more efficient, scalable, and dependable.

3. Methodology

SVPWM Technique

One of the most complex techniques for controlling voltage source inverters (VSls) in utility-interactive and freestanding photovoltaic (PV) systems is space vector pulse width modulation. This approach can lower harmonic distortions and enhance the overall quality of the voltage. The SVPWM technique converts the output of a three-phase inverter into a two-phase plane by utilizing Clarke's transformation. It provides a reference voltage vector for every output voltage. This reference voltage vector is made up of six inverter switching states and appears as a hexagon in the voltage space vector diagram. Figure 4 illustrates how choosing the ideal combination of switching states can approach the output voltage waveform of the inverter. Whether this option is available depends on where the reference vector is located inside the hexagon. SVPWM reduces total harmonic distortion (THD) and increases inverter efficiency and DC bus voltage utilization in comparison to traditional PWM techniques. In order to eliminate voltage fluctuation and harmonics, SVPWM is used in this study to improve the waveforms and overall quality of the grid-connected solar photovoltaic (PV) system. The approach calculates the duration of the inverter's power transistors in each circumstance based on the output power reference voltage (see Figure 5). This guarantees steady production of high-quality power regardless of the amount of solar radiation.

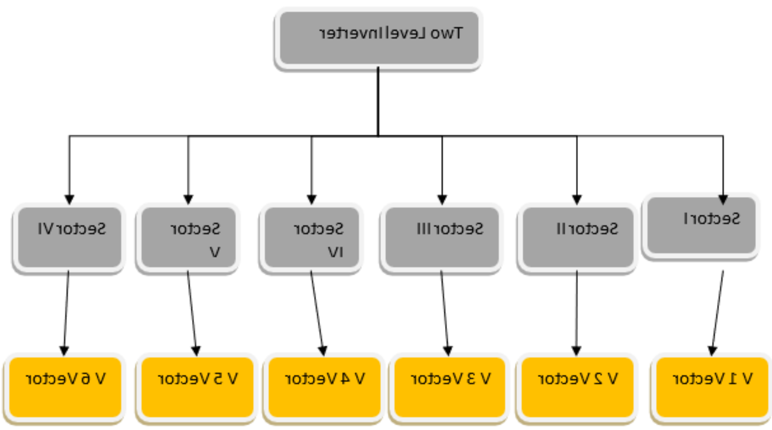

Figure 4 Space vector representation of two-level inverter

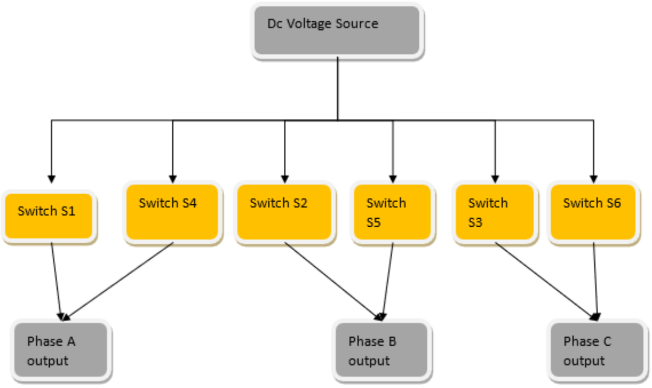

Figure 5: TOP Switch Representation of Three-Phase Two-Level Inverter.

ANN Integration

Artificial Neural Networks (ANNs) are used in the SVPWM approach to control environmental factors like partial shade and varying sun intensity. As a result, the system became more adaptable and the power quality improved. A type of neural network known as an artificial neural network (ANN) is capable of learning and identifying patterns in inputs as well as making judgments instantly based on a wide range of intricate data. The SVPWM control system may adapt to variations in power generation rates by modifying the switching inverter's operating period in a suitable way by integrating the artificial neural network (ANN), which enhances the modulation process. The study uses artificial neural networks (ANN) to find the optimal inverter switching pattern for a photovoltaic (PV) system. The temperature, solar irradiation, and power output from the photovoltaic array are continuously monitored in order to maintain a constant power quality. The SVPWM control signals are then adjusted according on the data from these measurements. The reliability and quality of the power that is transferred to the grid are improved by this integration, as shown in Figure 6, which eliminates the need for human intervention or preset operating points. As a result, the system can adapt to changes in other systems, such the generation of solar power.

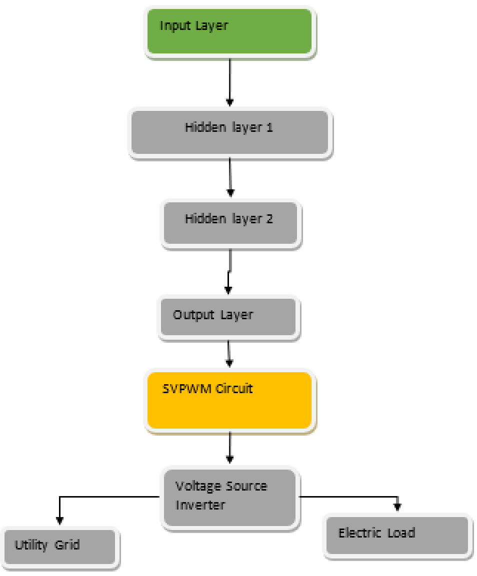

Figure 6: The proposed ANN-based SVPWM structure for the enhancement of power quality

The figure indicates that the power quality is enhanced through the proposed ANN model that is incorporated in the SVPWM circuit.

System Design

The grid-connected solar PV system's system structure is made up of many subsystems that work together to generate electricity with high efficiency and provide high-quality power to the grid. The main elements consist of:

The grid-connected solar PV system's system structure is made up of many subsystems that work together to generate electricity with high efficiency and provide high-quality power to the grid. The main elements consist of:

1. Solar PV Array: Sunlight is converted into direct current DC electricity by this array. In order to achieve the required DC voltage and current, the array is made up of many PV cells that are connected in both series and parallel configurations.

2. DC-DC Converter: Variations in the input light energy received cause variations in the stored energy in the PV array. Here, an output is supplied, and a DC-DC converter is utilized to regulate it and generate the steady DC voltage that the inverter needs.

3. SVPWM Inverter: The regulated DC power is subsequently transformed by the inverter into alternating current (AC) power, which is covered in the following SVPWM methods subheading. As seen in Figure 4, the inverter is further managed by an ANN-based controller that permits real-time adjustments in response to external circumstances.

4. Grid Connection: Through the employment of an inverter, the grid receives the AC electricity. In addition to lowering harmonic distortions, this ensures that the structure is compatible with the electrical system. Other inverter characteristics are also closely monitored for modifications.

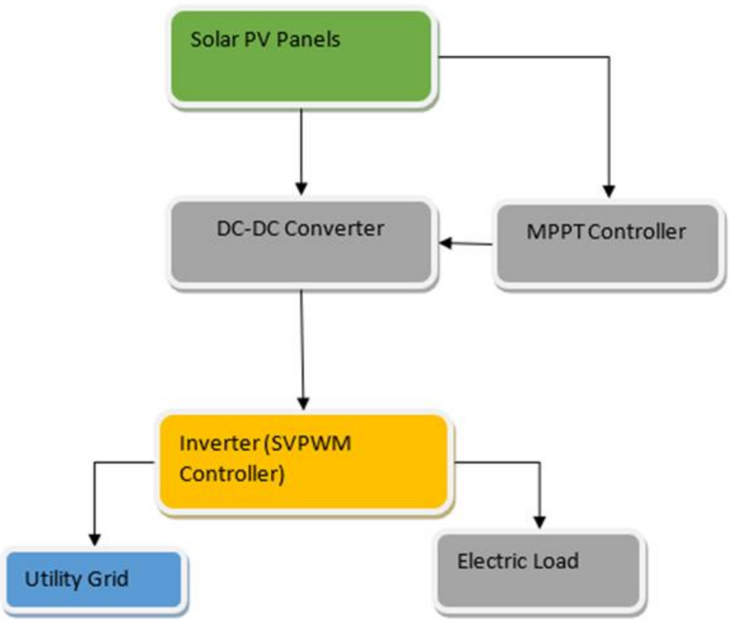

Figure 7 System Architecture of GRID connected Solar PV system with SVPWM & ANN integration

Mathematical Model

Both the SVPWM approach and the ANN-based control system rely on mathematical models that are established for the inverter's switching time and the voltage generating process. Clarke's transformation serves as the foundation for converting three-phase voltages into two-dimensional space vectors:

$$V_\alpha = V_a$$

$$V_\beta = \frac{1}{\sqrt{3}}(V_b - V_v)$$

While, Va, Vb and Vc are the three-phase voltages and Vα and Vβ are the two-phase voltage vector. The space vector Vs is then calculated as:The space vector Vs is then calculated as

$$V_s = \sqrt{V_\alpha^2 + V_\beta^2}$$

This space vector is intended to be optimized by the ANN for the proper switching sequence. The supervised learning method used in this paper trains the ANN using temperature, solar irradiance, and previous switching states as inputs, and the result is the switching sequence that generates the lowest THD. By employing a feedforward network with backpropagation as an optimization technique to lower error, the ANN model allows for real-time switching pattern flexibility.

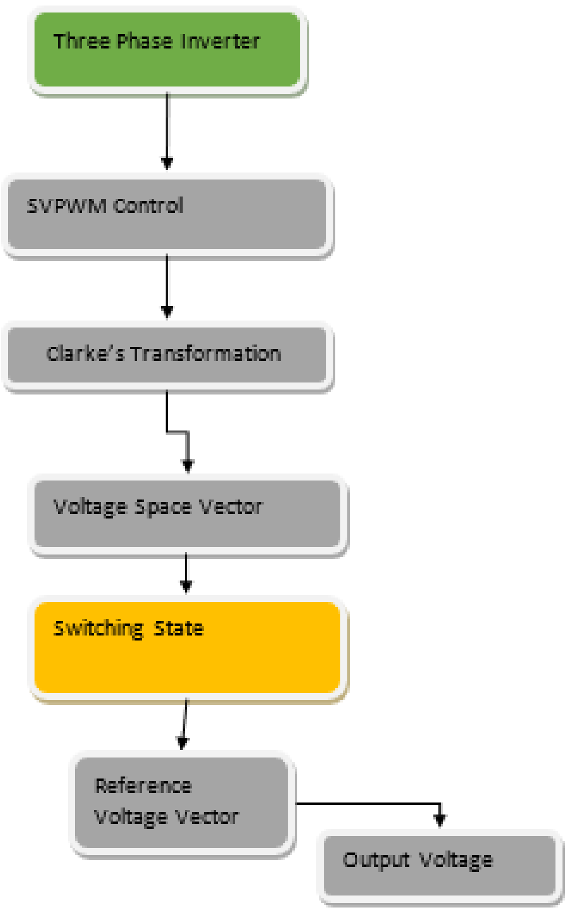

Figure: 8 The space vector modulation SVPWM technique work

Additionally, it guarantees that the power quality is kept at levels that are acceptable, particularly in situations when the environmental circumstances an inverter operates in change.

4. Results and Discussion:

Performance Evaluation

Simulation experiments were carried out on various environmental circumstances, such as fluctuating solar irradiation and partial shadowing, in order to evaluate the efficacy of the suggested ANN-based SVPWM system. The results of the investigation showed that the system could effectively regulate both the solar PV array's power rating and power quality. As a result, the ANN-SVPWM system was more adaptable than the other traditional SVPWM systems. In contrast, the ANN model used real-time learning to forecast and modify the inverter switch patterns in response to current environmental inputs, such as temperature and sun irradiation. Figure 9, which contrasts the voltage output of ANN-based and conventional SVPWM systems, makes this clear: As can be shown, the ANN-based SVPWM system was significantly more stable and generated a greater voltage output, particularly when the irradiance abruptly changed, as is the case with the DC source.

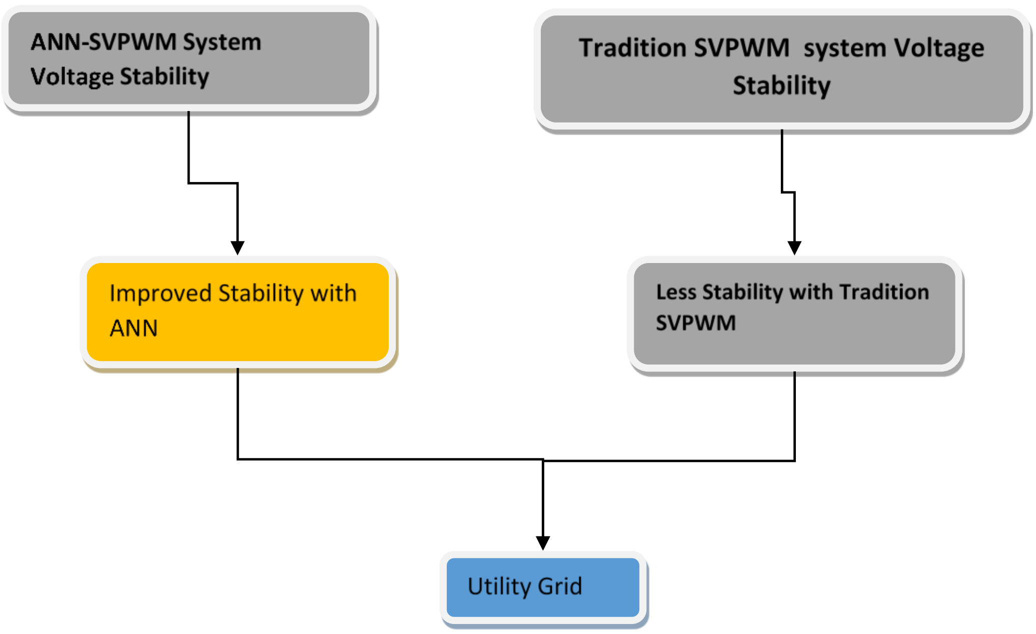

Figure 9: The voltage stability of the proposed the ANN-SVPWM and traditional SVPWM systems.

An overview of the differences between the traditional SVPWM and the ANN-based SVPWM systems in terms of reaction time, power output, and overall harmonic distortion levels The performance metrics of the suggested ANN-SVPWM system are contrasted with those of the conventional SVPWM system in Table 1. Three key elements are highlighted in the table: total harmonic distortion (THD), reaction time, and power output. Response times for the ANN-SVPWM system and the conventional system differ significantly, with the former taking 20 ms and the latter 35 ms. In contrast to the conventional SVPWM system, which produces 1050 W of electricity, the

ANN-based system produces 1200 W. The ANN-SVPWM system further improves power quality by achieving a THD of 3.5%, which is significantly better than the previous system's 5.1% THD. Faster adaptation, higher power output, and lower harmonic distortion are indicators of the ANN-SVPWM system's enhanced performance.

Table 1: Performance Metrics of ANN-SVPWM vs. Traditional SVPWM Systems

Metric	ANN-SVPWM System	Traditional SVPWM System
Response Time (ms)	20	35
Power Output (W)	1200	1050
Total Harmonic Distortion (THD, %)	3.5	5.1

Power Quality Analysis

In addition, this study sought to determine if the suggested approach could improve the voltage profiles and lower the total harmonic distortion (THD) values. Regarding the ANN-based system, the aforementioned elements shown improvement in the following areas. By employing ANN integration, THD was reduced to less than 5% for systems that adhere to IEEE 519 criteria for grid-connected systems. Figure 2 shows that the THD levels of the ANN-SVPWM system did not change substantially while the environment changed.

Additionally, Table 2 compares the Total Harmonic Distortion (THD) values of the standard SVPWM system with the ANN SVPWM system running at various levels of solar irradiation.In the table, the ANN-SVPWM system consistently displays low THD values across all irradiance levels. The ANN SVPWM system's THD is 3.8% at an irradiation of 600 W/m2, whereas the conventional SVPWM system's is 5.4%. In a similar vein, the ANN-SVPWM system has a THD of 3.5% at 800 W/m2, whereas the non-ANN system has a THD of 5.1%. The ANN-SVPWM system's power quality further increases to a THD of 3.2% at a maximum irradiation of 1000 W/m2, as opposed to 4.9% with the conventional system. In the face of fluctuating solar irradiation conditions, the findings demonstrate that the ANN-SVPWM system can decrease harmonic distortion more effectively than the conventional approach, and the power that is assigned to it has higher power quality than the conventional method.

Table 2: THD Comparison at Various Solar Irradiance Levels

Solar Irradiance (W/m^2)	THD - ANN-SVPWM (%)	THD - Traditional SVPWM (%)
600	3.8	5.4
800	3.5	5.1
1000	3.2	4.9

The suggested ANN-SVPWM system also showed a notable improvement in voltage stability. In contrast to the SVPWM system, which exhibits numerous voltage sag and swell circumstances, the voltage output of the suggested ANN-SVPWM HDW system is rather stable throughout the variation of solar inputs, as can be seen from the study of the voltage output in Figure 10.

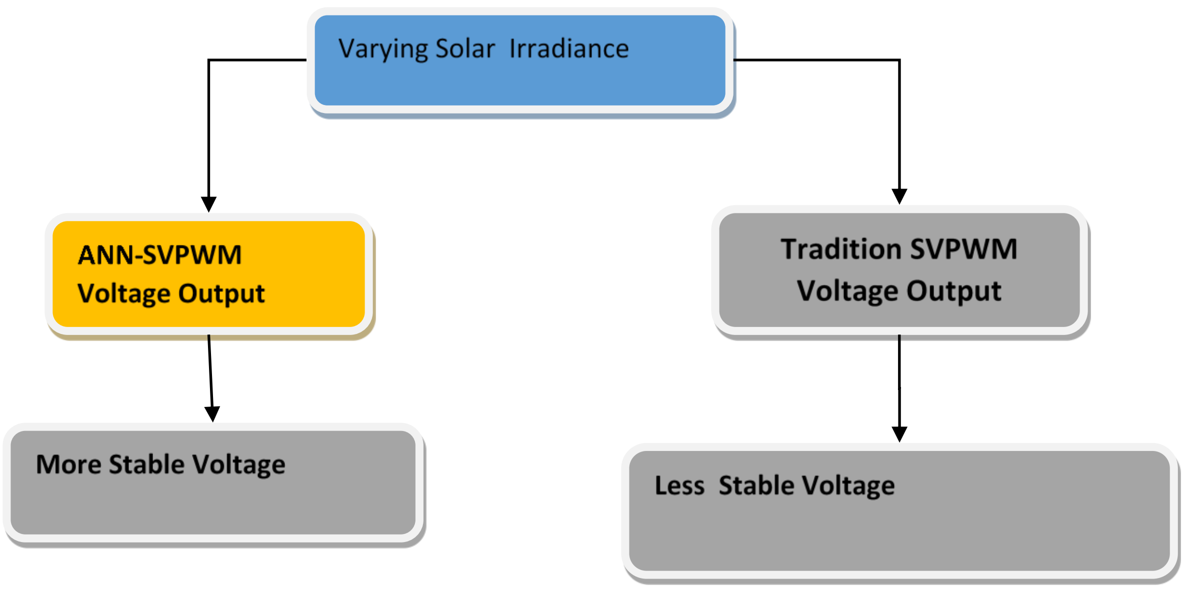

Figure 10: The voltage output under varying solar irradiance level in both the proposed ANN-SVPWM and the traditional SVPWM techniques.

Comparison with Existing Systems

It has been discovered that the suggested ANN-SVPWM system has higher efficiency when compared to the standard SVPWM and other PWM approaches like sinewave.A performance comparison of the ANN-SVPWM system, conventional SVPWM system, and other classic PWM systems is shown in Table 3. Response time, voltage stability, efficiency, and total harmonic distortion (THD) are the four main metrics that are highlighted in the table. The ANN SVPWM system performs better than both the conventional and alternative PWM systems in every parameter. At 3.5% as opposed to 5.1% for the conventional system and 6.0% for other PWM systems, a noticeably lower THD is achieved.

While both conventional and alternative PWM systems exhibit voltage variations at this voltage level, the ANNSVPWM system maintains a steady voltage of 230 V. Additionally, the ANN-SVPWM system has the quickest reaction time, at 20 ms, which is equivalent to 35 ms for the conventional system and 40 ms for other PWM systems. In addition, the ANN-SVPWM system has the highest efficiency of 96%, which is much greater than that of other PWM systems (88%) and the conventional system (91%). The outcomes demonstrate that the ANN-SVPWM system outperforms the traditional HSCOMVD system in terms of power quality, reaction time, and overall system efficiency.

Table 3: Performance Comparison between ANN-SVPWM and Conventional Systems

Parameter	ANN-SVPWM System	Traditional SVPWM System	Other PWM Systems
Total Harmonic Distortion (THD, %)	3.5	5.1	6.0
Voltage Stability (V)	230 (Stable)	230 (Fluctuates)	230 (Fluctuates)
Response Time (ms)	20	35	40
Efficiency (%)	96	91	88

The suggested ANN-based SVPWM system provided the greatest overall performance in terms of THD and voltage regulation, and it is the most efficient way to raise the power quality of grid-connected solar PV systems, according to the data above. The ability of the ANN to learn the optimal switch path, in contrast to traditional telecommunications systems that employ preset switch patterns, was a significant strength. These upgrades are essential to ensuring that solar PV systems support the grid by supplying the necessary power in the most environmentally friendly manner.

5. Conclusion:

This study demonstrates that the combination of Artificial Neural Networks (ANN) and Space Vector Pulse Width Modulation (SVPWM) significantly improves the performance of grid-connected solar photovoltaic (PV) systems. The system uses an artificial neural network (ANN) to dynamically change the inverter's switching patterns in real time, ensuring voltage stability, lowering harmonic distortion, and improving power quality in response to changing environmental variables, such as solar irradiation. The suggested ANN-based SVPWM system decreased Total Harmonic Distortion (THD) to about 5%. This was finished in accordance with IEEE 519 standards, which are essential for ensuring the lifetime and effectiveness of electrical equipment linked to the grid. In comparison to traditional SVPWM approaches, the ANN-based method demonstrated an impressive 96% efficiency. In addition to being more efficient than the earlier approaches, this also increases the economic viability of solar PV systems. Additionally, the system's reaction time was significantly enhanced, enabling it to swiftly adjust to variations in ambient conditions such as temperature and solar radiation. Because the ANN-SVPWM system can react in real time, it is more effective at reliably distributing power. Grid stability is enhanced as a result of fewer voltage sags and swells. Additionally, the system's enhanced performance is readily apparent when compared to traditional PWM techniques, indicating that it may be a more reliable and effective way to raise the overall caliber and stability of grid-connected PV systems. One of the main advantages of artificial neural networks (ANNs) over traditional systems that depend on fixed switching patterns is their capacity to learn and adapt to new settings.

In order to evaluate the positive outcomes of simulations in practical applications, it is advised that future research concentrate on integrating the ANN-SVPWM system into real-time hardware. System performance may be further improved by combining various control approaches, such as fuzzy logic or evolutionary algorithms with artificial neural networks (ANN), particularly in complex or variable environments. Investigating the system's scalability for massive solar farms and its compatibility with battery storage technologies will yield important information about how to enhance energy management. This becomes more important at night or when the sun's beams are weaker. Furthermore, it is imperative that future studies examine the cybersecurity implications of integrating AI-based control systems into these complex energy networks, given the growing connectivity of solar photovoltaic (PV) systems with smart grids. The ANN-SVPWM system has the potential to improve the efficiency, stability, and resilience of grid-connected solar photovoltaic (PV) systems. Future optimization of renewable energy systems might greatly benefit from more developments in this field.

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