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Neural Pq Strategy For Photovoltaic Shunt Active Power Filter

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Abstract : In recent years, the integration of photovoltaic (PV) systems into the electrical grid has gained significant traction due to its potential for sustainable energy generation. However, this integration poses challenges in maintaining power quality (PQ), as PV systems are susceptible to fluctuations in solar irradiance, temperature, and other environmental factors. This research work presents a novel approach employing an Adaptive Linear Neuron (Adaline) neural network to enhance PQ in PV-integrated systems. The proposed strategy utilizes the Adaline model for real-time monitoring and compensation of PQ disturbances, such as voltage sags, swells, and harmonics. By continuously adapting to changes in the system, the Adaline-based control mechanism ensures optimal performance and stability of the PV system. Simulation results demonstrate the effectiveness of the Adaline neural network in maintaining power quality within acceptable limits, even under varying environmental conditions. To maximize power extraction from the optimally slanted modules and incorporate each module's distinct behaviour into MPPT.

I. INTRODUCTION

The Adaline (Adaptive Linear Neuron) neural network is a single-layer artificial neural network that utilizes the Widrow-Hoff learning rule, also known as the least mean squares (LMS) algorithm. It is used primarily for linear classification and function approximation. When applied to the power quality (PQ) strategy in photovoltaic (PV) systems, Adaline can play a crucial role in enhancing the efficiency and reliability of power distribution. In the context of PV systems, maintaining optimal power quality is essential to ensure the stable operation of both the PV system and the connected grid. Variations in solar irradiance, temperature, and load demand can cause fluctuations in the power output of PV systems, leading to issues such as voltage sags, harmonics, and frequency deviations.

The Adaline neural network can be integrated into a power quality (PQ) strategy for PV systems to address these challenges. Adaline, with its ability to learn and adapt in real-time, can be employed to monitor and control the power output of PV systems dynamically. It can adjust the output to match the desired power quality parameters, ensuring that the PV system operates within the acceptable limits set by grid standards. The Adaline neural PQ strategy provides a promising approach to enhancing the reliability and efficiency of photovoltaic systems, ensuring they contribute positively to the power grid. It offers real-time adaptation and robust performance in maintaining power quality, making it a valuable tool in modern energy management systems.

1.1 Advantages of Adaline in PV Systems

Adaptive Control: Adaline adjusts its weights continuously to minimize the error between the actual and desired power output, making it suitable for real-time PQ management in PV systems.

Harmonics Mitigation: By detecting and compensating for harmonic distortions in the PV output, Adaline helps maintain a clean power supply to the grid.

Voltage and Frequency Stability: The network's ability to react quickly to changes in the PV system output allows it to maintain stable voltage and frequency levels, crucial for grid stability.

Integration with Inverters: Adaline can be integrated with PV inverters to optimize their performance by regulating the power output based on real-time grid conditions and PV generation capacity.

Real-Time Adaptation: Adaline's real-time learning capability allows it to continuously adapt to changing environmental and load conditions.

Improved Power Quality: By mitigating power quality issues, Adaline helps reduce losses and improve the overall efficiency of PV systems.

Scalability: The neural network can be scaled to handle different sizes and configurations of PV systems, making it versatile for various applications.

II. RELATED WORKS

A dual-axis solar tracker without an offline sensor was proposed by Hassan (2016), and it may be widely applied in photovoltaic systems. The tracker uses the offline estimated data taken from solar map calculations to determine which way the sun is facing to harvest the most solar energy. He demonstrated how, depending on the season, the use of a dual-axis tracker increased solar energy by 19.1% to 30.2%. Compared to sensor-based solar trackers, the suggested offline sensor-less dual-axis solar tracker is less expensive initially and has a much simpler construction. Also, compared to other dual-axis solar trackers described in the literature, the tracking error is far smaller at just 0.43°. Even though solar trackers with pricey sensors mounted on very precise mechanical carriers function better, this technology may be used practically for less money. The suggested tracker does not utilize a feedback signal because the technology is offline, and it is also unaffected by foggy or external disturbances.

To minimize the Life Cycle Cost (LCC), CO2 emissions, and dump energy, Ogunjuyigbe et al. (2016) used Genetic Algorithm (GA) to develop a tri-objective design of a freestanding hybrid energy system for a typical residential structure. Rather than using a single large diesel generator, the author used small split diesel generators. Typical solar radiation statistics were used in the program to examine various source combinations for a typical residential dwelling load profile. The hybrid system is the best option when considering LCC, net dump energy, and net CO2 emission, according to the results. When compared to a solo system, it offers reductions of 46%, 28%, 82%, and 94% in LCC, CO2 emissions, and dump energy, respectively. The study's energy resources data set is made up of observations of the average sun irradiation for 10 minutes over 12 months.

Using empirical models for the diffuse solar radiation on the slanted surface, Khahro SF et al. (2015) assessed the solar energy resources and established the ideal tilt angle for a particular area in Sindh, Pakistan. In Abu Dhabi, Jafarkazemi et al. (2013) also assessed the impact of a solar module's ideal tilt angle. Using empirical models, the solar radiation at various tilt degrees is computed. It is also determined that the tilt angle ought to be adjusted at least twice a year. There are two models for estimating dispersed solar radiation: isotropic and anisotropic. The author demonstrated that the anisotropic model produced superior results with a comparative analysis of the isotropic and anisotropic models for dispersed solar radiation measurement.

Using a gear system, M. M. H. Prodhan et al. (2016) installed an autonomous solar tracker that tracks the sun's path from east to west during the day. The tracking is managed by the microcontroller (PIC 16F72). The sun's location is detected by an intelligent sensor, and the amount of sunlight is determined by a differential configuration of two LDRs. The motor is activated to position the solar panel to receive the most sunlight possible based on the sun's position and intensity. The suggested system integrates computer hardware and software, mechanical, electrical, and other elements to create a mechatronic system. When the PV module's construction and drive gear system are created using components that are readily available locally, the 15% more efficiency is shown by the automatic solar tracker than by the traditional tracker.

III. METHODOLOGY

Numerous renewable energy sources, such as solar cells and wind energy, exist; nevertheless, these have numerous benefits over other forms of renewable energy, such as affordability, simplicity in installation and maintenance, scalability, clean energy, and dependability. Thus, PV-integrated SAPF is considered in this research. Because of the photovoltaic effect, solar panels use sunlight, a renewable energy source, to create electrical energy. Even with the benefits, solar energy only produces its full power at the operational point due to its low efficiency and non-linear I-V characteristics. Therefore, to get the most power out of solar panels, maximum power point tracking, or MPPT, is required. The solar panel only draws its maximum power at a specific operating point, or at a specific voltage and current level. MPPT techniques because these methods are dependable and efficient for photovoltaic systems, offering fast and accurate tracking of the MPP, reduced oscillation, and stable operation over a wide range of conditions at a low cost. In renewable energy systems, maximum power point tracking (MPPT) is a technique that allows the system to extract its maximum power under all weather circumstances. To achieve maximum power under all circumstances, the appropriate resistance is delivered as a load resistance using the MPPT system.

In reality, the power converters function as MPPT devices in the renewable energy system, adjusting the load resistance in accordance with the solar module's specifications.

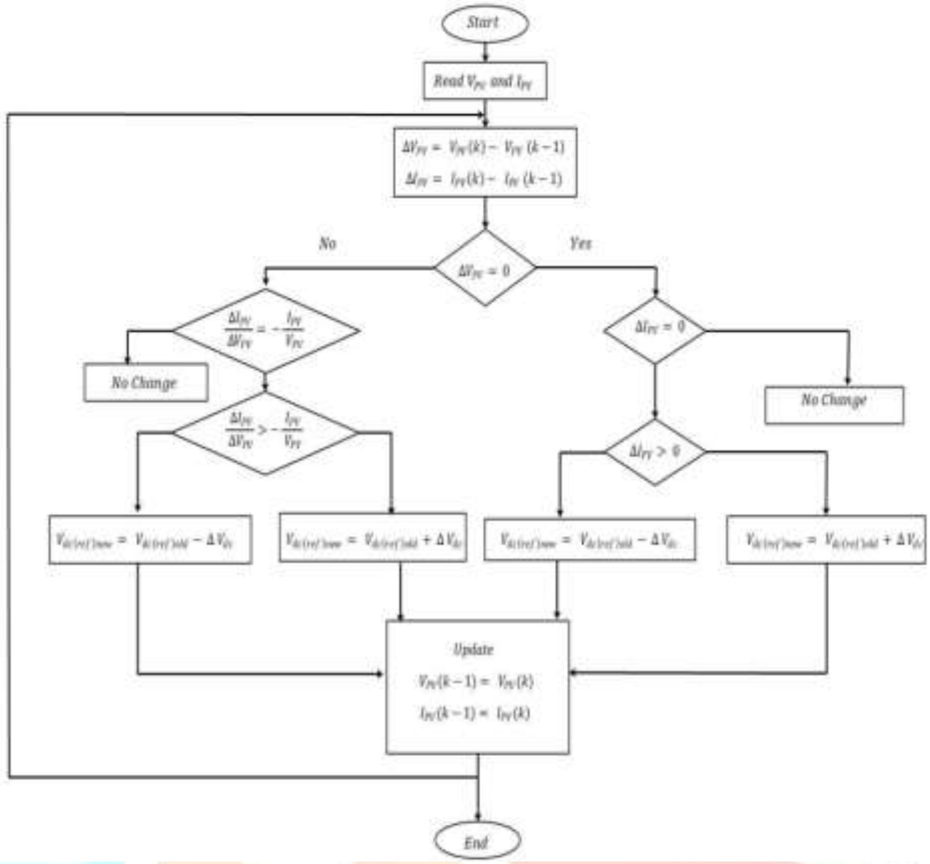

Figure 1 Flow chart of MPPT technique

a. Bridge Rectifier

The Adaline (Adaptive Linear Neuron) neural network is a type of artificial neural network used in various applications, including power systems. When integrated with photovoltaic (PV) systems, it can be employed for various control strategies, such as power quality (PQ) enhancement. A bridge rectifier plays a critical role in converting AC to DC, which can be useful in the context of a PV system. The bridge rectifier converts the AC output from the inverter back to DC if needed, enabling better control over the DC side of the PV system. The bridge rectifier is used within the power electronics circuit to maintain a stable DC bus, which is crucial for the neural network's adaptive capabilities.

b. Boost Converter

A boost converter is a DC-DC power converter that steps up (increases) the voltage from its input (supply) to its output (load) while stepping down the current. In the context of a photovoltaic (PV) system integrated with an Adaline neural network for power quality (PQ) enhancement, a boost converter can play a critical role in managing and optimizing the power flow. The converter works by storing energy in the inductor during the switch's ON phase and releasing it to the load during the OFF phase. By optimizing the operation of the boost converter, the Adaline neural network can enhance the overall efficiency of the PV system. This ensures maximum power extraction from the solar panels and efficient energy conversion, leading to better power quality and system reliability.

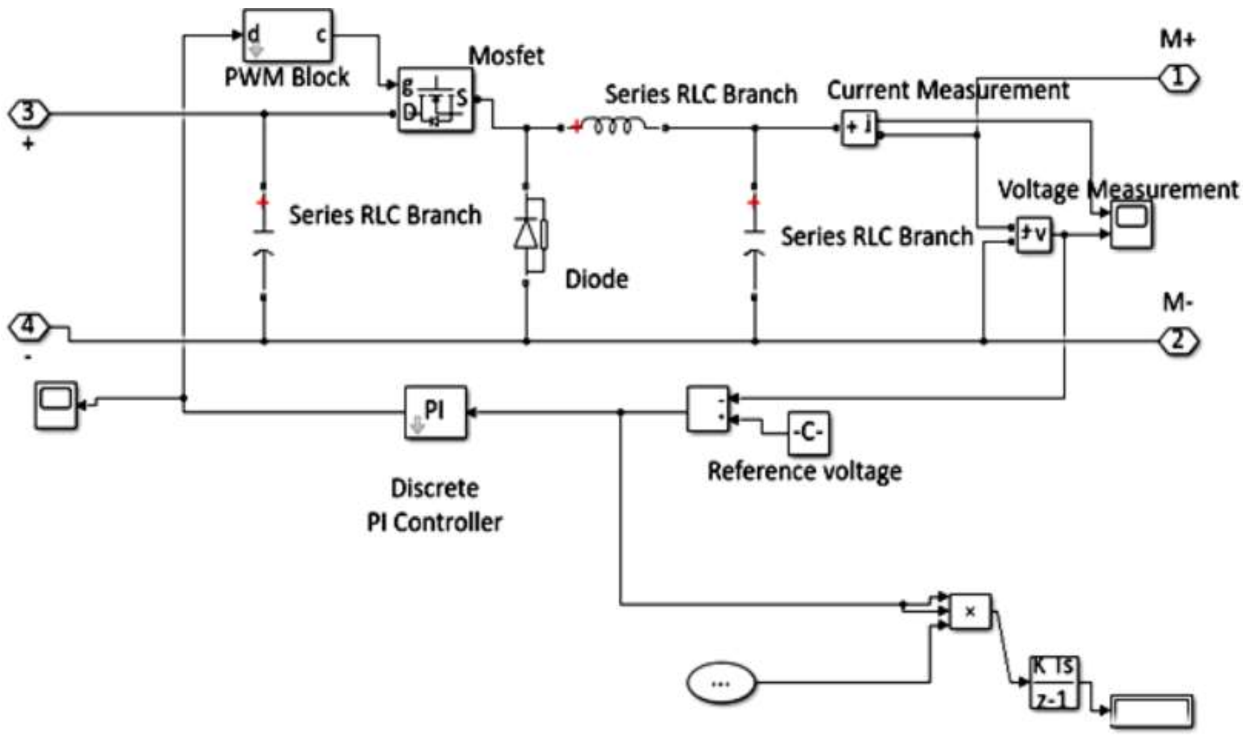

Figure 2 Schematic Diagram of the Boost Converter

c. Inverter

An inverter module is a critical component in a photovoltaic (PV) system, converting the direct current (DC) generated by solar panels into alternating current (AC) for grid integration or local consumption. When combined with an Adaline (Adaptive Linear Neuron) neural network for power quality (PQ) enhancement, the inverter's operation can be optimized to ensure high-quality power output, efficient energy conversion, and compliance with grid standards. By optimizing the inverter's operation through adaptive control, the system can achieve higher efficiency, leading to better energy utilization from the PV system.

d. Neural Network Control

The Adaline neural network is a type of single-layer neural network that uses a linear activation function. It is particularly effective for tasks that involve linear separability, such as signal processing and control applications. The network adapts its weights based on a training algorithm (usually the least mean squares (LMS) algorithm), enabling it to adjust its output to minimize error over time. The Adaline neural network can monitor the output voltage in real-time and adjust the inverter's operation to maintain a stable voltage level. This is critical for ensuring that the AC output remains within the required voltage range, especially during fluctuations in PV power generation or load demand. The integration of an Adaline neural network with the inverter module in a PV system offers significant advantages in terms of power quality, efficiency, and system reliability. The neural network provides adaptive, real-time control, ensuring that the inverter operates optimally under varying conditions. This leads to improved harmonic mitigation, better voltage and frequency stability, and enhanced MPPT performance, ultimately resulting in a more efficient and reliable PV system.

e. Photovoltaic (PV) integrated Shunt Active Power Filter (PV-SAPF)

A Photovoltaic Shunt Active Power Filter (PV-SAPF) is an advanced system designed to improve power quality in electrical grids that integrate photovoltaic (PV) energy. The PV-SAPF combines the functionalities of a Shunt Active Power Filter (SAPF) with a PV system, enabling the system to provide both renewable energy generation and power quality enhancement. This integration is particularly beneficial for addressing issues such as harmonics, reactive power, and load balancing in modern power systems. The inverter in a PV-SAPF system not only converts DC power from the PV array into AC but also acts as the control element for the SAPF. The system ensures that the energy generated by the PV array is used efficiently, either by supplying it to the grid or by improving power quality.

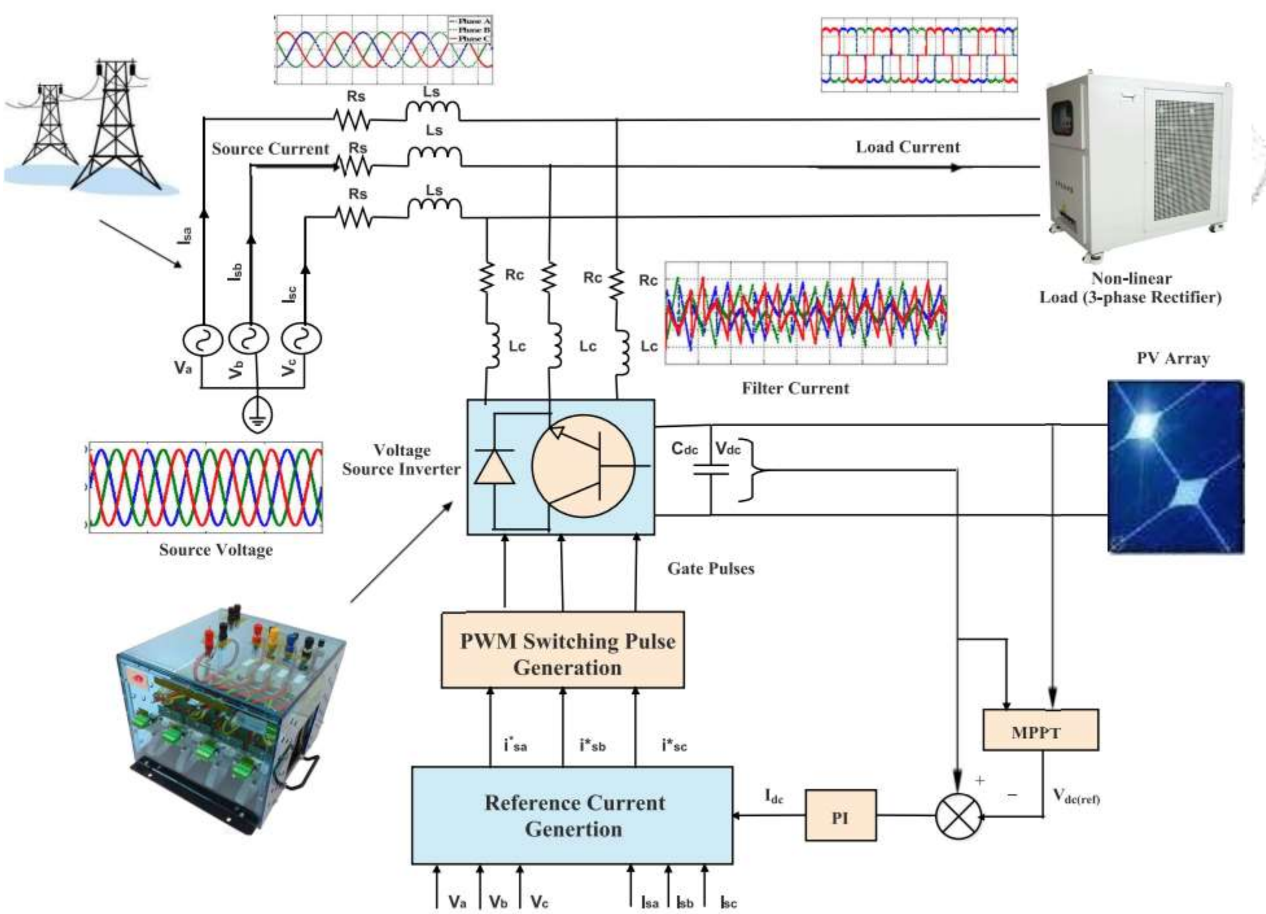

Figure 3 Configuration of PV-integrated Shunt Active Power Filter

However, the solar capacity to release radiation determines how well a photovoltaic array performs. However, because of its non-linear I-V characteristic, a photovoltaic system produces its greatest power at a specific voltage and current. The P-V and I-V properties of solar cells are shown in Figure 4. The short circuit current and open circuit voltage are shown in 'Sc and Voc. The voltage and current at the maximum power point are denoted by the letters Vmp and Imp. The P-V and I-V properties of solar cells make it evident that the PV array can only produce its maximum power at a specific voltage and current. To maintain the operating point at MPP and optimize the PV array's performance, the MPPT approach is necessary. Because PV-Integrated SAPF depends on the sun's radiation output, its operation is susceptible to dynamic variations in injection current. To guarantee that the SAPF can successfully compensate for current harmonics, it is imperative that the injection current be controlled suitably. At least three algorithms are actively used to do this: MPPT control algorithms, DC voltage, and current harmonics extraction.

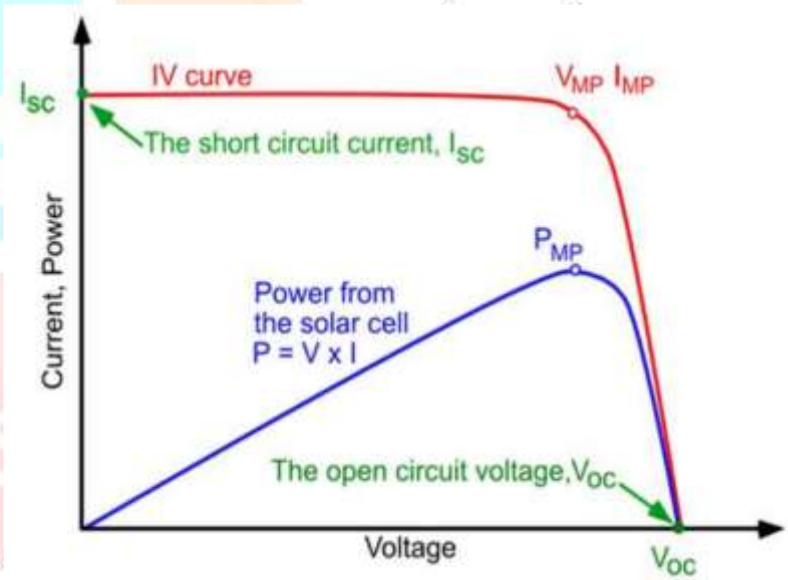

Figure 4 PV and IV integrated solar cell

f. Data acquisition and monitoring

It is used to collect real-time data from all sensors. This data is then used by the Adaline neural network for control and decision-making. The DAS must have an appropriate sampling rate to capture the dynamic behavior of the PV system and the inverter. Higher sampling rates provide more accurate data for the neural network but require more processing power. The raw data from sensors may contain noise, which needs to be filtered out to ensure the accuracy of the neural network's inputs. The data must be normalized to a specific range to stabilize the learning process of the Adaline neural network. Normalization helps in reducing the influence of large variations in data and ensures faster convergence during training. A graphical interface allows operators to monitor the system's performance in real-time. The monitoring system can generate alarms or notifications in case of anomalies, such as over-voltage, under-voltage, or overheating, allowing for quick corrective actions.

g. Microcontrollers and Inference

Integrating an Adaline neural network with a microcontroller for controlling an inverter module in a photovoltaic (PV) system involves several steps. The microcontroller serves as the central processing unit for managing data acquisition, running the neural network inference, and controlling the inverter based on the network's output. Choose a microcontroller with sufficient processing power to handle the computational requirements of the Adaline neural network. This includes both the inference (forward pass) and any necessary data preprocessing.

h. Power Management and Protection

Effective power management and protection are crucial for the successful integration of an Adaline neural network with an inverter module in a photovoltaic (PV) system. These aspects ensure that the PV system operates efficiently, safely, and reliably while utilizing the neural network's control capabilities to optimize performance. The neural network can predict power demand and adjust the inverter's output accordingly. This ensures that power generation aligns with consumption patterns, reducing losses and improving system efficiency.

i. Power Management and Protection

Power management and protection are essential components in any photovoltaic (PV) system, particularly when integrating advanced control systems such as an Adaline neural network with an inverter module. These elements ensure that the PV system operates efficiently, safely, and reliably. Ensure that the PV system operates at its maximum power output under varying environmental conditions. The neural network can enhance MPPT algorithms by learning and predicting optimal operating points based on historical and real-time data. Adjust the inverter's operation dynamically to track the maximum power point of the PV array. Protect the system from voltage levels that are too high or too low and prevent damage due to excessive current. Prevent overheating of components such as PV modules and inverters.

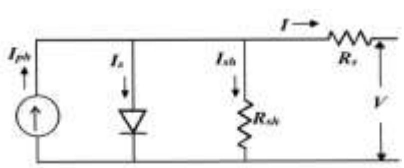

Figure 5 Single Diode Equivalent Circuit

IV. RESULT AND DISCUSSION

PV-Integrated SAPF is modeled using the MATLAB/Simulink environment. A grid supply and a three-phase diode rectifier with a series-connected R-L load are used as test loads in simulations. Because of the non-linear nature of this test load, the system produces harmonics. The parameters utilized to model the SAPF in MATLAB/Simulink for simulation are shown in Table 1.

Table 1 System parameters for simulation utilized to model the SAPF

Parameters	Specifications
line voltage	$V_s = 100V(peak), 3\phi$
line frequency	$f_s = 50Hz$
line resistance	$R_s = 3\Omega$
load resistance	$R_l = 100\Omega$
load inductance	$L_l = 50mH$
filter resistance	$R_f = 3.14\Omega$
filter inductance	$L_f = 10mH$
DC capacitance	$C_{dc} = 2200\mu F$
switching frequency	$f_{sw} = 10kHz$
proportional constant	$K_p = 0.0058$
integral constant	$K_i = 0.0036$
PV (Total Module and maximum power)	$20x60W = 1.2kW$

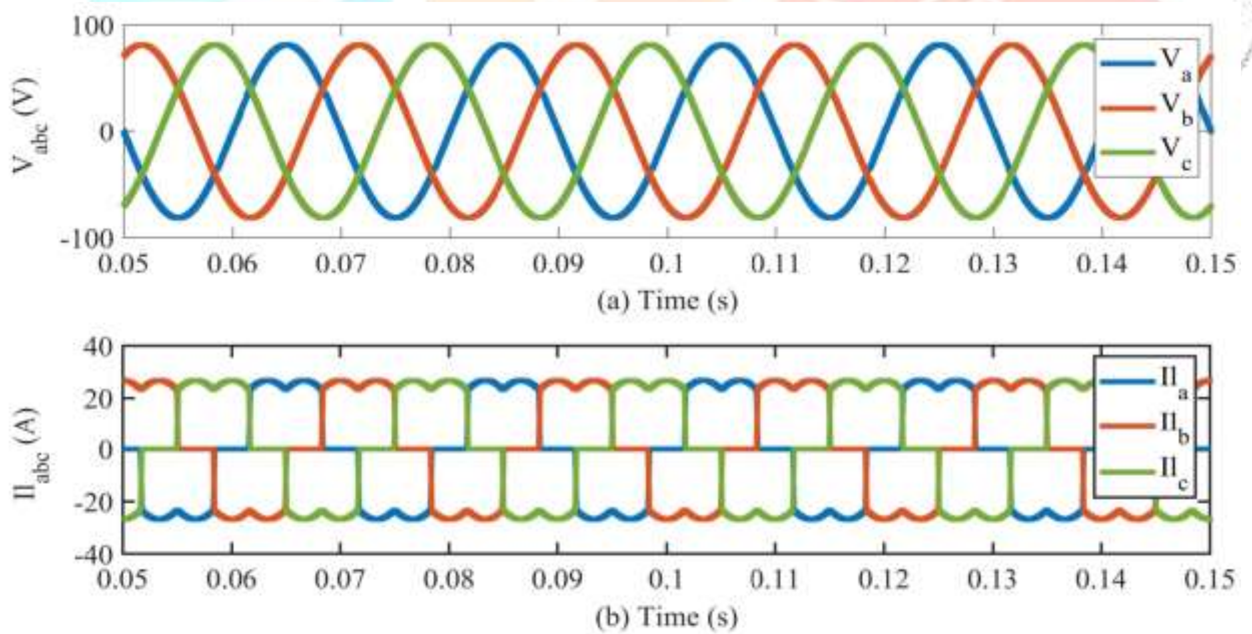

Figure 6 Supply voltage Supply current

The three-phase supply voltage and load current are shown in Figures 6a and 6b, respectively. From three three-phase supply voltages, it can be observed that the supply voltage is balanced and free of harmonics. However, as Figure 6b shows, there are harmonics in the load current, which are produced by the non-linear test load. SAPF is initially turned off and then turned on at 0.1 seconds to observe its effect. The source current waveform shows that when SAPF is switched off, the source current has high harmonics. However, when SAPF is turned on at 0.1 seconds later, the source current's harmonics decrease and it becomes sinusoidal as shown in Figure7a. Similar findings were made from the filter current 7b waveform: when SAPF is turned off, that is, before 0.1 seconds, there is no filter current, which means that the source current is not compensated for, and harmonics are present. However, when SAPF is turned on, at 0.1 seconds, there is a filter current that is equal in magnitude and out of phase from harmonics, which means that the harmonics are compensated for and the source current harmonics are mitigated, leading to the source current becoming sinusoidal 0.1 seconds later. The DC-link capacitor voltage in Figure 7c was initially zero, but upon activation of SAPF, it began to exhibit the state value.

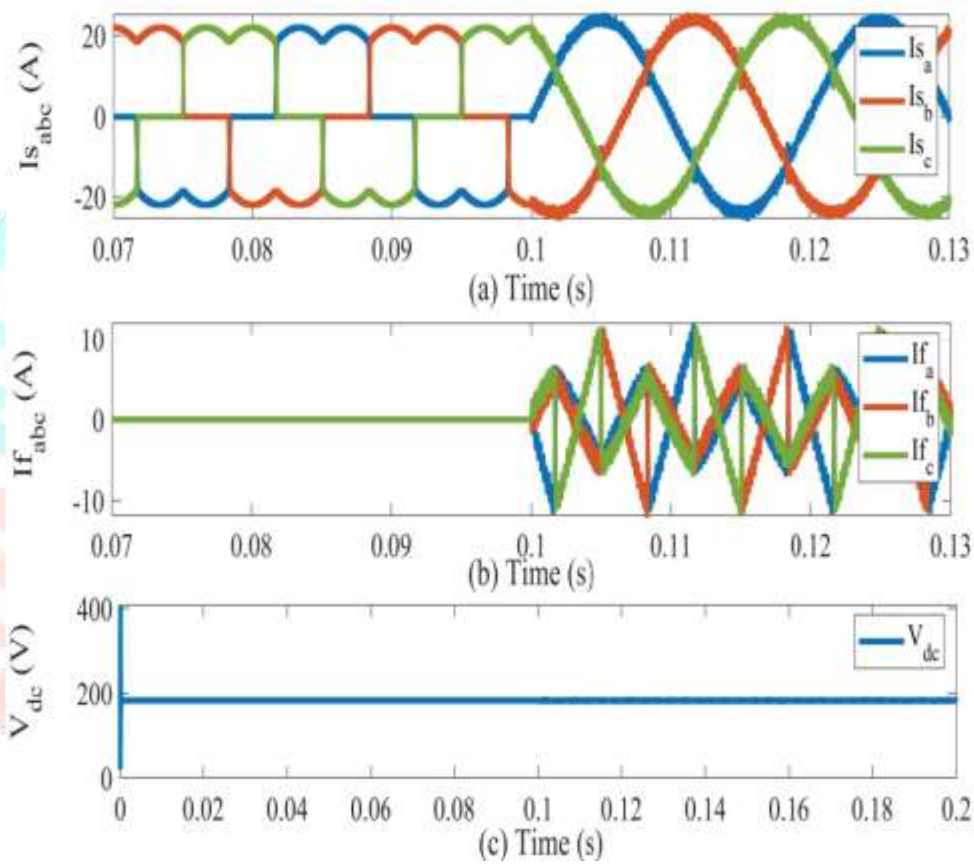

Figure 7 a. Source current b. Filter current c. DC-link Capacitor voltage

5. CONCLUSION

The Adaline neural network strategy for PV systems integrated with Power Quality (PQ) management presents a promising approach to optimizing energy generation and improving system reliability. By leveraging the simplicity and efficiency of Adaline in continuously adapting to varying conditions, this strategy effectively manages voltage regulation, harmonic distortion, and other PQ issues within the integrated PV systems. The ability of Adaline to operate in real-time with minimal computational complexity makes it an attractive solution for dynamic environments where PV generation fluctuates due to factors such as weather conditions. Moreover, the use of Adaline in PQ management enhances the overall stability and efficiency of the grid by minimizing the impact of disturbances and ensuring consistent power delivery. This strategy not only supports the sustainable integration of renewable energy sources but also contributes to the long-term viability of smart grid technologies. The Adaline neural PQ strategy represents a significant advancement in the integration of photovoltaic systems into modern power grids, offering both economic and environmental benefits by optimizing energy use and ensuring high-quality power delivery.

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