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Mitigation of High- Frequency Components in Distribution System using Artificial Neural Network

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Abstract-

Artificial Neural Networks (ANNs) are a powerful tool that can be used to mitigate the high-frequency components in a modern distribution system. ANNs are able to learn from data and identify patterns that can be used to predict and control the behavior of the system. In this study, an ANN was used to predict the high-frequency components of the system and to develop a control strategy to mitigate their effects. The results of the study showed that the ANN was able to accurately predict the high-frequency components of the system and that the control strategy was able to effectively mitigate their effects. This study demonstrates the potential of ANNs for mitigating the high-frequency components in a modern distribution system. This work presents a novel approach to mitigating high-frequency components in a modern distribution system using an Artificial Neural Network (ANN). The proposed method utilizes the capability of an ANN to learn the complex relationship between system parameters and high-frequency voltage harmonics. The trained ANN model is then used to predict the high-frequency components and generate control signals to mitigate them. Experimental results demonstrate the effectiveness of the proposed method in reducing high-frequency voltage harmonics and improving system stability.

Keywords- ANN, HF-Components, Distribution System, Renewable energy Sources, Fuzzy Controller.

Introduction-

An electrical distribution system is a vital component of any electrical network. It is responsible for delivering electricity from transmission lines to end-users, ensuring a reliable and efficient flow of power. An electrical distribution system is a complex and essential part of the electrical grid. Proper design, operation, and maintenance are critical for ensuring a reliable and efficient flow of electricity to end-users. As the electricity industry evolves, new challenges and innovations will continue to shape the future of electrical distribution systems. By embracing these advancements, we can create a more sustainable and resilient electrical infrastructure for the 21st century[1].

The integration of photovoltaic (PV) and wind energy generation into the grid presents several challenges, including the generation of intermittent energy, problems with grid integration, a load on grid capacity, power quality disruptions, management complications, and the requirement for supportive regulatory frameworks and market mechanisms. These challenges are brought about by the intermittent nature of renewable energy sources (RES), the requirement for grid reinforcement, concerns over power quality, the balancing of supply and demand, and the guaranteeing of appropriate pay for producers of renewable energy. In order to effectively address these difficulties, rigorous planning, advanced forecasts, grid control systems, and supportive legislation are required[2,3,4].

Figure 1 depicts a power distribution network including the grid equivalent circuit, PE-based renewable power sources, PFC capacitors, and a linear load. The time-variant currents of the PE-based applications (i.e., $I_{PVt,WT}(t)$, and $i_{EV}(t)$) are composed of fundamental and harmonic components being injected into the power grid at the Point of Common Coupling (PCC)[5]. The power grid is usually associated with background harmonics originating from other electrically distant harmonic sources that could be amplified by resonances introduced by the PFC capacitor. Due to the interactions between the harmonic sources and the state changes at the power network level, the resulting harmonic distortions calculated only from a harmonic source output current would not accurately reflect its actual harmonic distortions[6].

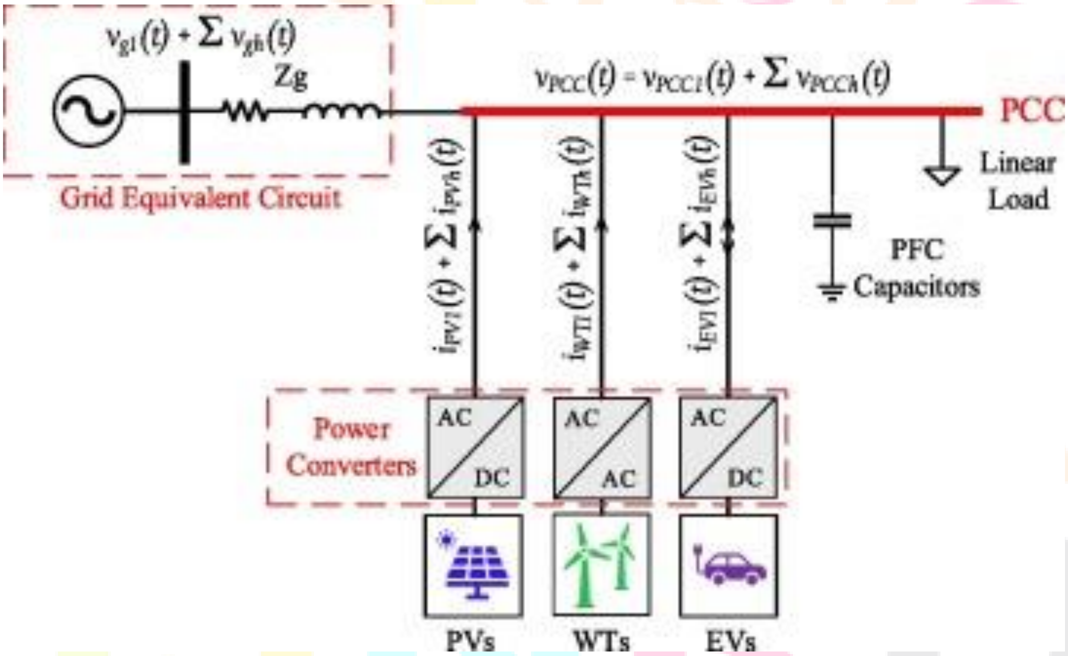

Figure 1- Illustration of modern power distribution systems

The power systems operators and users are, therefore, required to extensively monitor the harmonic performance of each grid-connected system over different operating conditions to identify its actual contribution to the harmonics-related problems. However, the true harmonic distortions can only be obtained when the voltage at the PCC is a pure-sinusoidal, which is impractical since it requires the disconnection of all other potential nonlinear loads/harmonic sources and reducing the grid impedance to zero [4, 5].

High-frequency (HF) components in modern distribution systems can pose significant challenges for system stability and power quality. To address these challenges, researchers are exploring various mitigation strategies. One promising approach involves the use of passive filters. These filters are designed to attenuate HF components while allowing low-frequency (LF) components to pass through. Passive filters can be installed at various locations within the distribution system, such as at substations or at the point of common coupling (PCC). Another mitigation strategy involves the use of active filters. Active filters are more sophisticated than passive filters and can provide more precise control over the HF components. Active filters can be used to cancel out HF components or to shape the frequency response of the distribution system[7].

Literature Review-

Woodley N.H. (1999) *et al.*[1] presented their experience to install the prototype series compensator, which they called DVR, on the existing power system. In this paper, a bypass control scheme to protect the power electronics from load current and fault current was described. When fault occured on the transmission system the harmonic disturbance would be imposed on voltage sags or swells. These harmonics might be harmful to the customers load and might affect the DVR hardware and/or the accuracy of inverter control.

Chang C.S. (2000) *et al.* [2] presented the performance of voltage sag mitigation devices such as the Dynamic Voltage Restorer (DVR) in highly simplified electrical environment consisting of simple line and load models. The negative influences of dynamic motor loads on the existing voltage disturbance, such as post-fault sags, further during-fault phase-angle deviations, during-fault and post-fault voltage fluctuations had often been unnoticed.

Zhan Changjiang (2001) *et al.* presented a compensation strategy based on SPLL (Software Phase-Locked Loop) algorithm for the DVR, which was applied for the dynamic compensation of voltage sags with a phase jump. In this paper, a PWM inverter control of the DVR adopted a conventional SVPWM method for the maximum utilization of the dc-link voltage supported by lead-acid batteries.

Godsk Nielsen John (2001) *et al*. [3] presented different control strategies for dynamic voltage restorer with emphasis put on the compensation of voltage sags with phase jump. Different control methods to compensate voltage sags with phase jump were proposed and compared. Two promising control methods were tested and carried out with simulations and finally tested on a 10 kVA rated Dynamic Voltage Restorer in the laboratory. Both methods could be used to reduce load voltage disturbances caused by voltage sags with phase jump. One method completely compensated the phase jump, which was the best solution for very sensitive loads.

As per Thamer et al(2023), [4] Grid-connected solar Photovoltaic (PV) systems are predicted to cause significant harmonic distortions in today's power networks due to the increase utilization of power conversion systems widely recognized as harmonic sources. Estimating the actual harmonic emissions of a certain harmonic source can be a challenging task, especially with multiple harmonic sources connected, changes in the system's characteristic impedance, and the intermittent nature of renewable resources[9]. A method based on an Artificial Neural Network (ANN) system including the location-specific data is proposed in this paper to estimate the actual harmonic distortions of a solar PV inverter. A simple power system is modelled and simulated for different cases to train the ANN system and improve its prediction performance. The method is validated in the IEEE 34-bus test feeder with established harmonic sources, and it has estimated the individual harmonic components with a maximum error of less than 10% and a maximum median of 5.4%.

Methodology-

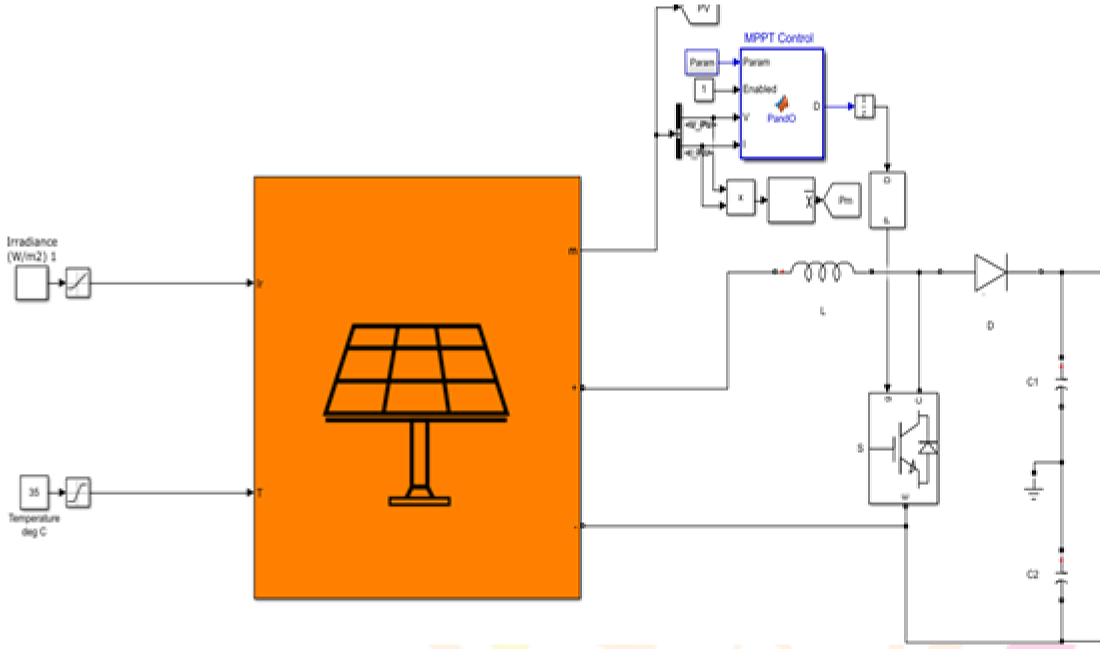

Figure 2- Solar panel with MPPT controller

Maximum Power Point Tracking (MPPT) is a crucial technology used in solar photovoltaic (PV) systems to ensure maximum energy extraction from solar panels under varying environmental conditions (Figure 2). Perturb and Observe (P&O) is one of the most widely used MPPT algorithms due to its simplicity and effectiveness. In this explanation,I'll describe the principles behind solar panels, MPPT, and specifically the Perturb and Observe algorithm, highlighting its operation and significance in maximizing solar energy conversion efficiency. P&O is a popular MPPT algorithm widely used in solar PV systems due to its simplicity and effectiveness. The P&O algorithm operates based on the principle of perturbing (changing) the operating voltage or current of the solar panel and observing the resulting change in power output. Based on this observation, the algorithm adjusts the operating point to approach the maximum power point.

The real-time estimate of moderately time-varying harmonics of voltage/current signals is presented as a quick and precise method. The suggested methodology relies on the rotational invariance technique-assisted Artificial Neural Network (ANN) signal parameter estimation. The ANN to handle time-varying signals more accurately while still providing rapid estimates of the prominent harmonics. The proposed method can estimate the main harmonics of the signals precisely when the time is varying. The suggested technique also makes use of the idea of learning on the fly to take advantage of ANN's learning capabilities and enhance its performance for time-varying inputs. Figure 3 depicts the proposed method's concept (Flow Diagram). The data acquisition (DAQ) system is used to acquire the signal, and two parallel processing channels are used to process it.

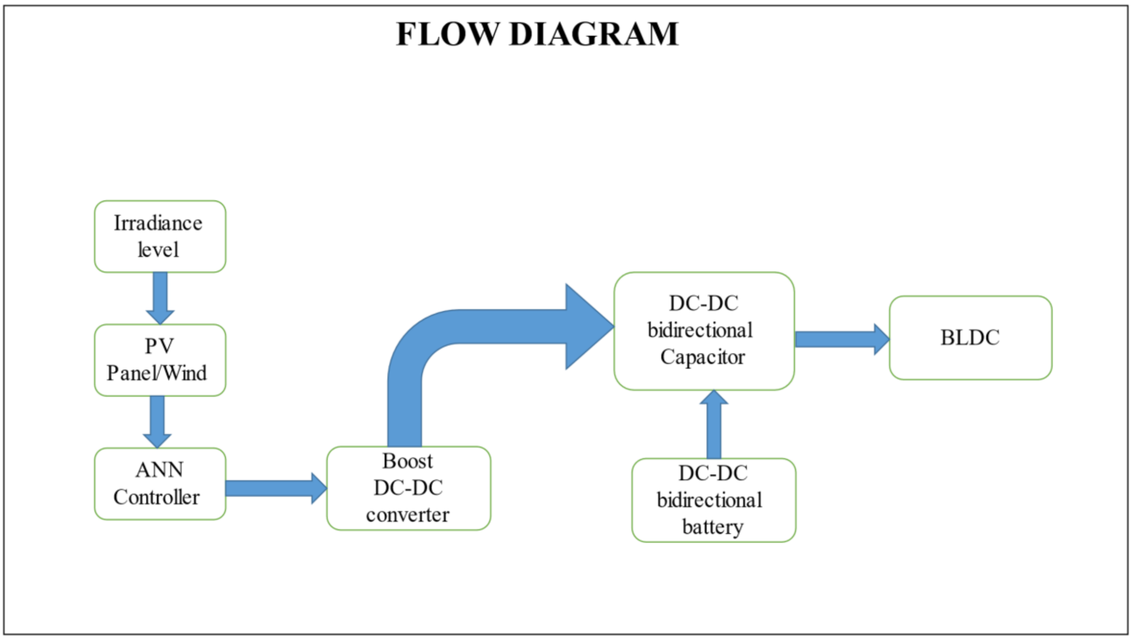

Figure 3 – Flow diagram of Proposed ANN method

Artificial Neural Networks (ANNs) are computational models inspired by the structure and functioning of biological neural networks. They are widely used in various fields, including electrical engineering, for tasks such as voltage and current control in power systems. In this context, MATLAB provides a powerful environment for implementing ANNs due to its extensive libraries and tools for neural network design and simulation. Before constructing an ANN, it's crucial to prepare the data. In voltage and current control loop applications, shown in Figure 4 involves collecting and preprocessing input-output data pairs.

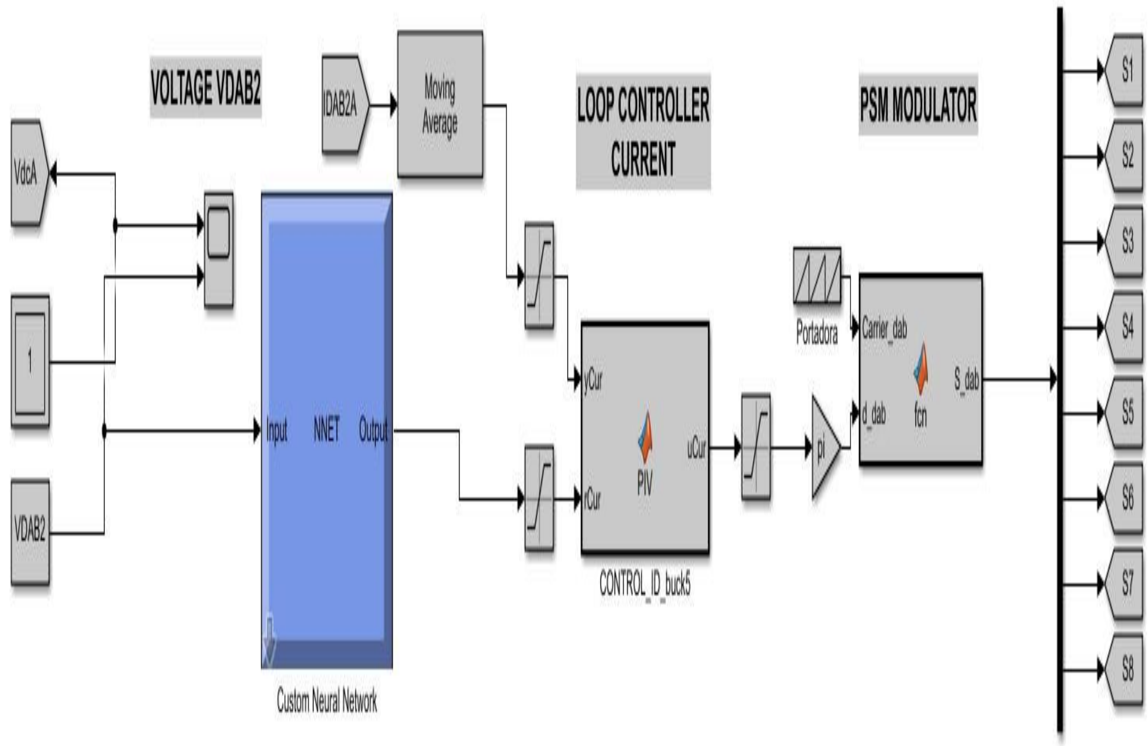

Figure 4- Closed loop voltage and current control loop using ANN

ANN Layers proposed-

ANN includes three layers, viz., Input layer, Hidden layers, and output layer shown in Figure 5.

- **Input layer:** Neurons representing input variables, such as voltage and current measurements.
- **Hidden layers:** One or more layers of neurons that perform intermediate processing.
- **Output layer:** Neurons representing the desired output, such as the control signal for voltage or current regulation.

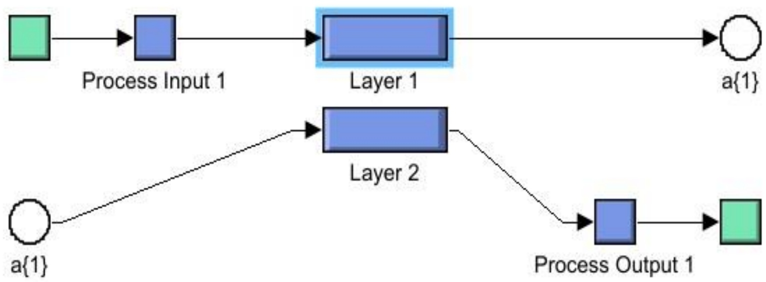

Figure 5 Layers in the ANN

The choice of activation functions in the hidden layers depends on the specific problem and may include sigmoid, tanh, or ReLU (Rectified Linear Unit) functions. For the output layer, the activation function is chosen as sigmoid as shown in Figure 6.

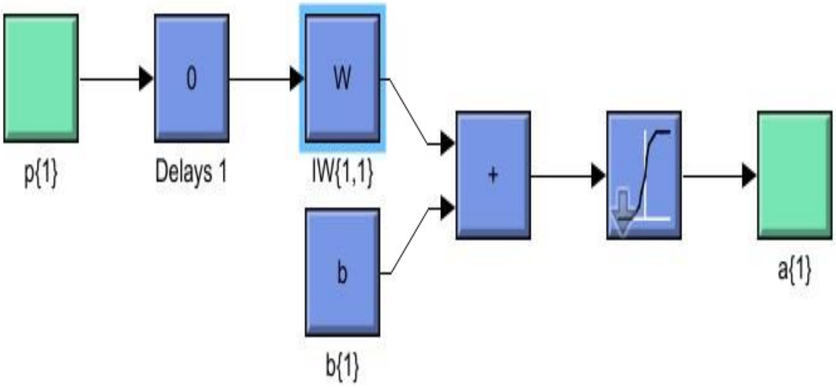

figure 6- Detailed view of the layer with activation function

During training, the ANN learns to map input data to the corresponding output data by adjusting its internal parameters (weights and biases) through an iterative process. The goal is to minimize the difference between the predicted outputs and the actual outputs in the training data [Figure 7].

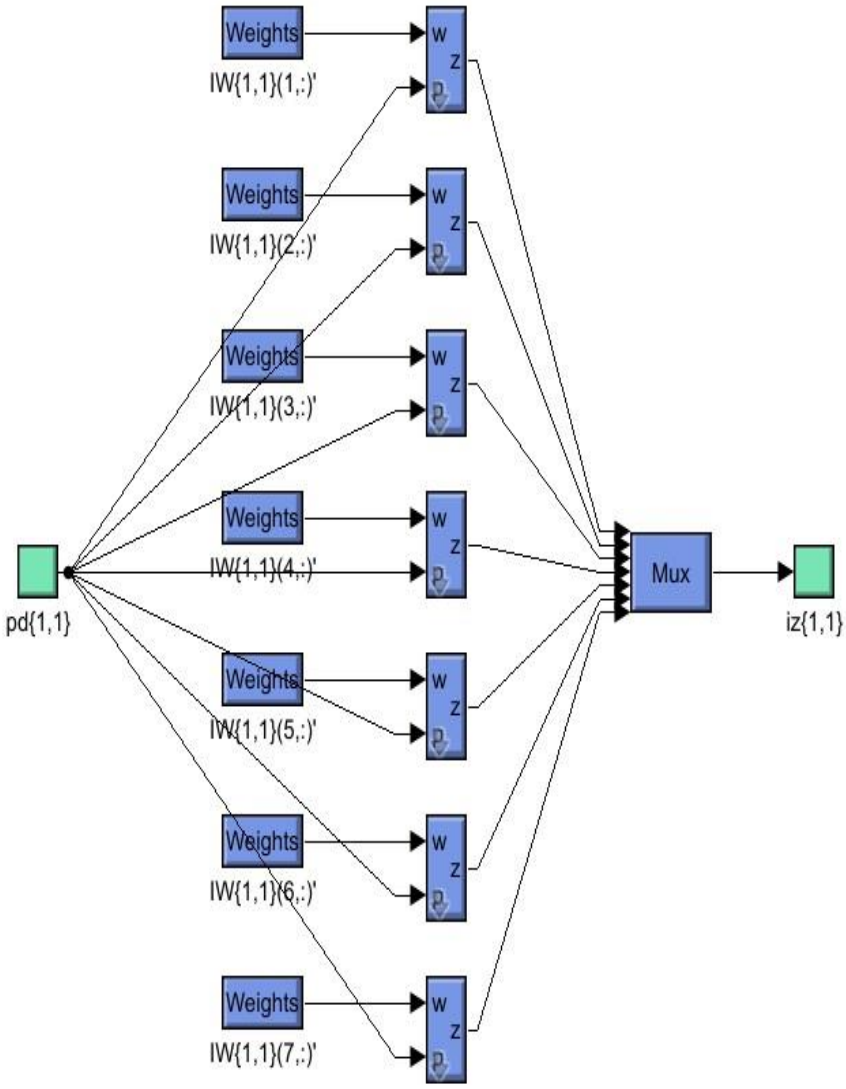

Figure 7- Weight adjustment while training the ANN

Results and Discussion-

The MATLAB 2018a is used for the simulation. Figure 8(a) shows the graph of frequency vs power. The graph shows the spread frequency spectrum. The same simulation is run and tested by using the fuzzy controller. The result of the simulation using a Fuzzy controller is shown in Figure 8(b). Finally, the result of the simulation by using ANN as a controller is shown in Figure 8(c).

Figure 8 clearly shows that the result of using ANN as a controller gives the most suppressed version of the higher frequencies. The system is requirement of any distribution system. Thus mitigation of High frequency components are not possible with PI and Fuzzy Controllers.

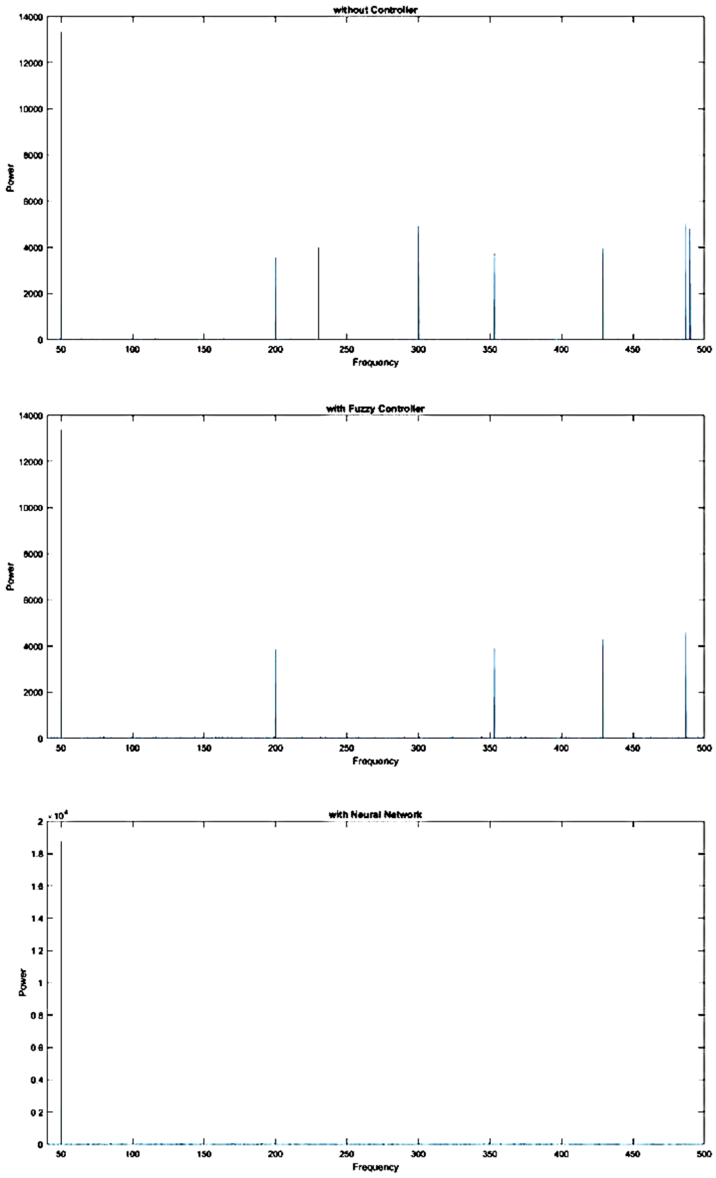

Figure 8 -Frequency components present in the output (a). Without controller action, (b). With Fuzzy controller, (c). With ANN as a controller

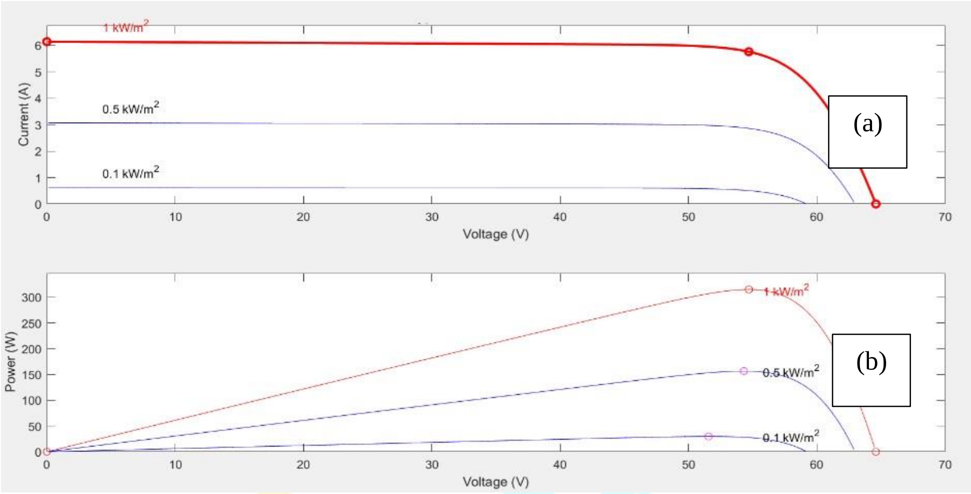

Figure 9- Graph of solar panel with Voltage vs. current and Voltage vs. Power

Figure 9 (a) illustrates the relationship between the voltage (V) and current (I) output of a solar panel under various operating conditions and Figure 9 (b) illustrates the relationship between the voltage (V) and power (P) output of a solar panel under various operating conditions. By analyzing these graphs, it becomes easy to determine the optimal operating conditions for solar panels and design MPPT algorithms to track the MPP efficiently. Additionally, these graphs provide valuable insights into the performance characteristics of solar panels under different environmental conditions and can aid in system optimization and design.

Figure 10 gives the time vs amplitude graph of the resultant waveform after mitigation of the higher frequencies using ANN as a controller. The waveforms shown in Figure 5.4 are more likely towards the ideal waveforms.

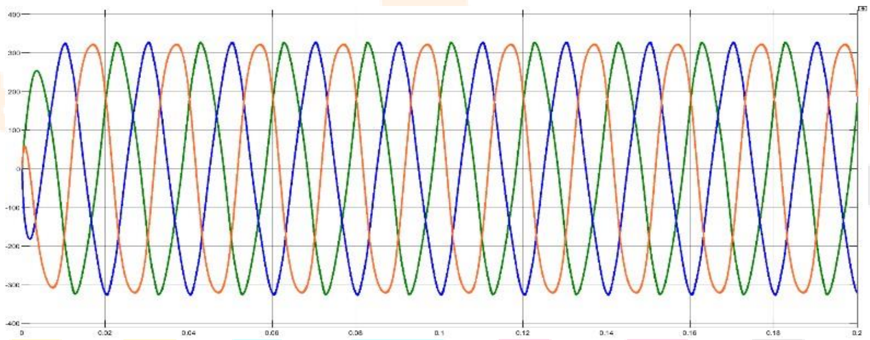

FIGURE 10- TIME VS AMPLITUDE WAVEFORM AFTER MITIGATION OF THE HIGHER FREQUENCIES USING ANN

The use of ANN for the mitigation of higher frequencies gives more reliable results. Also, the time required [19] for the mitigation of the higher frequencies is much less.

Conclusion-

ANNs are able to learn from data and identify patterns that can be used to predict and control the behavior of the system. In this study, an ANN was used to predict the high-frequency components of the system and to develop a control strategy to mitigate their effects. The results of the study showed that the ANN was able to accurately predict the high-frequency components of the system and that the control strategy was able to effectively mitigate their effects. This study demonstrates the potential of ANNs for mitigating the high-frequency components in a modern distribution system. We also compare the result observed by ANN wit Fuzzy Controller and PI Controllers. The results are more better than the other controllers. The Harmonic frequency components are completely suppressed by proposed ANN method by using High frequency components removal. So the output of the proposed system is smooth and having no HF components.

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