

AI BASED SMART CONTROLLER FOR OPTIMAL GRID STABILIZATION IN HIGH PENETRATED SOLAR PV POWER SYSTEM

Kamlesh Jat, Vikramaditya Dave

E-Mail Id: kamleshjat386@gmail.com

Department of Electrical Engineering, College of Technology & Engineering, Udaipur, India

Abstract- The rising temperatures on Earth and the acceleration of climate change have alarmed humanity, prompting advocates to promote solar, wind, hydrogen, biomass, and other renewable energy sources. Solar photovoltaic (PV) installations are massive due to government funding. Despite the fact that PV yield capacity at night can be reduced owing to lack of sunlight and other factors like as air temperature. The photovoltaic system is best suited as an excellent source of energy in an individual arrangement, and the battery can be utilized to store coordination during the nighttime. PV modules for electric vehicles are becoming increasingly common in some applications.

Keywords: Solar photovoltaic, AI, Artificial neural network, CNN.

1. INTRODUCTION

The rapid integration of renewable energy sources, particularly solar photovoltaic (PV) systems, has significantly transformed the global energy landscape. With increasing concerns over climate change and the depletion of conventional energy resources, solar energy has emerged as a viable and sustainable alternative. However, the large-scale deployment of solar PV systems introduces several challenges, particularly in maintaining grid stability. High penetration of solar power can lead to voltage fluctuations, frequency deviations, and reverse power flow issues, posing risks to the overall efficiency and reliability of power distribution networks.

Currently, distribution networks are prone to PQ issues such as interruptions, disturbances, flickering, sagging/swelling, harmonics, PF, and so on. This is due to a combination 2 of 30 of inconsistent behaviors involving wind, the tides, the sun, and so on, as well as large nonlinear and unbalanced loads being used with electronic power equipment; however, increased usage of large nonlinear industrial loads leads to a decline in PF, and therefore, maintaining PQ has become the primary challenge for engineers who work in the power industry[1]. Various configurations of single and three phase SUAPFs, using various control techniques, were suggested for three and four wire distribution systems, for balanced and unbalanced supply voltages, in order to attend to PQ issues.

Conventional grid control methods, such as proportional-integral-derivative (PID) controllers, often struggle to manage the dynamic nature of solar energy generation, resulting in inefficiencies and operational challenges[2]. To address these limitations, advanced control strategies leveraging Artificial Intelligence (AI) have gained attention. AI-based smart controllers can dynamically predict, optimize, and stabilize grid parameters in real-time, offering a more adaptive and efficient approach to grid management. These controllers utilize machine learning algorithms, fuzzy logic, and neural networks to enhance power quality, mitigate fluctuations, and ensure seamless grid operation under varying solar and load conditions[3]

This work focuses on the design of an AI-based smart controller for optimal grid stabilization in high-penetration solar PV power systems. The proposed controller aims to outperform conventional methods by improving response times, minimizing voltage instability, and efficiently managing power distribution. Through a comparative analysis of different inverter topologies and control strategies, this study seeks to develop an intelligent and robust solution for enhancing grid resilience in the face of increasing solar energy integration [4].

The growing adoption of solar photovoltaic (PV) systems as a renewable energy source has introduced challenges in maintaining power grid stability. When solar PV penetration is high, fluctuations in power generation due to weather variations can cause voltage instability, frequency deviations, and reverse power flow issues. Traditional control methods, such as PID controllers, struggle to handle these challenges effectively[5].

Artificial Neural Networks Due to the nonlinear mapping characteristics of neural networks, ANNs have been successfully employed for many years to identify and control complex systems. Neural networks may be employed as controllers rather than traditional PSSs when suitably trained. The neural network (NN) must be trained for various operating situations to fine-tune the traditional PSS parameters and obtain reasonable performance. Interference is created during learning using a traditional backpropagation network under many circumstances. A modular NN was proposed by [119] in place of a backpropagation network to address this flaw. Three local expert networks and one gate network, each having three layers, make up this model[6]. The ANN was trained directly from a traditional PSS's input and output. According to the simulation results, the modular PSS is more efficient at dampening system oscillations and delivering high-quality outcomes.

2. INVERTER

The inverter is defined as a power electronic device, which converts dc voltage into ac voltage at specified magnitude and frequency[7]. Depending on the number of levels in the output voltage waveform, the inverter is broadly classified into two types, i.e., two level inverter and MLI. Figure shows the circuit diagram of single phase h-bridge configuration and the bipolar output voltage waveform. It consists of four main switches, input dc voltage source, feedback diodes and load. The output voltage has two levels i.e. $+V_{dc}$ and $-V_{dc}$. The one cycle operation is shown in Figure. For generating $+V_{dc}$, the main switches S_1 and S_2 are switched ON and the other two switches are in OFF. For generating $-V_{dc}$, the main switches S_3 and S_4 are ON and vice versa.

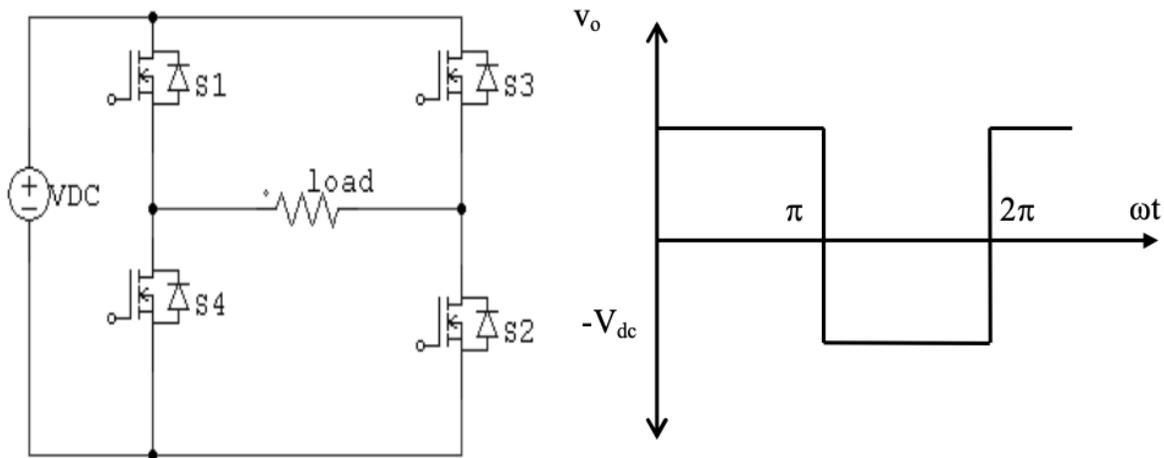


Fig. 2.1 Single Phase h-bridge Inverter Configuration and Bipolar Output Voltage

2.1 Multi level Inverter

The MLI history started from h-bridge cascading connection in the mid- 1970s and how to synthesize separate dc voltage sources to generate stepped ac voltage, is patented by Baker and Bannister, 1975. This topology is implemented in series connection of single-phase h-bridge inverters [8]. It has several advantages compared to other topologies of MLI family. The additional h-bridge inverter can be connected with the existing circuit to increase the number of levels in MLI. The generalized circuit diagram of CMLI is shown below. More than one h-bridge inverter unit is connected in series to synthesize the separate dc input voltage to generate staircase output voltage almost similar to sinusoidal shape. If the dc voltage magnitude is equal, it is called as Symmetrical Cascaded Multi Level Inverter (SCMLI). The implementation of SCMLI enhances the efficiency and reduces the harmonic distortion in the output voltage. This is crucial for applications requiring high-quality power supply, such as renewable energy systems. Furthermore, SCMLI can effectively balance the load and improve the system's reliability. As the demand for renewable energy sources continues to rise, the relevance of multi-level inverters in modern power electronics will only increase[9]. Overall, SCMLI represents a significant advancement in inverter technology, facilitating the transition to cleaner energy solutions

2.2 Generalized Configuration of SCMLI

Solar power is an important source of renewable energy. It is abundant, clean, and easy to get to. Photovoltaic (PV) panels, which can be used in both local and large-scale solar farms, make it easy to harvest solar energy. Solar energy can be converted into electricity to power a building or connected into the power grid. One of the most promising technologies for capturing solar energy right now is PV technology, which has advanced dramatically in recent years. The number of installed PV solar panels, both stand-alone and grid-connected, has increased dramatically as a result of their increased efficiency and affordability. Solar energy is one of the most promising forms of renewable energy[10]. Its market share is steadily increasing. This variance has a major detrimental impact on the overall use of solar energy in the electrical system. The successful integration of solar electricity into the electrical grid needs accurate forecasting of the power supplied by PV systems [11]. The purpose of this thesis is to study the possibilities for using machine learning and soft computing approaches to precisely predict solar power generation, enabling for better use of this renewable energy source. The study approaches can be used by energy market and PV plant operators to make decisions about maximizing the use of PV power generated, reducing waste, planning maintenance, and cutting costs, as well as enabling the widespread integration of PV electricity into the electrical grid.

2.3 Networks of Artificial Neural

The type of ANN has only increased over time, which may be ascribed to the company's popular apps that use this technology. As a result, average developers have gradually developed pretty robust libraries for open source and services. To get the most out of these libraries, developers must consider the fundamentals of the algorithms. ANNs are employed in digital learning algorithms that are powered by biological NN characteristics. It is used for a variety of tasks, ranging from fairly simple classification to language and computer vision recognition. ANNs are versatile brain-inspired computational models. Unlike other research tools, they are capable of handling difficult issues such as function approximation, classification, and pattern recognition. It was also utilized as an optimization method for nonlinear and complex problems. An ANN is made up of different neurons with a trustworthy structure that are layered and connected to each other's frames. Neurons are the fundamental building components of any neurological system. Figure 2.2 shows Architecture of ANN.

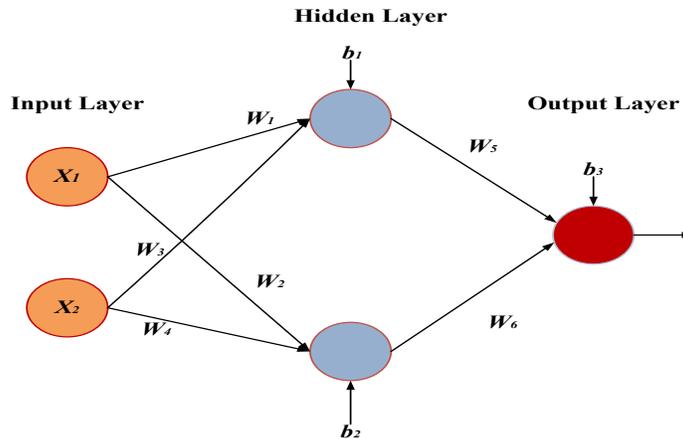


Fig. 2.2 Architecture of ANN

An artificial neural network's parameterized function, $f(x, \theta)$, can be shown as a composition of layers.

$$f(x, \theta) = (f^{(1)} \circ f^{(2)} \circ \dots \circ f^{(L)})(x, \theta) \quad \dots(1)$$

Where x is a network input, α is the model parameter, \circ is the composition of functions, $f^{(L)}$ is the index layer, and L is the total number of network layers. Layer parameterization may occur, and the model's parameters will be shown as a set of $\{f^{(l)}\}$, the parameters of the layers, with L_p the number of trainable layers. ANNs typically have numerous layer types, and the precise type of layer used is determined by the problem. An architecture is defined as the layer set connected in the given sequences [12].

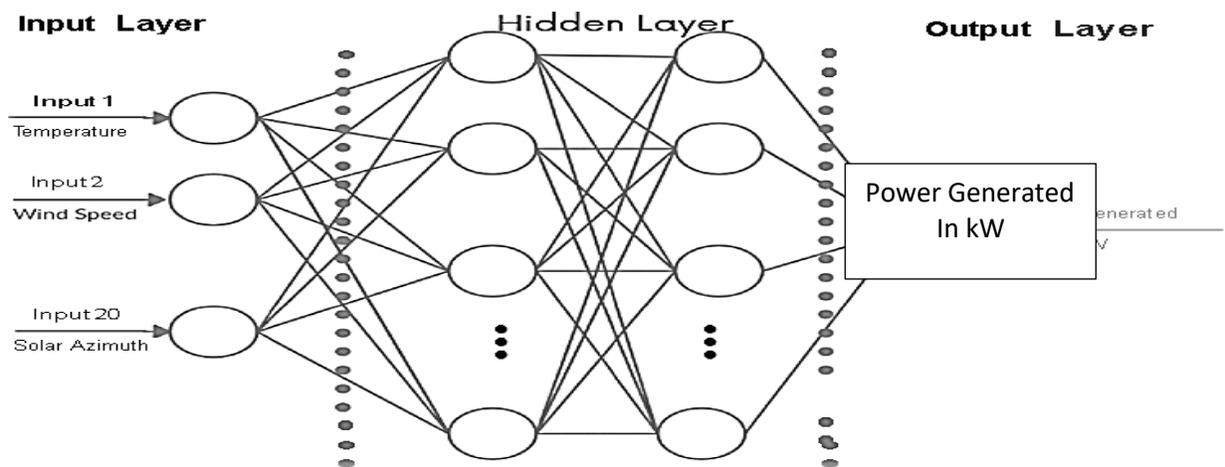


Fig. 2.3 Architecture of Designed Dense Deep CNN for Solar Generation Forecasting

A CNN model with a large number of input variables and nodes may suffer from overfitting, which occurs when the model performs well in training but makes incorrect predictions in testing. It was revealed that the candidate model with 14 input variables had the smallest RMSE for solar forecasting. The CNN's buried layer contains 15 nodes for each case. The proposed technique use applied mathematics to train the CNN to recognize similar patterns.

The gradient descent method is an appropriate optimization strategy that attempts to minimize errors by adjusting the strength (weights) of synapses (links) between nodes as information travels in one direction between neurons (nodes) and errors propagate back in the opposite direction. The weights between the nodes are adjusted until they produce the correct response after enough training iterations with known input data. The CNN will then respond appropriately to (unknown) input data that it has never encountered before. This allows CNN to learn to generalize introduce sophisticated ANN training methods with multiple optimization strategies to improve performance.

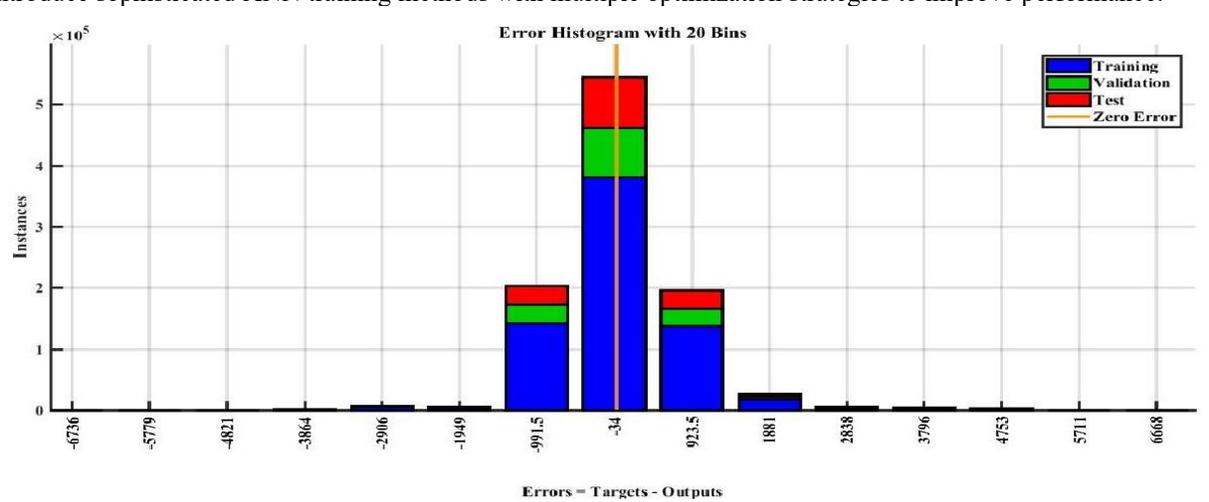


Fig. 2.4 ANN Training Error Histogram Characteristics

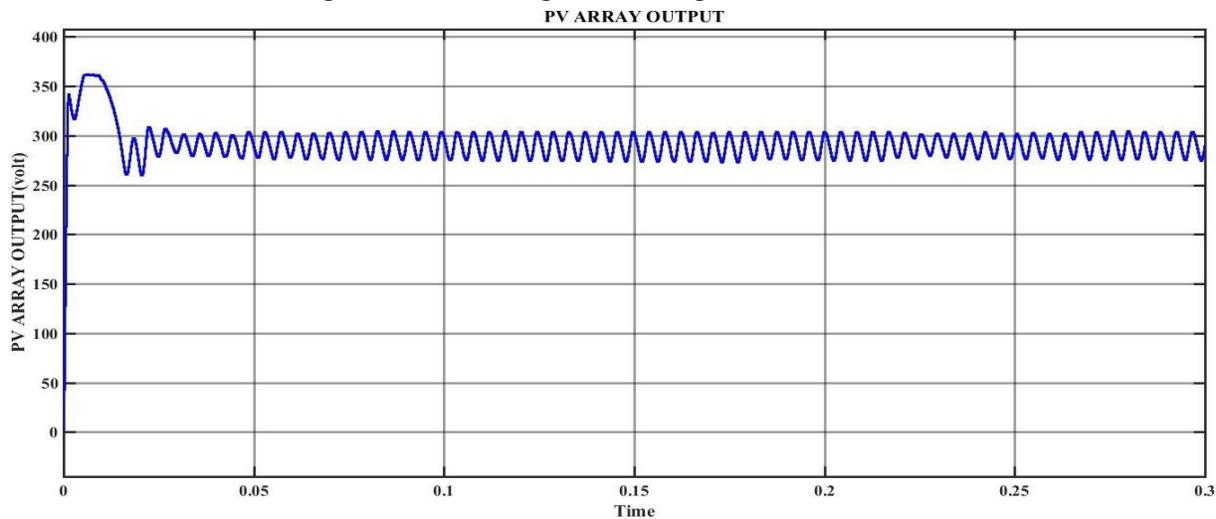


Fig. 2.5 PV Array Output Voltage (290V)

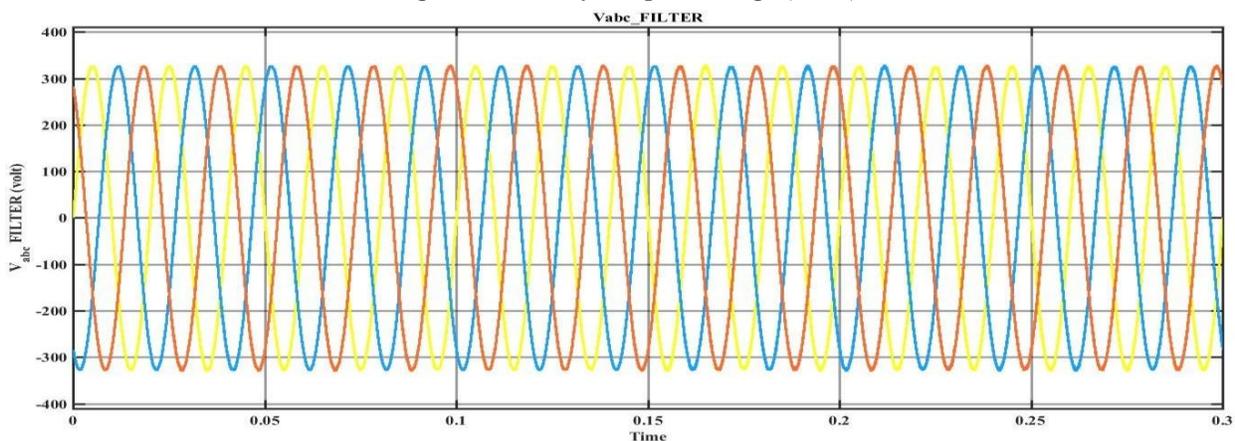


Fig. 2.6 MPPT Controlled Boost Converter Output Voltage (600V)

Fig. 2.6 shows the ANN training error histogram characteristics and Figure 2.7 shows the PV array output voltage for constant 1000W/m² irradiance and 250C temperature. The 600 V constant DC input voltage generated by PV Module with boost converter to the VSI is shown in and 6.3. The filtered and unfiltered output voltage and current of the VSI are shown in Figure 2.8 and 2.9.

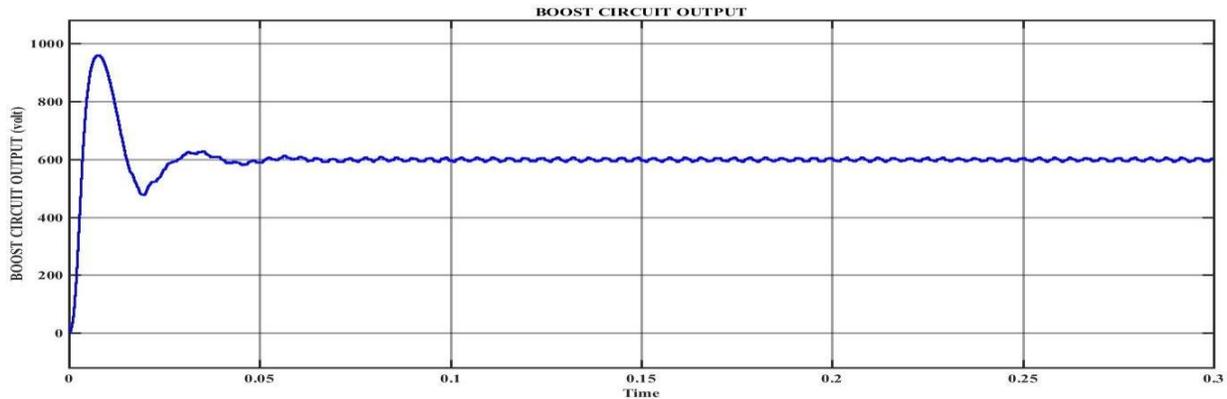


Fig. 2.7 PVGS connected VSI output Voltage

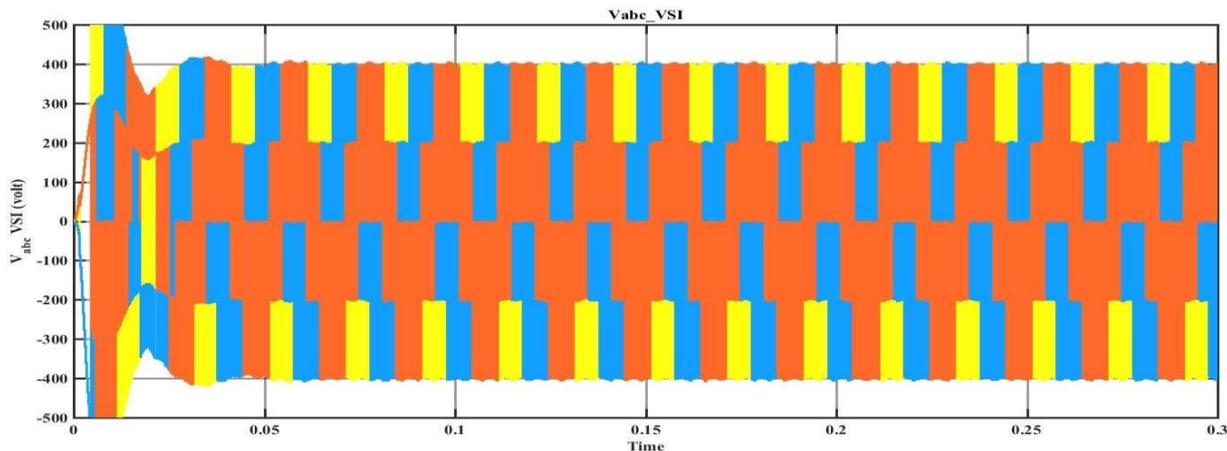


Fig. 2.8 PVGS connected filtered VSI Output Voltage

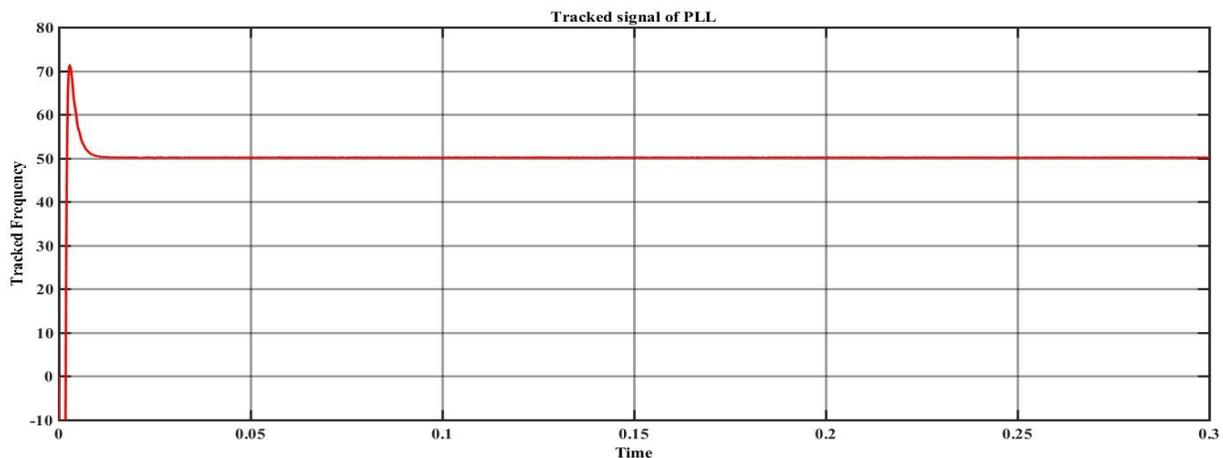


Fig. 2.9 Tracked Three Phase Reference Frequency by PLL

CONCLUSION

This dissertation project focuses on the study and software implementation of a grid-connected PV generation system to meet a 100-kilowatt energy demand for the electrification of remote end users. To track maximum produced power and identify maximum power point in power current and voltage graphs, the Perturb and Observe Maximum Power Point Tracker algorithm is utilized. The artificial neural network-based shunt active power filter used in this thesis

study is meant to minimize source current harmonics and improve power quality with enhanced power factor. The PLL-based positive sequence detection approach is employed as the unit vector generation for reference current production of SAPF gating signals since it requires fewer sensor counts and has a shorter calculating time.

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