IMPROVING POWER QUALITY IN EV CHARGING STATIONS WITH ANN-CONTROLLED 3-PHASE GRID INTEGRATION

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Abstract
The main objective of this project is Improving Power Quality in EV Charging Stations with ANN-Controlled 3-Phase Grid Integration. This paper focuses on improving power quality in a solar photovoltaic (PV) array-based EV (Electric Vehicle) charging station. The charging station operates in standalone mode, utilizing the power generated by the PV array to charge the EV battery. Additionally, it can interface with the utility grid and supply surplus power back to the grid. One of the key advantages of this charging station is its ability to compensate for reactive power, thereby enhancing grid power quality. The charging station serves multiple functions: (i) compensating for harmonic currents, (ii) controlling the charging and discharging of the EV battery, (iii) enabling simultaneous EV battery charging and harmonic current compensation, and (iv) facilitating both discharging and harmonic current compensation at the same time. The proposed ANN controllers show better efficiency in power flow and voltage regulation. The ANN controller productivity continually varies in the changing system conditions which increases the stability and stability of the system . The result suggests that using ANN controller reduces the tuning complexity and Harmonic Distortion and performance in 6% Disturbance.

I.INTRODUCTION

The environmental concerns for increased pollution, resource conservation have led to the increase in the usage of the electrical vehicles (EVs) . Due to rise in the EV demand, charging stations are required to be installed. Conventionally, the EV battery is charged using the power from the grid. The charger topologies using grid to charge the EV battery are demonstrated in [2-4]. These topologies use the enormous amount of grid power to charge the EV battery. However, due to unidirectional power flow nature of the charger, the active power is not allowed to flow from vehicle to the grid. However, EV battery may be utilized as an energy storage to use the power in case of peak demand. Most of the times EV is parked with a large amount of energy stored in it. When EV is idle, the power stored in the battery is supplied to the grid to meet the peak power requirement. To accomplish this objective, the EV charger needs to support the bi-directional active power flow. When EV supplies power to the grid, the procedure is named as vehicle to grid (V2G). In this mode, the EV charges may also provide the reactive power support to the grid [7-10]. The reactive power support is provided near to the load end [9]. The PV intermittency is overpowered by the utilization of the EV battery as a buffer storage and interfacing the charging station to the grid [10]. An onboard charge to charge the EV battery has been demonstrated in [11]. However, onboard charges use for low powered batteries. Therefore, an off-board charger proves to be more viable solution as compared to the on-board chargers. The topologies with off-board chargers are discussed in [12-13]. In the present work a single stage PV based off-board EV charging station connected to the grid is demonstrated. This charging station supports the bi-directional flow of power. The EV is connected at the DC-link of the charging station using a bi-directional converter. The benefit of a bidirectional converter is that it blocks the second harmonic current and the DC-link ripples to enter the EV battery and deteriorates the battery by decreasing its lifetime. Moreover, the dependency of the selection of the EV battery rating on the DC-link voltage is eliminated. The duty cycle of the bidirectional converter is controlled to charge/ discharge of the battery. The PV array is used here for EV battery charging and the extra power is supplied to the utility to reduce the generation requirement. The VSC is utilized for the reactive power compensation demanded by the grid. The PV based EV charging station improves the grid power quality in the grid connected mode and during the grid failure, it operates in the standalone mode and PV array generation is used for the charging the EV battery. The system is also tested during various dynamic conditions such as PV insolation variations, unbalancing of the grid voltages, compensation of the grid reactive power. Whenever, the grid is restored back, the charging station synchronizes to the grid. The control of the charging station is designed using the reference active power and reactive power command. The reference active power command is decided by the EV owner whether to charge/ discharge the EV battery. The reference reactive power is selected according to the inductive/capacitive reactive power requirement for the persistent operation of the charging station. The charging station is controlled in such a manner that EV owner decides the charging/discharging of EV battery. If it is required to charge the EV battery using grid power, the system operation is known as G2V (Grid to Vehicle). However, if EV battery discharges to provide power to the grid, the system operation is known as V2G (Vehicle to Grid). Moreover, the charging station has the ability to provide the reactive power compensation (lagging/leading) as per the requirement.

The increasing adoption of Electric Vehicles (EVs) has brought about significant changes in the way electrical infrastructure is utilized. One of the critical areas impacted by this shift is the power quality at Electric Vehicle Charging Stations (EVCS), where the demand for electricity is high and variable. The integration of EVCS into the electrical grid can create issues such as voltage fluctuations, harmonic distortion, and unbalanced load conditions, all of which affect the overall quality of power delivered to the grid and to consumers. As the number of EVs grows, these power quality challenges will only intensify, posing risks to both grid stability and the efficiency of the charging process.

To mitigate these problems, the integration of advanced control systems is essential. Among the most promising solutions is the use of Artificial Neural Networks (ANNs) for real-time control of charging processes and grid interactions. ANNs can offer highly adaptive and efficient methods for managing the dynamic load demands of EV charging, ensuring the provision of high-quality power with minimal disruptions.

This paper explores the application of ANN-controlled 3-phase grid integration in EV charging stations to enhance power quality. A 3-phase grid is often preferred due to its stability and balanced load distribution, which is critical when managing multiple charging points. By utilizing ANN-based control strategies, it is possible to monitor and adjust the charging stations' behavior in real-time, balancing the power supplied to the grid while ensuring that the charging process remains efficient, reliable, and free from harmful distortions.

The primary goals of this research are:

1. To explore the role of ANNs in managing power quality at EVCS.
2. To demonstrate how 3-phase grid integration can help in stabilizing the power supply.
3. To propose a model for ANN-based control that adapts to varying load conditions in a scalable and responsive manner.
4. To assess the impact of these techniques on the overall efficiency of EV charging stations and their interaction with the electrical grid.

II.LITERATURE SURVEY

[1] M. Shatnawi, K. B. Ari, K. Alshamsi, M. Alhammadi and O. Alamoodi, i, "Solar EV charging,"

In this paper, the authors introduce a novel approach to charging electric vehicles (EVs) using hybrid renewable energy sources like wind generators and photovoltaic modules. They highlight the limitations of current EV recharging mechanisms, which rely on dedicated recharging stations and can impact long-distance travel. To address this, they propose an automated charging mechanism (ACM) that autonomously recharges EV battery packs, eliminating the need to wait for recharging and thereby extending travel distances. The ACM is developed using a MATLAB-Simulink model. The authors conduct experiments to measure the output voltage of wind turbines under various speed scenarios and analyse the performance of solar photovoltaic systems at different irradiance levels. They also study the ACM's behaviour under different load conditions, focusing on metrics such as total harmonic distortion (THD) of output current and voltage, efficiency, and vehicle coverage distance. To demonstrate the ACM's effectiveness, the authors compare it with commercial charging mechanisms across different EV brands. Simulation results indicate that the ACM satisfactorily recharges EV batteries without relying on traditional recharging stations. They argue that automatic recharging can boost EV usage, leading to a reduction in fossil fuel vehicles and associated CO2 and CO-related emissions. Ultimately, the authors believe that their proposed method can decrease overall travel time and promote greater EV adoption.

[2] P. P. Nachankar, H. M. Suryawanshi, P. Chaturvedi, D. D. Atkar, C. L. Narayana and D. Govind, "Universal off-board battery charger for light and heavy electric vehicles,"

In this paper, an off-board unidirectional conductive type DC fast charger for light and heavy electric vehicles is presented. The converter is adaptable for charging of light as well as heavy electric vehicles. The proposed charger is based on resonant series converter with adaptable restructured multiplier rectifier. The restructuring element for adaptable rectifier is a simple bi-directional switch. The doubler configuration is recommended for light electric vehicles (400V Class) while quadrupler configuration is recommended for heavy electric vehicles (800V Class). In this paper, both the configurations and their associated operation modes are explained with respective waveforms. Further, all semiconductor switches and rectifier diodes are naturally soft switched owing to resonant converter above resonant frequency operation for minimizing losses. The charging rates and power levels can be scaled up or down by adopting modular approach.

[3]P. K.Sahoo, A.Pattanaik,A. K. Dey and T. K. Mohapatra, "A novel circuit for battery charging and motor control of electric vehicle,"

A new method of battery charging and motor controlling of an electric vehicle (EV) is disclosed in this paper. The entire system consists of two major divisions, those are, EV charger and motor controller, which determine the arrangement of the battery, acting as load or source, and the motor that comes into action during the driving mode. Both the charging and motor control can be performed by two separate highly efficient DC-DC converters named as TA converter which is a Buck-Boost by its nature. While charging a battery it is necessary to make the charging process effective. Microcontroller employs to control all parameter of EV in all conditions. When the motor draws over current, the invented circuit will be tripped through the microcontroller. The supply for the charger will be either from the renewable source or rectified output from the grid. Keywords- Electric Vehicle, DC-DC Converter, PI & Hysteresis Controller.

III.PHOTOVOLTAIC TECHNOLOGY

Photovoltaic's is the field of technology and research related to the devices which directly convert sunlight into electricity using semiconductors that exhibit the photovoltaic effect. Photovoltaic effect involves the creation of voltage in a material upon exposure to electromagnetic radiation.

The photovoltaic effect was first noted by a French physicist, Edmund Becquerel, in 1839, who found that certain materials would produce small amounts of electric current when exposed to light. In 1905, Albert Einstein described the nature of light and the photoelectric effect on which photovoltaic technology is based, for which he later won a Nobel prize in physics. The first photovoltaic module was built by Bell Laboratories in 1954. It was billed as a solar battery and was mostly just a curiosity as it was too expensive to gain widespread use. In the 1960s, the space industry began to make the first serious use of the technology to provide power aboard spacecraft. Through the space programs, the technology advanced, its reliability was established, and the cost began to decline. During the energy crisis in the 1970s, photovoltaic technology gained recognition as a source of power for non-space applications.

The solar cell is the elementary building block of the photovoltaic technology. Solar cells are made of semiconductor materials, such as silicon. One of the properties of semiconductors that makes them most useful is that their conductivity may easily be modified by introducing impurities into their crystal lattice. For instance, in the fabrication of a photovoltaic solar cell, silicon, which has four valence electrons, is treated to increase its conductivity. On one side of the cell, the impurities, which are phosphorus atoms with five valence electrons (n-donor), donate weakly bound valence electrons to the silicon material, creating excess negative charge carriers.

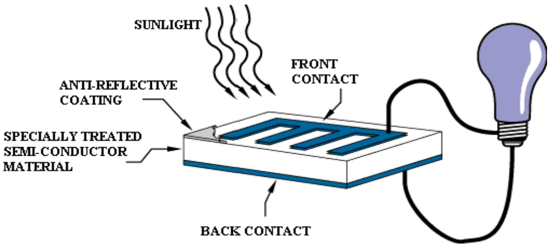


Fig 1: Solar cell.

IV.POWER QUALITY

Our technological world has become deeply dependent upon the continuous availability of electrical power. In most countries commercial power is made available via nationwide grids, interconnecting numerous generating stations to the loads. The grid must supply basic national needs of residential, lighting, heating, refrigeration, air conditioning and transportation as well as critical supply to governmental, industrial, financial, commercial, and medical and communications communities. Commercial power literally enables today's modern world to function at its busy pace.

Many power problems originate in the commercial power grid, which with its thousands of miles of transmission lines is subject to weather conditions such as hurricanes, lightning storms, snow, ice and flooding along with equipment failure, traffic accidents and major switching operations. Also power problems affecting today's technological equipment are often generated locally within a facility from any number of situations such as local construction, heavy start up loads, faulty distribution components and even typical background electrical noise.

Widespread use of electronics in everything from home electronics to the control of massive and costly industrial processes has raised the awareness of power quality. Power quality or more specifically a power quality disturbance is generally defined as any change in power (voltage, current or frequency) that interferes with the normal operation of electrical equipment.

The study of power quality and ways to control it is a concern for electric utilities, large industrial companies, businesses and even home users. The study has intensified as equipment has become increasingly sensitive to even minute changes in the power supply voltage, current, and frequency.

V.MODELLING OF CASE STUDY

5.1 EXISTING SYSTEM

The basic block diagram of the single stage PV based EV charging station is demonstrated in Fig. 2. The sole aim of the PV based charging station is to charge the EV battery with the DC power generated by the PV array. A bi-directional converter is used for the charging/discharging of the EV battery. The PV array is directly connected to the DC-link. Thus, eliminating the use of a boost converter and reducing the overall cost of the charging station. An IGBT based VSC is used for the conversion of DC power to AC power to be interfaced with the grid. The switches used for the connection of the charging station with the grid are also IGBT based and are known as static transfer switches (STS).

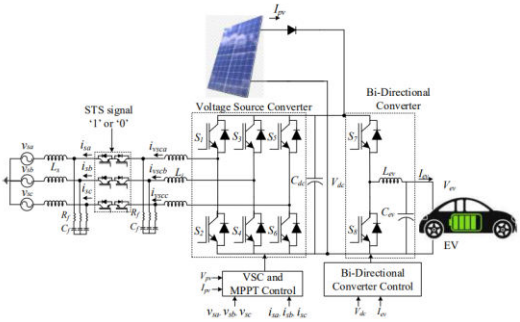


Fig. 2 Three-phase Three wire single-stage grid connected PV system with EV

5.2 PROPOSED SYSTEM

The proposed block diagram of the single stage PV based EV charging station is demonstrated in Fig. 3. The sole aim of the PV based charging station is to charge the EV battery with the DC power generated by the PV array. A bi-directional converter is used for the charging/discharging of the EV battery. The PV array is directly connected to the DC-link. Thus, eliminating the use of a boost converter and reducing the overall cost of the charging station. An IGBT based VSC is used for the conversion of DC power to AC power to be interfaced with the grid. The switches used for the connection of the charging station with the grid are also IGBT based and are known as static transfer switches (STS).

The proposed system integrates an ANN-based control strategy with a three-phase grid-tied inverter to ensure smooth power delivery and enhance grid stability. The ANN controller is trained to detect power disturbances, predict fluctuations, and adjust the charging process dynamically.

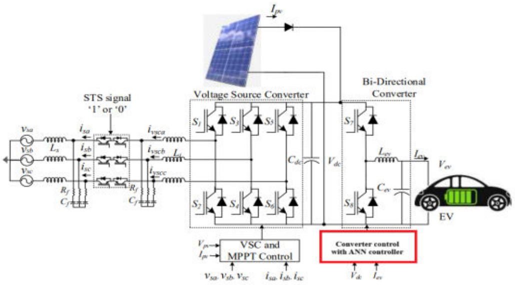


Fig. 3 Proposed Three-phase Three wire single-stage grid connected PV system with EV Based ANN Controller

5.3 CONTROL SCHEME

The fundamental purpose of the present charging station is the utilization of the PV array generation in EV charging. The charging station is synchronized to the grid and the PV array power could be supplied to the grid. Moreover, EV can also discharge and supply the power to the grid. Therefore, an intelligent control scheme should be developed for the better and efficient utilization of the charging station. The control approach developed is demonstrated in Fig. 5.3. The controller basically has two input commands

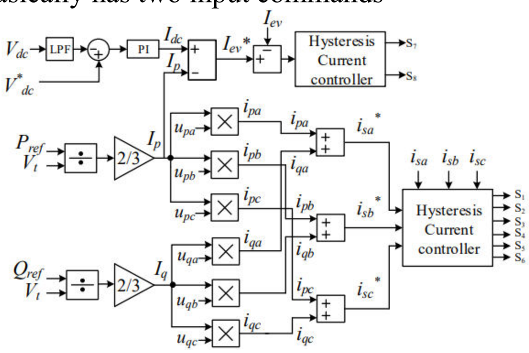


Fig. 4 Controller diagram

5.3.1 Active Power Reference Command

It is decided according to charging or discharging requirement of the EV battery. This active power command is decided by the EV owner, as per his choice of either charging the EV battery or discharging the EV battery to provide power to the grid and earns the incentives by selling the power to the grid during peak demand.

5.3.2 Reactive Power Reference Command

It governs the amount and the nature of reactive power exchanged, whether the exchanged power is inductive in nature or capacitive in nature. The control of the EV charging station is classified in two subsections – VSC and EV charging/discharging control in grid connected mode control and standalone mode control. The active power reference command and the reactive power reference command contributes to the VSC switching pulse generation in grid connected mode of operation. The EV battery charging/discharging is controlled using a DC-DC bidirectional converter. The control scheme is described in the following section in details. **5.3.3 VSC Control in Grid Connected Mode**

The VSC gate pulse generation in the grid connected mode is demonstrated in Fig. 5.3. The Pref (Active Power Reference Command) contributes to the active component of the current (Ip) and the reactive power reference command (Qref) contributes to the reactive component of the current (Iq). The per phase active currents (ipa, ipb, ipc) are estimated by the multiplication of the active component of the current (Ip) with the in-phase unit templates (upa, upb, upc). Similarly, the per phase reactive currents (iqa, iqb, iqc) are estimated by the multiplication of the reactive component of the current (Iq) with the quadrature-phase unit templates (uqa uqb, uqc).

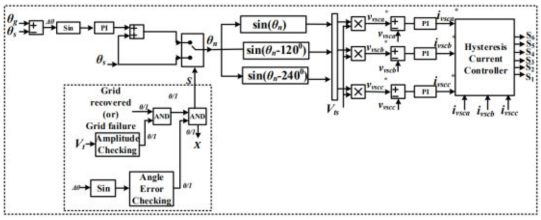


Fig. 5 Synchronization control

VI. PROPOSED ANN CONTROLLER

An Artificial Neural Network (ANN) is an information processing paradigm that is inspired by the way biological nervous systems, such as the brain, process information. The key element of this paradigm is the novel structure of the information processing system. It is composed of many highly interconnected processing elements (neurons) working in unison to solve specific problems. ANNs, like people, learn by example. An ANN is configured for a specific application, such as pattern recognition or data classification, through a learning process. Learning in biological systems involves adjustments to the synaptic connections that exist between the neurons. This is true in case of ANNs as well. The basic building block of all biological brains is a nerve cell, or a neuron as shown in the Fig.5.8. Each neuron acts as a simplified numerical processing unit. In esssence, the brain is a bundle of many billions of these biological processing units, all heavily interconnected and operating in parallel. In the brain, each neuron takes several input values from other neurons, applies a transfer function and sends its output on to the next layer of these neurons. These neurons in turn send their output to the other layers of neurons in a cascading fashion [14].

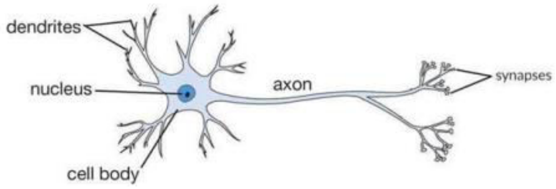


Fig. 6 A Biological Neuron

In similar manner, ANNs are usually formed from many hundreds or thousands of simple processing units, connected in parallel and feeding forward in several layers. In a biological neural network, the memory is believed to be stored in the strength of interconnections between the layers of neurons. Using neural network terminology, the strength or influence of an interconnection is known as its weight. ANN borrows from this theory and utilizes variable interconnections weights between layers of simulated neurons. ANNs were proposed early in 1960's, but they received little attention until mid-80's. Prior to that time, it was not generally possible to train networks having more than two layers. These early two layers networks were usually limited to expressing linear relationships between binary input and output characters. Unfortunately, the real world is analog and doesn't lend itself to a simple binary model. The real innovation in ANN research came with the discovery of the backpropagation method. Because of fast and inexpensive personal computers availability, the interest in ANNs has blossomed. The basic motive of the development of the neural network was to make the computers to do the things, which a human being cannot do. Therefore, ANN is an attempt to simulate a human brain. Hence, the ANN architecture can be easily compared with the human brain. An artificial neural network is a system based on the operation of biological neural networks, in other words, is an emulation of biological neural system.

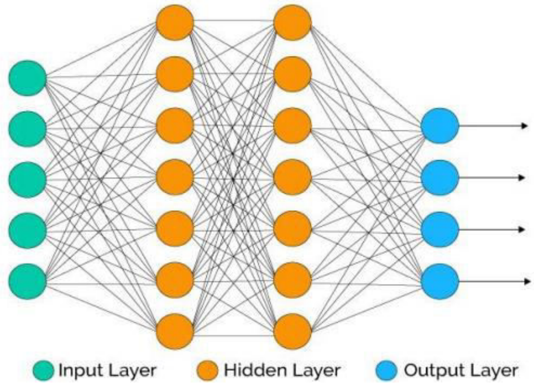


Fig. 7 Model of ANN

VII.SIMULATION RESULTS

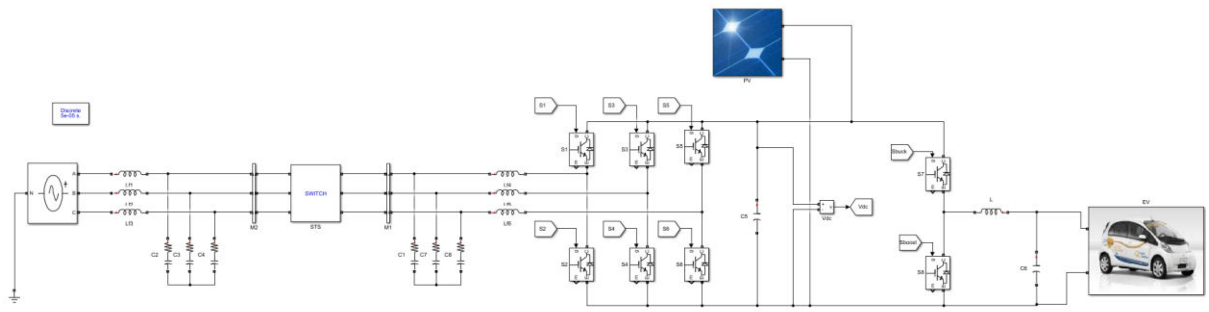


FIGURE 8. Simulink diagram of Three-phase Three wire single-stage grid connected PV system with EV

7.1 EXISTING RESULTS

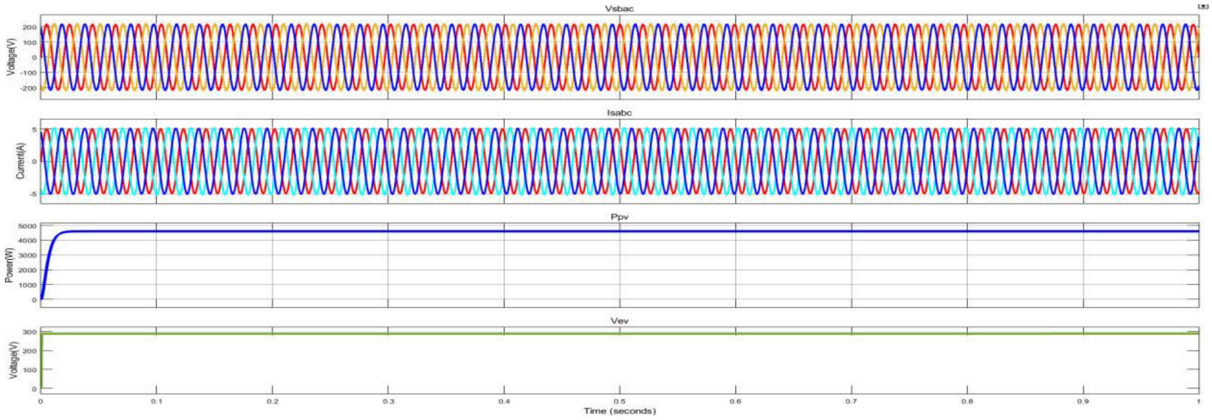


Fig 9 Simulation results of Charging Station at Steady State

7.2 EXTENSION RESULTS

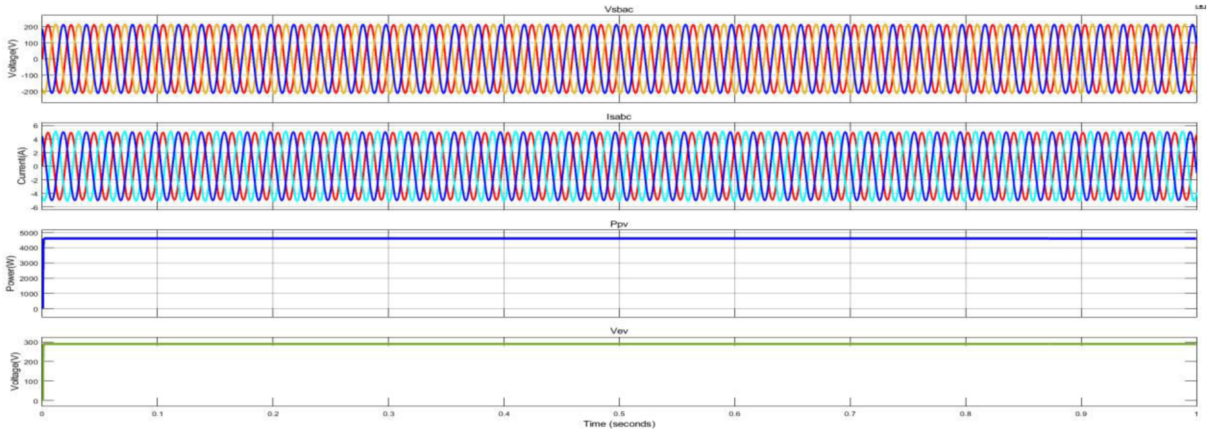
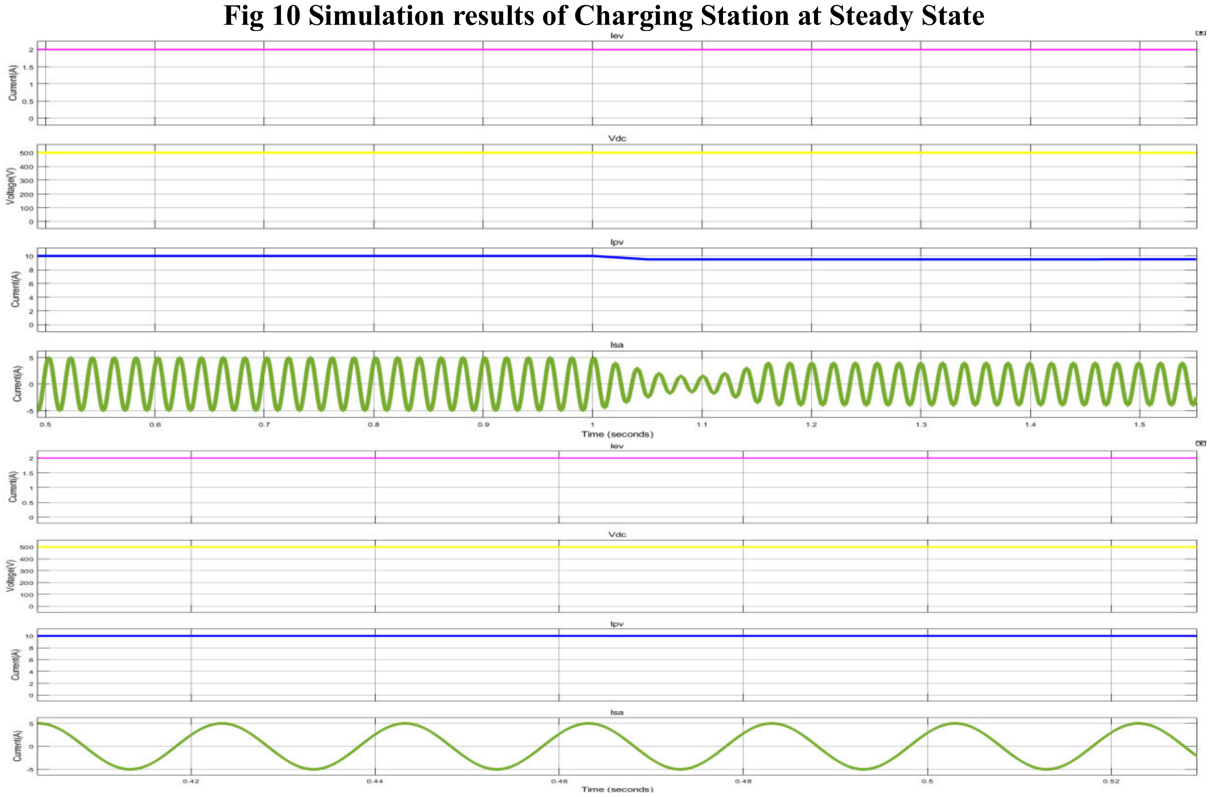


Fig 10 Simulation results of Charging Station at Steady State



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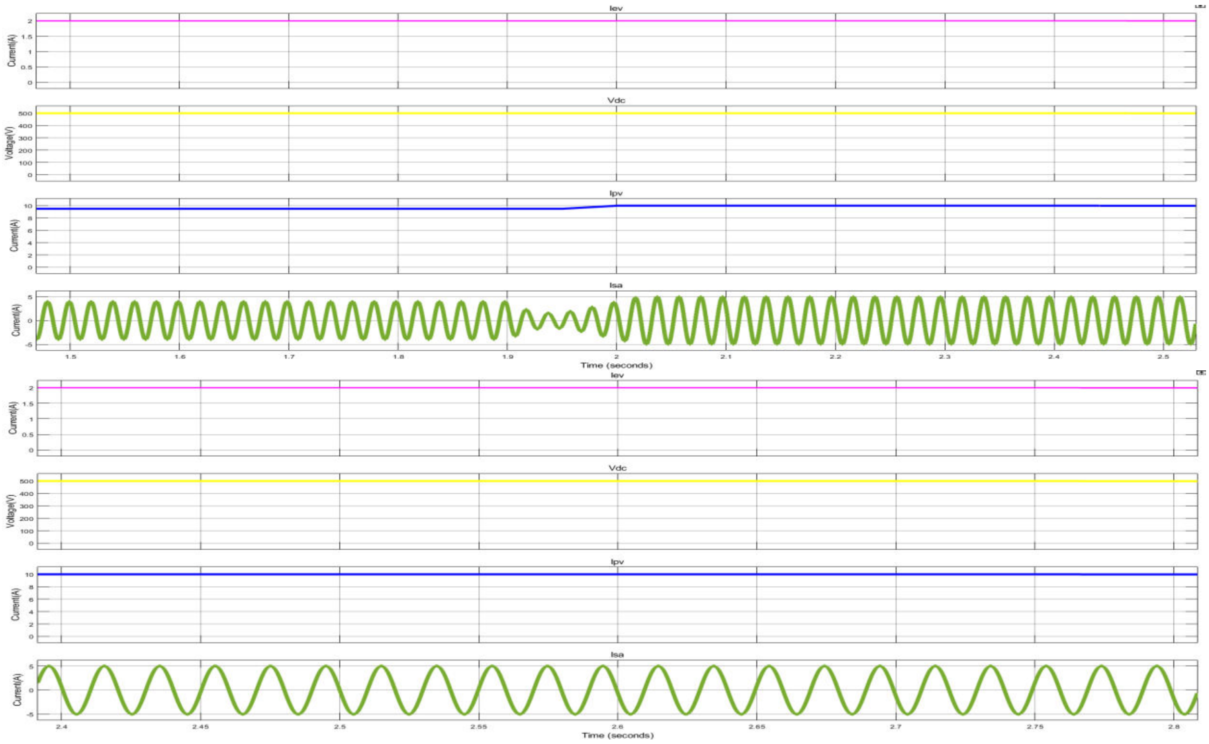
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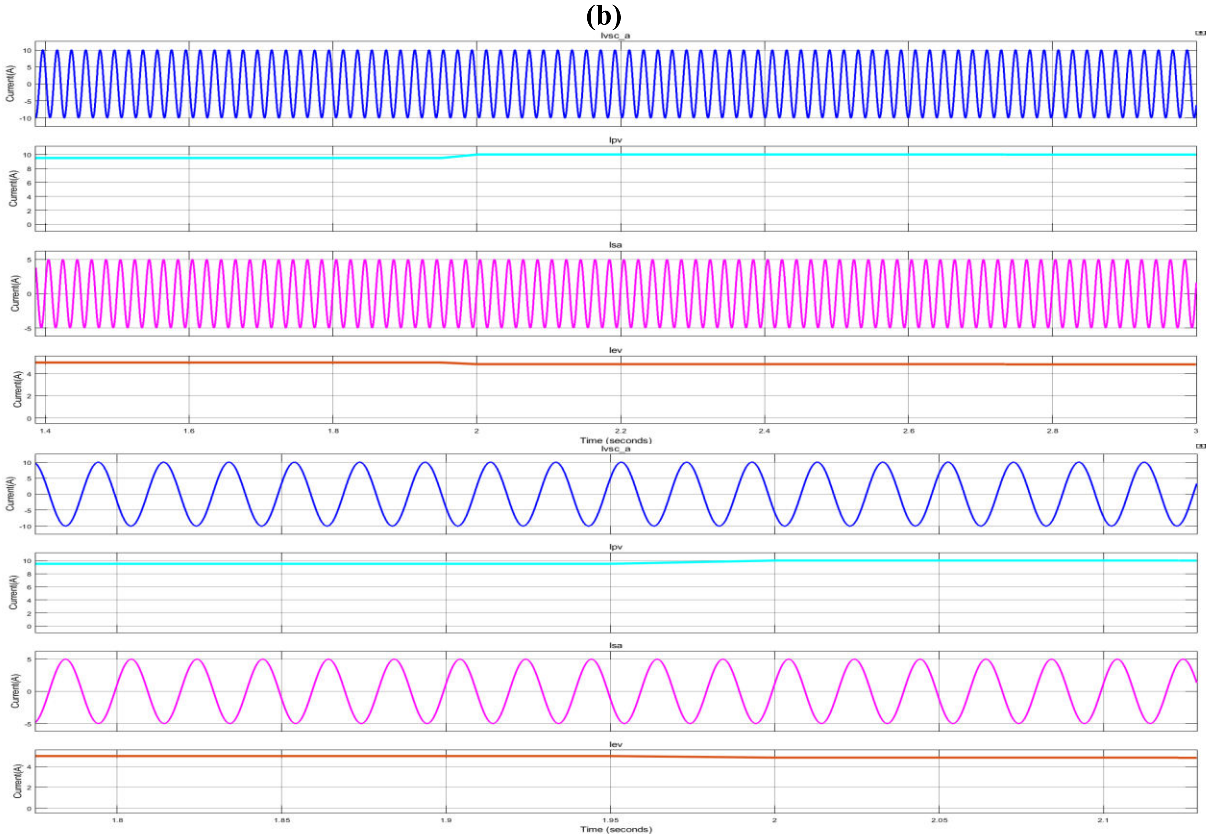
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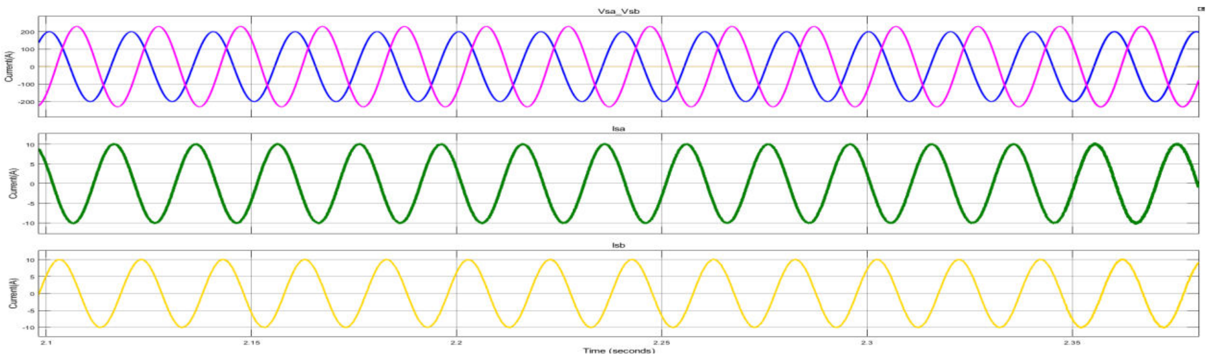
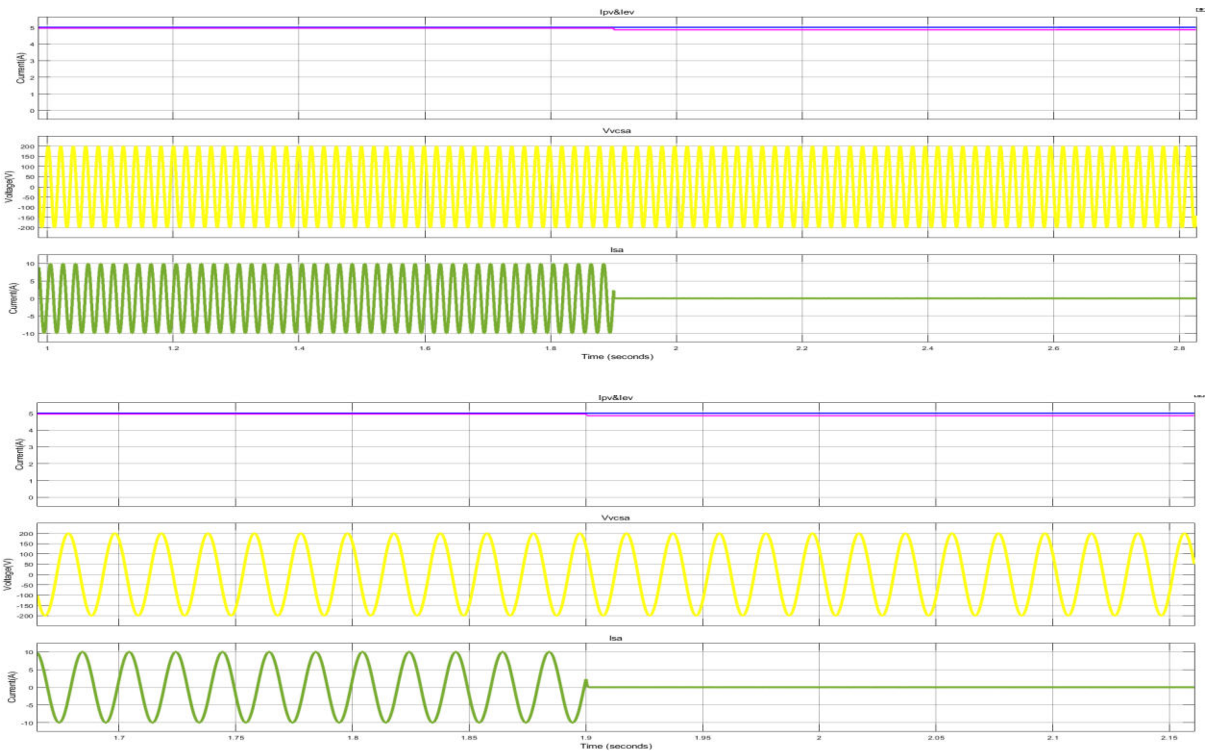


(d)

Fig 11 Dynamic response of grid connected system at (a) Increase in solar insolation (b) Fall in PV insolation (c) and (d) voltage unbalance and rise in PV insolation



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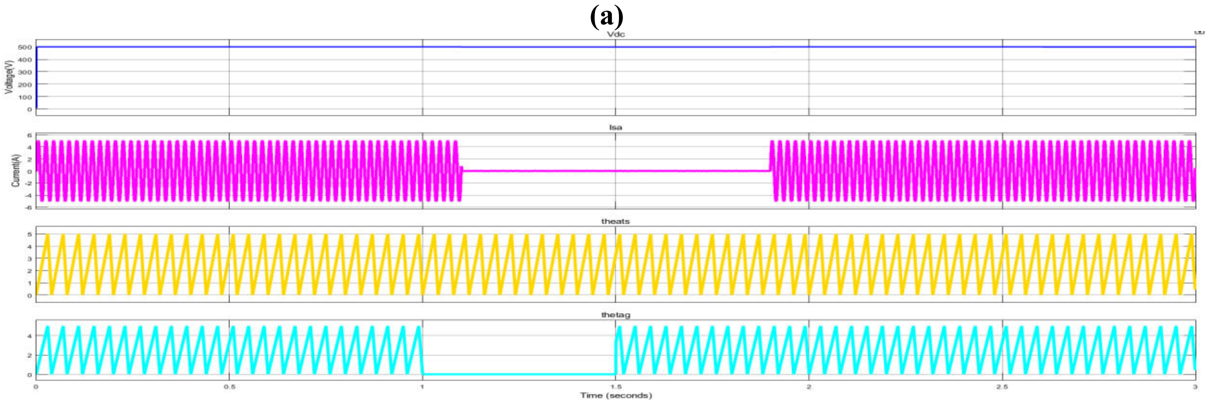
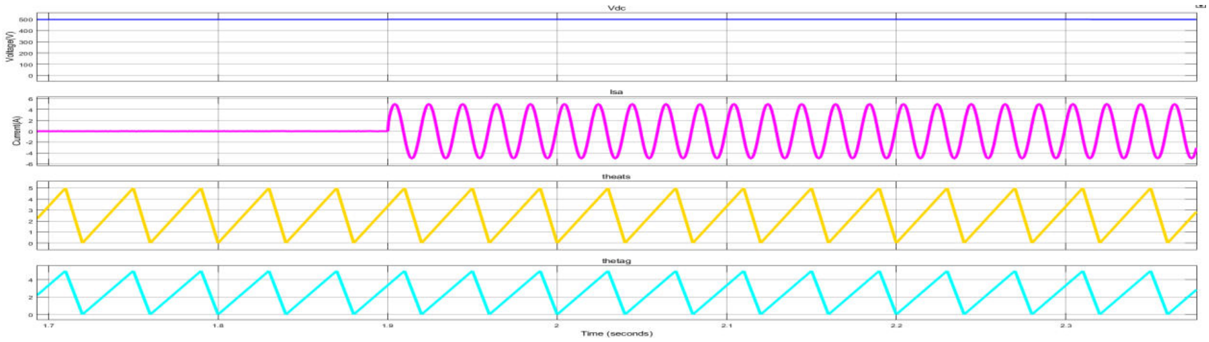
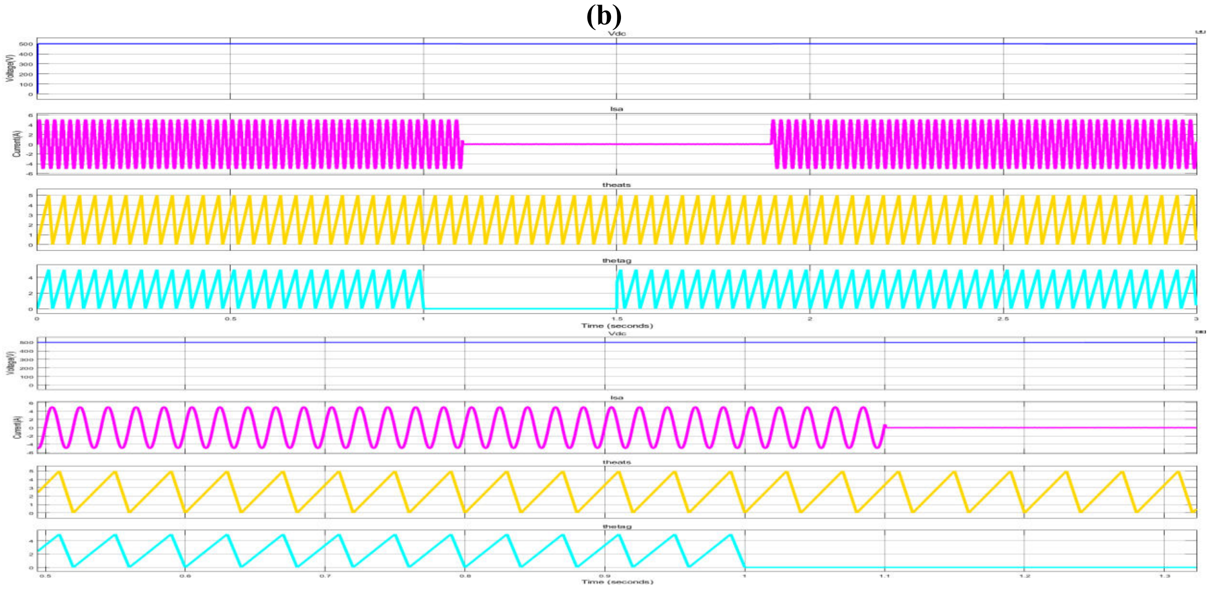




(b)



(c)

Fig 12 Performance during synchronization

VIII.CONCLUSION

The integration of Artificial Neural Network (ANN)-controlled 3-phase grid systems in EV charging stations significantly enhances power quality, ensuring stable and efficient energy transfer. By leveraging ANN-based control, the system effectively mitigates power fluctuations, reduces harmonic distortions, and improves power factor, leading to a more reliable and grid-friendly EV charging infrastructure. Compared to conventional control methods, the ANN-based approach offers real-time adaptability, faster response to grid disturbances, and optimized energy management, making it an ideal solution for modern smart grids. The implementation of this technology not only enhances grid stability but also supports the seamless integration of renewable energy sources, further promoting sustainable transportation. In conclusion, ANN-controlled grid integration for EV charging stations represents a significant step forward in power quality enhancement, ensuring efficient, cost-effective, and environmentally friendly energy distribution in the evolving EV ecosystem.

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