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POWER QUALITY IMPROVEMENT OF A SOLAR POWERED BIDIRECTIONAL SMART GRID AND ELECTRIC VEHICLE INTEGRATION SYSTEM USING ANFIS

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ABSTRACT:
This research primarily focuses on the integration of photovoltaic (PV) smart grids (SG) and electric vehicles (EVs) with two-way power flow capabilities. This includes charging, discharging, and enhancing power quality using power converters. Given the rising energy demand due to rapid population growth, modernizing the power grid to improve power quality is essential. This modernization allows the energy generated by solar PV systems to be transmitted and stored as excess power in batteries for use during peak load demands. Electric vehicle batteries can be charged during low-demand periods and discharged during peak demand. This dual function enables EVs to serve both as loads and as energy suppliers to the smart grid. Simulation results illustrate the operation of the smart grid-to-vehicle (G2V) system, highlighting improvements in factors such as power factor, power regulation, and harmonic elimination. These enhancements are achieved by constructing a power electronic network capable of bidirectional power flow and balancing the grid, using MATLAB/Simulink software. Additionally, the G2V controller has been enhanced with a ANFIS controller to achieve better stability in the battery current. The implementation of ANFIS control has notably reduced current ripple, peak overshoot, and settling time. Furthermore, the paper thoroughly examines improvements in the power quality of the integrated system, focusing on power compensation, voltage regulation, and harmonic mitigation.
Key Words: Electric Vehicles (EV), Grid to Vehicle (G2V), MATLAB/Simulink, Maximum Power Point Tracking (MPPT), Plug-in Hybrid Electric Vehicle (PHEV), Point of Common Coupling (PCC), Solar Photovoltaic (SPV) Adaptive Neuro Fuzzy Inference System.

INTRODUCTION The integration of renewable energy sources, particularly solar energy, into the power grid has gained significant momentum in recent years due to the global shift toward sustainable energy solutions. Solar photovoltaic (PV) systems play a crucial role in addressing the growing energy demand while reducing carbon emissions. However, the increasing penetration of solar PV systems into the grid introduces new challenges in maintaining power quality, stability, and reliability [1].Normally, foothold batteries are utilized in electric vehicles which can deal with high power and energy inside a restricted space and weight. As a result, extensive research is being conducted to advance EV-friendly battery technology. In the past, only electric vehicles made use of lead acid batteries. In any case, nickel batteries have the issue of high self-release and intensity age at high temperatures [2, 3]. Due to their small size, light weight, and high power density, lithium batteries are currently preferred. It beats the issues of low unambiguous energy, poor temperature attributes and compound spillage. Its wide temperature range, long life cycle, low self-discharge rate, and fast charging capability also increase its use in the electric vehicle industry [4]. The most frequently used lithium batteries are lithium titanate and lithium ferro-phosphate. Lithium ferro-phosphate battery has unrivaled warm strength in the completely energized condition and it has generally safe when coincidentally over charged. Lithium titanate batteries can be recharged quickly and operate at a wide temperature range [5, 6].The use of electric vehicles is limited because of the difficulties associated with charging the batteries, as well as the cost, life cycle, and cost. On-board and off-board chargers are the two main types of EV battery chargers. An on-board charger is inside the vehicle, whereas an off-board charger is only installed at the fixed location. The on-board charger is constrained by a number of factors, including weight, space, cost, and size [6, 7]. The motor winding itself can be used as the filter inductors or isolated transformer in order to circumvent these limitations by integrating this charger with the EV's motor drives. There are two types of charging systems: conductive and inductive. The EV connector and charger inlet are in direct contact in the conductive system. In contrast, power is transferred magnetically in an inductive system. One emerging area in this context is the bidirectional grid-to- vehicle (G2V) and vehicle-to-grid (V2G) integration. Bidirectional charging systems enable electric vehicles (EVs) to act not only as consumers but also as distributed energy resources, supplying energy back to the grid during peak demand periods. While this integration promises enhanced energy efficiency and grid flexibility, it also brings challenges such as voltage fluctuations, harmonic distortion, and unbalanced load conditions, which compromise overall power quality [8]. To address these challenges, advanced control strategies are essential. Among these, anfis have proven to be highly effective due to their ability to handle nonlinear, uncertain, and complex systems without requiring precise mathematical models. anfis provides a rule- based approach to regulate system parameters and ensure power quality enhancement in solar PV-based grid to vehicle systems.

PROPOSED METHEDOLOGY :

A comprehensive appraisal of the writing is given the objective of diminishing the quantity of gadgets expected to help an expanded number of result levels. The thesis's objectives and structure are discussed in depth in this section. These days, interests in new sustainable and economical energy areas are quickly done to lessen CO_2 outflows and address an Earth-wide temperature boost brought about by the utilization of petroleum products.

Solar photovoltaic and wind energy-based power generation systems are largely due to developments in power electronics in order to connect these sources to either local loads or the distribution grid. Figure 1 depicts the proposed work's fundamental application.

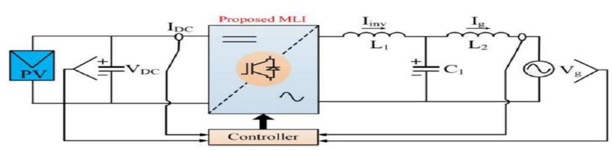

Figure 1: Block Diagram of Methodology

ADAPTIVE-NEURO FUZZY INFERENCE SYSTEM (ANFIS) :

Fuzzy neural networks (FNNs), also known as fuzzy inference systems, have been very successful in the fields of approximation and control modelling within machine learning.

In contrast to ANN, FNN learns a rule-base as it maps inputs to the intended output(s) through input membership functions and output membership functions. In FNN, these principles are incorporated exactly into the network's neural architecture. Rule precision relies on type suitability (Fig.2) and membership function parameters.

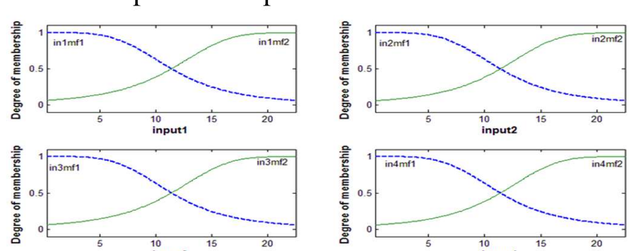

Figure 2 : basic shapes of membership functions

The base of ANFIS is the Takagi-Sugeno-Kangmodel (TSK), often known as the Sugeno fuzzy model, ANFIS's five-layer design has two kinds of nodes—fixed and dynamic (Fig. 3 Nodes outside of the membership function layer and the subsequent layer are fixed.

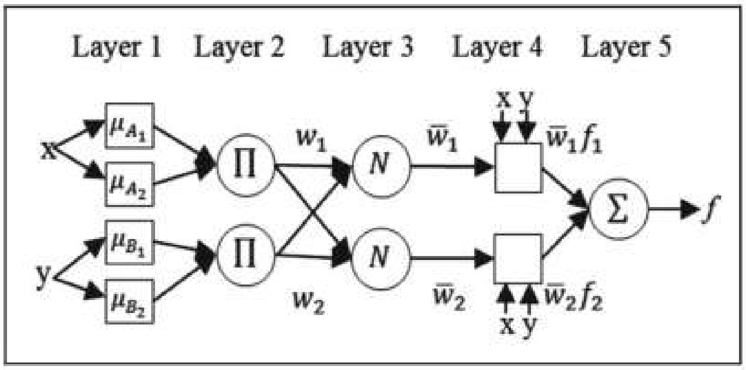

Figure 3: ANFIS architecture

A membership function, such as a triangle, trapezoid, gaussian, etc., is represented by the node i in Layer 1. For example, if µA1, µA2 and µB1, µB2 are the membership functions of gaussian shape with two parameters center (c) and width (σ).

In Layer 2, the firing strength of a rule is determined via the product Π operation. The third layer is the rule's firing strength normalised by the second layer. In the fourth layer, the nodes stand in for the outcomes of the fuzzy rule. Rule consequent linear coefficients may be learned. Defuzzification of the subsequent portion of rules is carried out by nodes in Layer 5 by adding the results of each rule.

ANFIS CONTROLLER WITH A PWM (PULSE WIDTH MODULATION):

Generator is a widely used control approach in power electronics and renewable energy systems. It combines the decision-making flexibility of ANFIS with the precision of PWM signal generation, enabling efficient control of power converters and related components in complex systems.

PWM Generator:

- **Purpose**: Converts the continuous control signal from the FLC into discrete pulses that drive switching devices such as IGBTs or MOSFETs in inverters, converters, or other power electronic systems.
- **Pulse Generation**: The PWM generator compares the FLC output signal with a high-frequency carrier waveform (e.g., a triangular wave). When the FLC output exceeds the carrier signal, a pulse is generated. The width of the pulse is proportional to the magnitude of the FLC output, thereby controlling the energy transfer.
- **Switching Control**: These pulses directly control the switching of power devices, enabling dynamic regulation of output voltage, current, or power.

Adaptive Neuro Fuzzy System (ANFIS) with a PWM (Pulse Width Modulation :

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ADAPTIVE-NEURO FUZZY INFERENCE SYSTEM (ANFIS):

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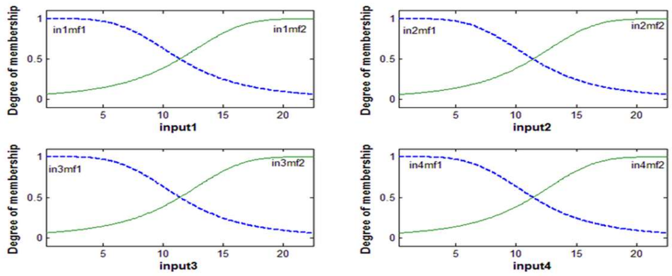

Figure 4 basic shapes of membership functions

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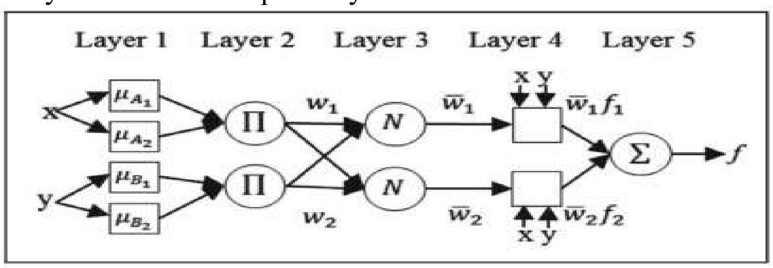

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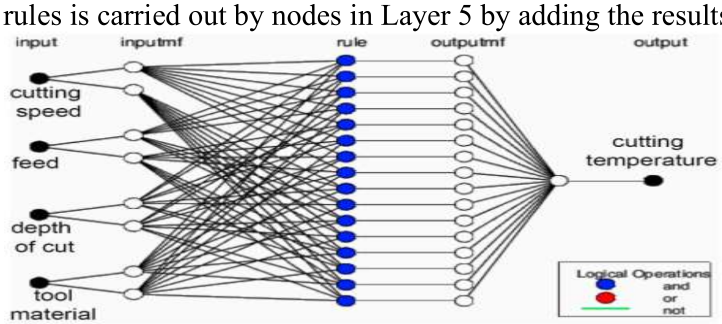

Figure 6 Adaptive fuzzy inference systems

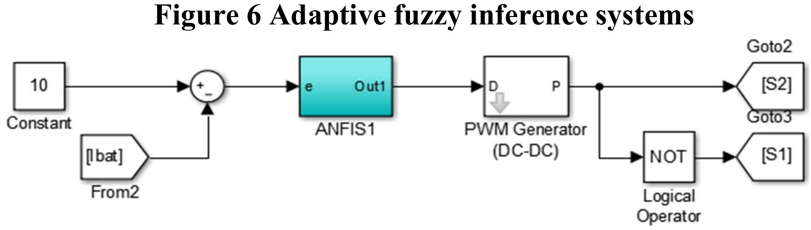

Figure 7: Adaptive Neuro Fuzzy System with PWM Generator

An Adaptive Neuro Fuzzy Inference System (ANFIS) is a computational model that merges neural networks and fuzzy logic to leverage their respective strengths. This approach enables ANFIS to utilize the approximate reasoning capabilities of fuzzy systems and adapt from data-driven features inherent in neural networks. The result is a versatile system capable of modeling complex nonlinear relationships that might be challenging with traditional method.

III. SIMULATION MODEL &DESCRIPTION :

The transition to sustainable energy systems has accelerated the adoption of electric vehicles (EVs) as a viable alternative to traditional fossil-fuel-based transportation. The integration of EVs with the power grid, known as Grid-to-Vehicle (G2V) systems, has emerged as a crucial component in this transformation. G2V systems enable the efficient transfer of electricity from the grid to EV batteries, supporting the dual objectives of meeting transportation energy demands and optimizing grid operations.

As the penetration of EVs continues to rise, their charging infrastructure introduces both opportunities and challenges for power grid stability and efficiency. A G2V system facilitates the seamless charging of EVs, leveraging smart grid technologies to ensure efficient energy management. However, challenges such as grid overloading, voltage fluctuations, and harmonic distortion must be addressed to prevent adverse impacts on power quality.

To overcome these challenges, advanced control mechanisms and intelligent energy management strategies are essential. Fuzzy logic controllers (FLCs) and other optimization techniques have proven effective in addressing the dynamic and nonlinear nature of G2V systems. By managing real-time charging demands, minimizing grid disturbances, and integrating renewable energy sources, G2V systems can contribute to building a resilient and sustainable energy ecosystem.

This research explores the design and optimization of Grid-to-Vehicle integration systems, focusing on their role in improving power quality, enhancing grid efficiency, and enabling the widespread adoption of EVs. By examining the interplay between advanced control systems and power electronics, this study aims to propose innovative solutions that align with the goals of smart grids and sustainable transportation.

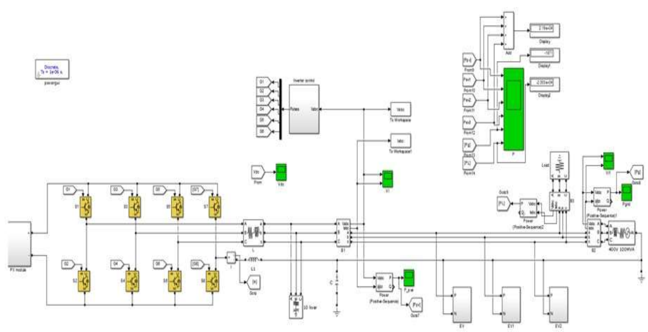

Figure 8: Simulation Model of Smart Grid and EV integration system with controllers and loads

The Electric Vehicle (EV) Circuit Structure with MOSFET Switch is commonly used in the power electronics system of EVs, particularly in battery charging circuits, inverters, and motor controllers. MOSFETs (Metal-Oxide-Semiconductor Field-Effect Transistors) are preferred in these applications due to their high efficiency, fast switching capabilities, and ability to handle high currents and voltages.

PROPOSED MULTILEVEL CONVERTER :

MLIs have a significant advantage over two-level inverters, including lower *dv/dt*, less electromagnetic interference, improved harmonic performance and reduced output filter size. NPC inverter, FC inverter and CHB inverters are three of the earliest well-established inverter topologies that have been around for a long time. These conventional topologies each have their own set of advantages and disadvantages. In the case of NPC and FC suffer the capacitor voltage balancing issues and require a complex control strategy to balance the capacitor voltage.

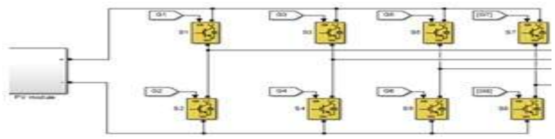

Figure 9: Multi-level Inverter

The number of clamping diodes and capacitors required increases as the voltage levels increase. To synthesize a multistep voltage waveform, Separate dc sources are required for the CHB inverter and consequently, the voltage gain in all the classical topologies is limited to one. To address these difficulties, the concept of switched DC source and reduced device count to maximize the voltage level have been investigated, as they provide a compact architecture that reduces the systems cost and control complexity. Existing topologies have the problem of voltage boosting capabilities. Novel topologies based on a Switched Capacitor (SC) are being researched to improve boosting ability and significantly reduce the number of devices further. Figure 4.3 shows the proposed PV module integrated with a modular multilevel converter.

This diagram appears to depict a photovoltaic (PV) module integrated with a MMC or a switching circuit, commonly used in applications such **as** DC-DC converters, inverters, or maximum power point tracking (MPPT)**.** Let me explain its components and functionality step by step.

EV CIRCUIT STRUCTURE:

The number of clamping diodes and capacitors required increases as the voltage levels increase. To synthesize a multistep voltage waveform, Separate dc sources are required for the CHB inverter and consequently, the voltage gain in all the classical topologies is limited to one. To address these difficulties, the concept of switched DC source and reduced device count to maximize the voltage level have been investigated, as they provide a compact architecture that reduces the systems cost and control complexity. Existing topologies have the problem of voltage boosting capabilities. Novel topologies based on a Switched Capacitor (SC) are being researched to improve boosting ability and significantly reduce the number of devices further. Figure 4.4 shows the proposed PV module integrated with a modular multilevel converter.

This diagram represents a battery charging system designed to efficiently manage and regulate power delivery to a battery, possibly in a renewable energy application such as solar or wind power. The input power is supplied through terminals labeled P and N, which may come from a DC source or rectified AC. The Universal Bridge rectifies the input and provides a DC output, which is then filtered by an inductor (L) and capacitor (C) to smooth ripples and stabilize the voltage. A PWM (Pulse Width Modulation) Generator generates control signals for the switches (S1 and S2), which are part of a DC-DC converter. These switches regulate the current and voltage delivered to the battery through an additional inductor (Lb), which helps in efficient energy transfer and voltage regulation. Feedback loops using PI controllers (proportional-integral controllers) monitor the battery's voltage (Vbat) and current (Ibat) to ensure safe and optimized charging. The system prevents overcharging or excessive current by dynamically adjusting the operation of the switches based on the feedback signals. This configuration is well-suited for battery management in renewable energy systems, electric vehicles, or uninterruptible power supplies (UPS), ensuring reliable and efficient charging while protecting the battery.

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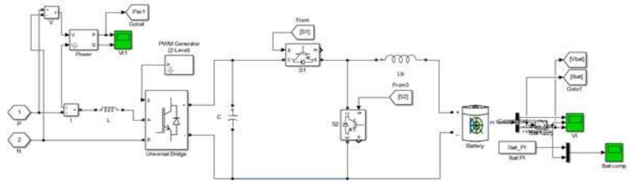

Figure 10:EV circuit structure with MOSFET Switch

SIMULATION RESULTS:

The details for each parameter are shown in Table 1, and the PV array irradiance is 1000, temp 35 with 6 parallel strings. The switching frequency is 10 kHz, whereas the grid frequency is 50Hz. A capacitor which is used with the C_i as 1000 uF and inductor 1 mH. For vehicle charging is performance use a lithium-ion battery where the nominal voltage of the battery is 400 V with rated capacity 90 Ah and response time 30 sec.

The characteristics of the PV array for the given solar irradiation can be observed in figure 11.

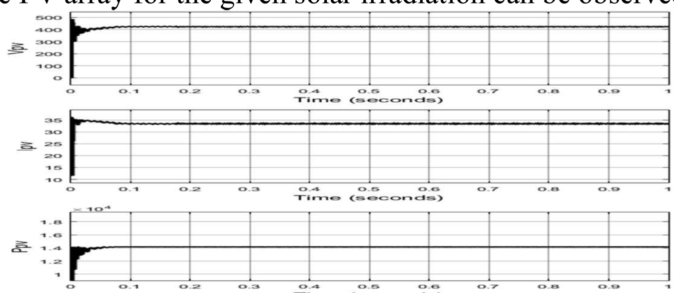

Figure 11: PV characteristics

The DC link voltage at the output of the PV array module is before the three phase four legged inverter. The value of the DC link voltage is noted to be 830V which is generated as per the requirement of the grid voltage of 440Vrms line voltage.

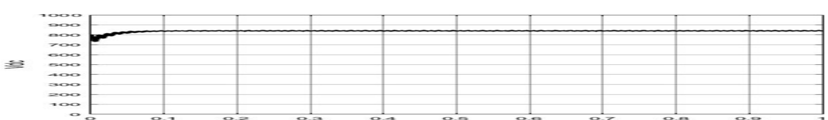

Figure 12: DC link voltage

The DC Link voltage is seen to be constant throughout the simulation of 1sec which reduced ripple content. The below figure 7 are the three phase voltages and currents of the PV inverter after the LC filter.

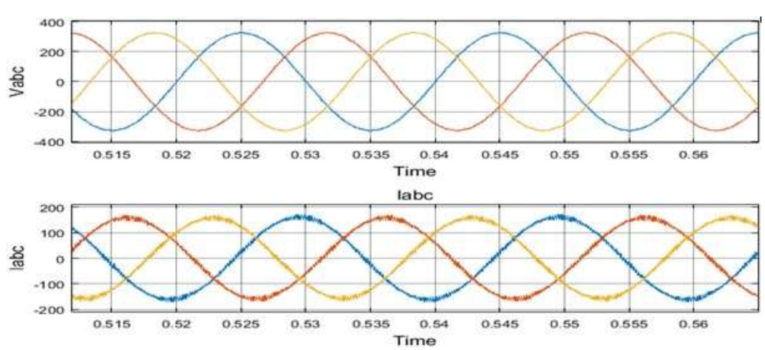

Figure 13: PV inverter three phase voltages and currents

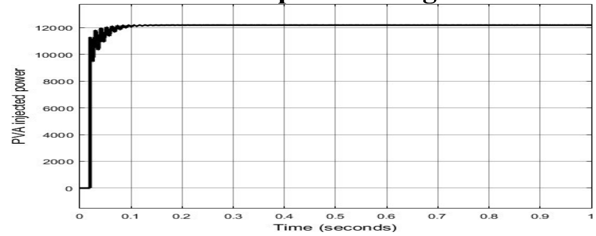

Figure 13: Power injected by the PV array module

The above figure depicts the total injected power of the PV array recorded to be 12kW. The PV array power either compensates the load demand or injected to the grid. The below graphs are the three phase voltages and currents of the grid.

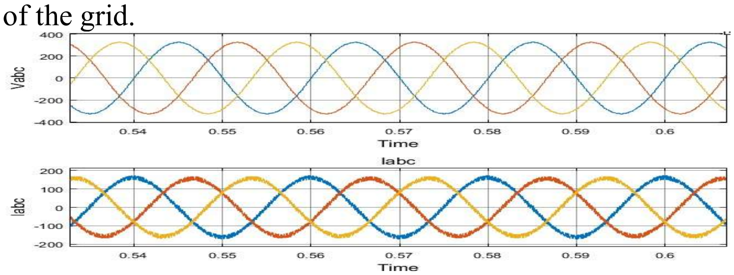

Figure 14: Grid voltages and currents

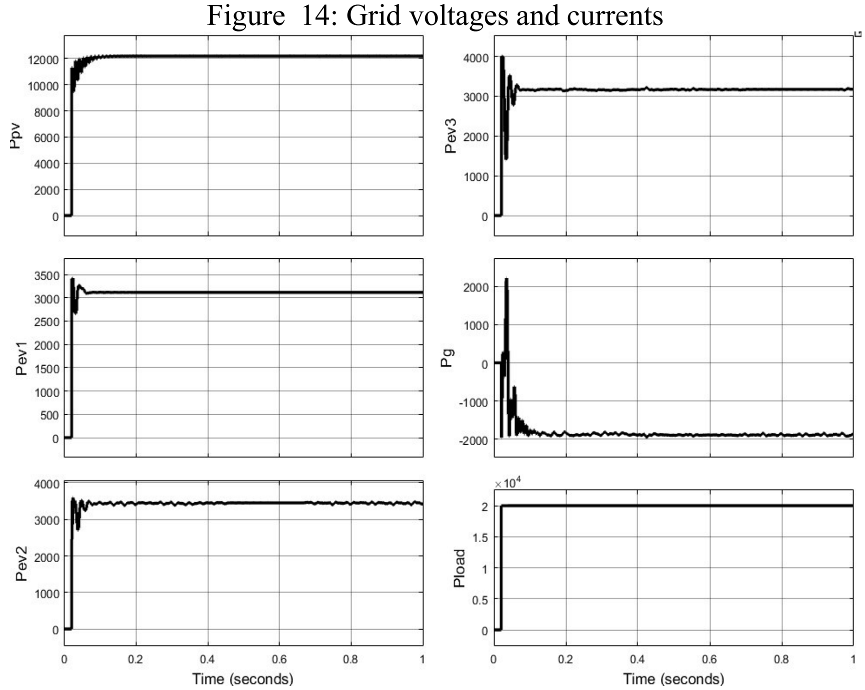

Figure 15: Active powers of all modules

All the above graphs are the active powers of PV array (Ppv) – 12kW, EV1 power (Pev1) – 3.1kW, EV2 power (Pev2) – 3.4kW, EV1 power (Pev1) – 3.1kW, Grid power (Pg) – „-2kW‟ and load power (Pload) - 20kW. The complete generated power from the PV array and the EV units is 12 + 3.3 + 3.4 + 3.3 = 22kW. From the 22kW of power extracted from PV array and EV units, 20kW is consumed by the load and the remaining power is injected to the grid with negative 2kW power reading denoting absorption. The figure 16 and 17 are the THDs of the PCC voltage and PV inverter current noted to be 0.75% and 3.63% respectively. These harmonics are very low and are maintained below 5% as per IEEE standard.

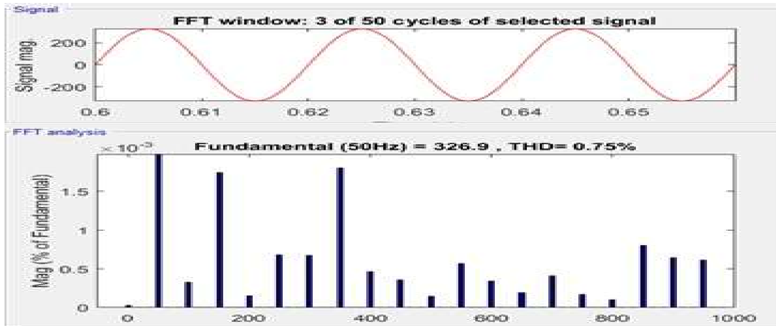

Figure 16: THD of PCC voltage

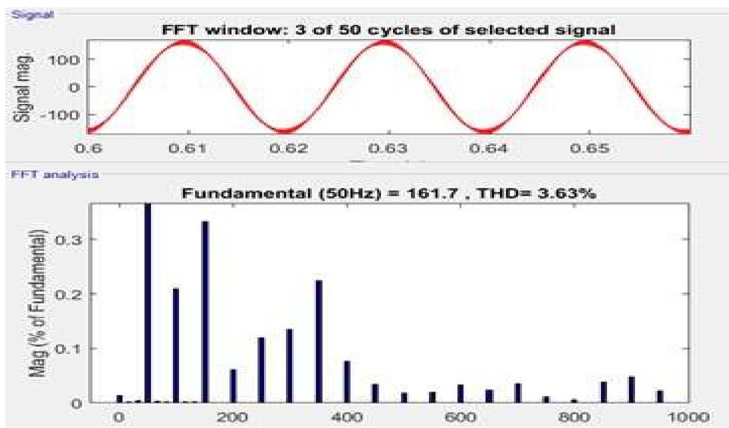

Figure 17: THD of PV inverter current

The below figure is the rules of the anfis controller integrated in the EV unit for current control of the EV battery. There are 7 rules set with seven membership functions in each input and output variable.

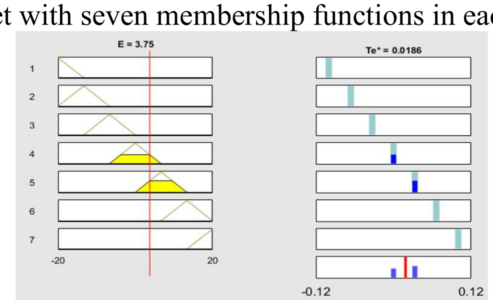

Figure 18: ANFIS Rules

The figure 19 is the EV battery comparison at the initial condition showing a drastic drop in initial peak overshoot with ANFIS Logic controller.

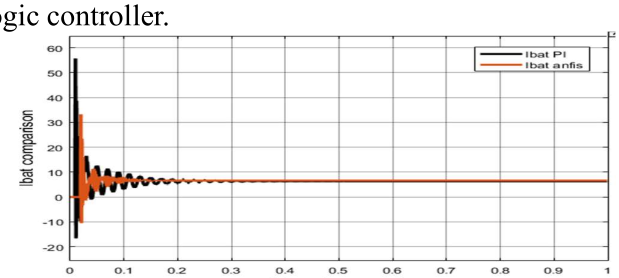

Figure 19: EV battery initial comparison Between PI and Anfis

CONCLUSION :

In this report an optimized design for developing power electronic converters that facilitate dual-way power transfer in a smart grid-based solar photovoltaic (SPV) building, enhancing both power loading/unloading capabilities and power quality. Additionally, the solar electric power generation system powers the batteries of electric vehicles (EVs) stored at the base of a modern building. The findings indicate that the SPV system effectively transmits power to the AC mains, while a three-phase voltage source converter (VSC) manages the DC-Link voltage. The batteries of the EVs and plug-in hybrid electric vehicles (PHEVs) are charged and discharged as needed. During peak solar intensity, a portion of the SPV current is utilized to charge the EVs and PHEV batteries. The simulation network is designed to evaluate the phase voltage and current components under non-linear load conditions. The total power injected from the PV array is recorded at 12 kW, with the average power contribution from the EVs being 3 kW. The total harmonic distortion (THD) values for the point of common coupling (PCC) voltage and inverter current are measured at 0.75% and 3.63%, respectively. These THD values are within the permissible limits set by IEEE 519 standards, which allow up to 5%. The results demonstrate that the integration of the smart grid and electric vehicle systems has improved power quality, power factor compensation, and voltage regulation. Furthermore, using a ANFIS controller has reduced the ripple, peak overshoot, and settling time in the EV battery current.

FUTURE SCOPE:

As a result, a new topology is created by formulaic modifying the matrix structure to mimic the high level ac output voltage of SDCs. Comparatively, the number of SDCs and semiconductor switches in the MMSMLI circuit is lower than in the comparable MLI topologies that are currently in use. To eliminate conduction losses, the number of switches in the current (conduction) path at each output level is effectively reduced.

The PV array renewable source system can be updated with multiple renewable sources like wind farm, fuel cell system, battery storage module for better power sharing and stability of the system. The number of EV modules connected can be increased for more EV power sharing to the grid for optimal power consumption. The ANFIS controller in the EV module can be updated with advanced control techniques like adaptive and hybrid controllers for more reduced ripple and overshoot times.

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