Design and modelling of solar and Hybrid power based EV charging station using ANFIS controller.

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***Abstract*- As escalation of air pollution and the rising cost of petrol and diesel, individuals are transitioning towards electric vehicles (EVs). This paper presents a novel approach to integrating controls for the purpose of enabling uninterrupted charging in various modes, including islanded, grid-connected, and DG set connected modes. The system under consideration employs a solar photovoltaic (PV) array, a battery-powered energy storage (BPES), a diesel generator (DG), and a grid-power electric vehicle (EV) charging station (CS). In instances where solar energy is accessible, the system will utilise this renewable source of energy to directly charge the electric vehicle. In the absence of solar energy, the system draws power from either the grid or a DG source. The integration of an Adaptive Neuro-Fuzzy Inference System (ANFIS) controller into the system is aimed at achieving efficient and optimal operation. The ANFIS controller has been formulated based on historical data pertaining to solar irradiation, electric vehicle charging patterns, and meteorological forecasts. The findings indicate that the charging station proposed in the study is capable of delivering consistent and environmentally-friendly energy to electric vehicles, while minimising reliance on the diesel generator. The efficacy and dependability of the system are assessed via simulations for performance evaluation purposes. The method's performance is assessed through the utilisation of Matlab/Simulink software.**

Keywords— Electric vehicle (EV), Battery-powered energy storage (BPES), charging station (CS), ANFIS.

I. Introduction

At present, electric vehicles (EVs) are widely acknowledged as a highly efficient and environmentally friendly mode of transportation. At present, there are approximately 16.5 million electric vehicles (EVs) in operation. It is projected that by the year 2030, the number of EVs in use will increase significantly to approximately 300 million, owing to their numerous benefits Research has indicated that electric vehicles (EVs) possess the capability to reduce carbon emissions by 45% in comparison to conventional internal combustion engine (ICE) vehicles.[2]. However, there exist several challenges that need to be addressed in order to achieve the desired goals. Among the range of renewable energy sources presently available, solar photovoltaic (PV) arrays are deemed the most pragmatic option for electric vehicle (EV) charging. This assertion is based on the comparative analysis of other renewable energy sources such as wind energy, hydroenergy, and fuel cell-based energy. The utilisation of solar energy for power generation has become increasingly prevalent relative to alternative sources of energy due to its convenience, cleanliness, lack of reliance on raw materials, environmental safety, and the decreasing costs associated with solar photovoltaic panels. [3][4]. Consequently, the integration of a photovoltaic (PV) array directly into the infrastructure for electric vehicle (EV) charging represents a promising approach to enhance the efficacy of EV emission mitigation and decrease dependence on the power grid. [5],[6]. The deployment of storage technologies such as batteries is necessary to mitigate the fluctuating power output of renewable energy sources, particularly solar photovoltaic (PV), which lacks consistency. [7]. The integration of renewable energy-based charging stations (CSs) into the current system introduces an additional power conversion stage, thereby increasing system complexity and resulting in greater power loss. Nonetheless, such CSs remain the most feasible approach for electric vehicle (EV) charging.

However, Numerous studies have been conducted to advance the utilisation of renewable energy sources in the field of computer science. Chandra Mouli *et al* [8]. The utilisation of a bidirectional EV charger with high power capacity was employed to facilitate the charging of electric vehicles through the utilisation of solar energy. however, it does not provide alternating current (AC) charging capabilities. Monteiro *et al.* [9] The study exhibited a three-port converter that establishes a connection between a solar panel array and an electric vehicle (EV) charger. Nonetheless, the proposed charger fails to consider the grid current distortions induced by the charger. Singh *et al.*[10] presented a modified z-source converter was proposed for the purpose of developing a grid-connected electric vehicle charger utilising a photovoltaic array. It should be noted that the charger is not designed to function in an islanded mode. Consequently, in the event of the lack of a grid, the system is incapable of furnishing electric vehicle charging. B.Singh *et al* [11] A proposal has been suggested whereby electric vehicle charging stations are powered by solar photovoltaic technology and a BPES. In the absence of these sources, the charging stations are supplied by the grid and a diesel generator to meet the required energy demand. In paper [12] The implementation of a grid-connected electric vehicle (EV) charging station has been suggested, whereby a control mechanism has been employed to reduce load demand and load variations on the grid. In paper [13] and [14], The article elucidates on the ANFIS algorithm, which exhibits superior dynamic and steady state performance in comparison to the conventional PI controller.

In this article, following are the main contributions:

1. The integration of the grid with a charging station is facilitated through the implementation of a photovoltaic (PV) array, an energy storage system, and a distributed generation (DG) set. This system enables the simultaneous direct current (dc) and alternating current (ac) charging of electric vehicles (EVs) through a unified voltage sources converter.
2. The charging station receives a three-phase grid supply for the purpose of battery charging during periods of solar energy unavailability.
3. The control algorithm of the charging station prioritises the utilisation of energy resources. The initial step involves harnessing energy from both the solar photovoltaic (PV) array and the storage batteries. In cases where solar energy is unavailable, the charging of electric vehicles may rely on power drawn from the grid or, as a last resort, from a diesel generator.

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4. The estimation of the reference sinusoidal current during power draw from the grid or the DG is facilitated by the utilisation of the ANC filter, which effectively segregates the active and reactive constituents of the EV current. This guarantees that solely the active power is consumed from either the grid or the DG.
5. Design of anfis controller to regulates the charging procedure and ensures safe and effective charging of the battery.
6. It is imperative to ensure that the DG set is operating at maximum efficiency and is fully loaded prior to extracting power from it.

II. SYSTEM DESCRIPTION

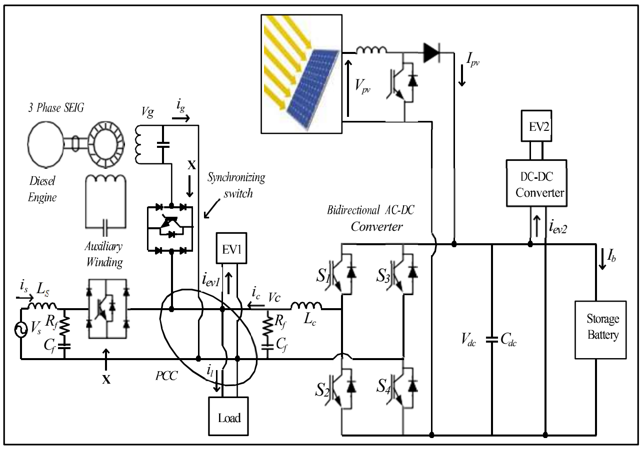

Fig. 1. Topology of charging station

The charging station depicted in Figure 1 employs a solar photovoltaic (PV) array, a storage battery, a diesel generator (DG) set, and grid energy to facilitate the charging of electric vehicles and provision of power to associated loads. The solar photovoltaic (PV) array is linked to the direct current (DC) link of the voltage source converter (VSC) via a boost converter, while the storage battery is directly connected to the DC link. The AC side of the VSC is connected by a coupling inductor to various components, including a single-phase SEIG (Self Excited Induction Generator), an EV, and a nonlinear load. The utilisation of a ripple filter at PCC facilitates the conversion of switching harmonics to sinusoidal currents in both the grid and generator. The self-excited induction generator (SEIG) features an auxiliary winding that is linked to an excitation capacitor. Furthermore, a small capacitor is connected in parallel with the main winding of the Self-Excited Induction Generator (SEIG).

III. CONTROL ALGORITHM

A. Control of VSC in Islanded Mode (Absence of DGand Grid power)

The control logic of the proposed charging station is depicted in Figures 2-3, with the aim of ensuring optimal and uninterrupted functionality of the charging station. Figure 2 depicts the schematic for the off-grid mode of operation. Once the solar photovoltaic (PV) array and storage battery have accumulated sufficient power to both charge the EV1 and provide for the load, the system enters into this operational mode. The charging station generates an alternating current (AC) voltage of 220 volts and a frequency of 50 hertz at the point of common coupling (PCC) for this specific objective. The digital controller obtains the switching signals for the voltage source converter (VSC) by utilising the reference voltage at the point of common coupling (PCC) generated by the off-grid control. Figure 2 depicts the control methodology employed to achieve synchronisation between the off-grid point of common coupling (PCC) voltage and the grid voltageThe algorithm for control computes the discrepancy and approximates the stage of two volts. In order to minimise the level of error, a proportional integral (PI) controller is utilised. The VSC's operational frequency is determined by utilising the PI controller's output. Subsequently, the controller generates a reference voltage with a modified frequency.

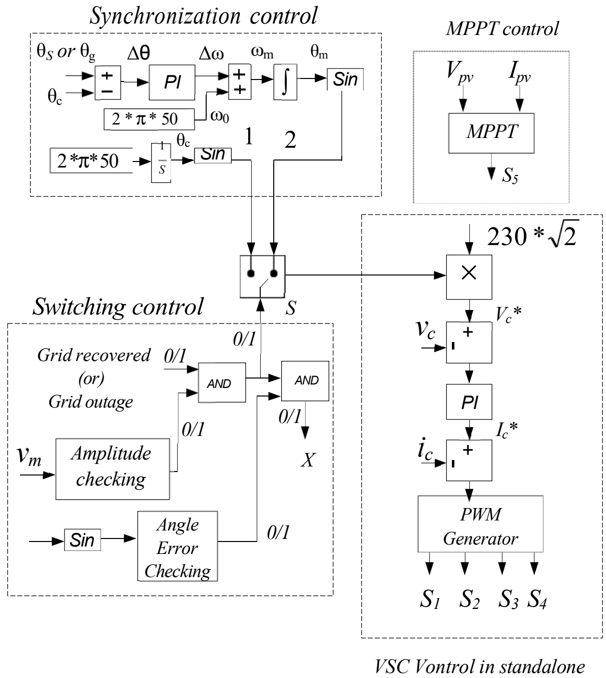

Fig 2. Integrated VSC control for standalone

A. Control of VSC in DG Set or Grid Connected Mode

Figure 3 illustrates the control methodology utilised for the voltage source converter (VSC) when operating in a grid-connected mode. The implementation of voltage source converter (VSC) guarantees the maintenance of sinusoidal current in the generator (i_g) or grid (i_s). To accomplish this task, the control algorithm computes the active (i_{ep}) and reactive (i_{eq}) components of the total current. The present scenario utilises the control technique that is based on adaptive noise cancellation (ANC). The estimation of the reference generator (i_g)or grid current(i_s)and the subsequent generation of switching pulses for the voltage source converter (VSC) are accomplished through the utilisation of i_{ep} and i_{eq}. The control system incorporates a voltage and frequency control loop to regulate the voltage and frequency of the generator. The voltage regulation is achieved through the implementation of an anfis controller, while frequency regulation is accomplished via a PI controller.

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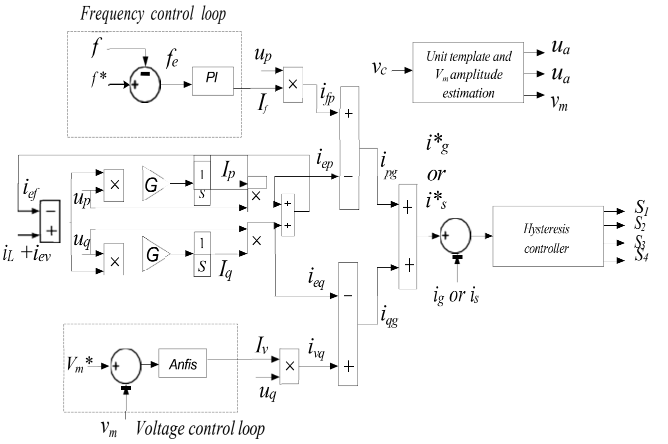


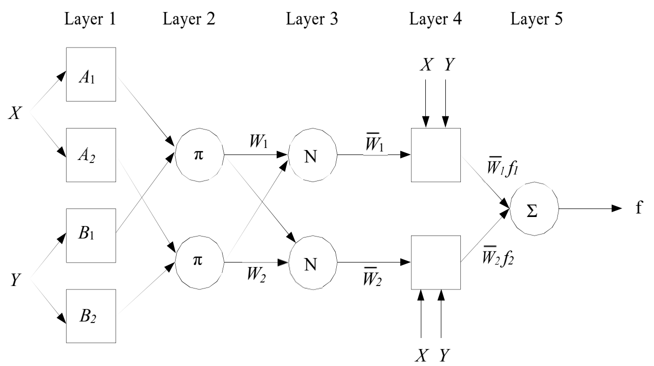
Fig. 3. VSC for grid and DG set connected mode.

B. ANFIS Control design

The control unit utilises an ANFIS controller, which is a neurofuzzy system that is based on Takagi and Sugeno's technique. This methodology aptly illustrates the correlation between the input and output. [15]

- Figure 3 depicts the fundamental model architecture of ANFIS. The model in question comprises two distinct inputs, namely error (x) and the rate of change of error (y). The linguistic variables x and y are assigned fuzzy membership functions A and B, respectively. The variable q denotes the cumulative sum of membership functions that are attributed to input nodes situated within a common layer and that correspond to analogous functions. The rectangular shape is indicative of nodes that are adaptive in nature, while the circular shape is representative of nodes that are fixed. The firing strength of each rule is denoted by $W1$, while W2 represents the normalised firing strength. The functions fi can be characterised as linear consequent functions of the variables x and y.

Basic architecture of ANFIS.



- The layer 1 is fuzzification layer. This layer is used to determine the membership function value (μ) that corresponds to a given set of inputs.
- In layer 2, the product of the membership function is used to calculate the firing strength of the rules

$$W_i = \mu_{A_i}(x) \times \mu_{B_i}(y)$$

- In layer 3. The calculation of the normalised firing strength of each rule is performed.

$$\overline{W}_1 = \frac{w_1}{w_1 + w_2}$$

- The output of layer 4 is determined by multiplying the firing strength with the output of the corresponding firing rule.

$$O_{4,i} = \overline{W}_i \times f_i$$

- Layer 5 is the result of aggregating the output generated by layer 4, thereby yielding the final output.

$$O_5 = \overline{W}_1 f_1 + \overline{W}_2 f_2$$

- The efficacy of the ANFIS controller is contingent upon the transfer function coefficients, namely ai, bi, and ci, as well as the distribution of membership functions for the inputs x and y.

IV. RESULT AND DISCUSSION

A. Simulation result

The simulation results depicted in Figures 4 and 5 provide evidence of the continuous functioning of the CS. The computer system (CS) is operating in an isolated state at first, whereby the electric vehicles (EVs) linked to the point of common coupling (PCC) are charged using the power supplied by the photovoltaic (PV) array. The surplus power produced by the photovoltaic (PV) array is stored in an energy storage system due to the fact that the amount of energy generated exceeds the demand required for charging electric vehicles (EVs).

The solar irradiance undergoes a fluctuation ranging from 1000 W/m2 to 300 W/m2 within a time interval of 0.32 seconds. Consequently, the output of the photovoltaic (PV) array decreases, leading to the discharge of the storage battery to ensure continuous charging. At 0.48 seconds, the storage battery is depleted due to the reduction of power to zero in the PV array.

The charging process of the storage battery is fully enabled, provided that the state of charge (SoC) is greater than the minimum state of charge (SoC min). Upon complete discharge of the battery, the controller facilitates synchronisation of the CS with the grid. At 0.79 seconds, the utilisation of grid electricity was initiated by the CS. Following the depletion of grid and storage battery power, the provision of continuous power supply is facilitated by the DG set, as illustrated in Figure 4. As depicted in Figure 4, the charging station undergoes automatic mode changes in response to variations in both energy generation and demand.

The utilisation of an Anfis controller, as opposed to a PI controller, yields superior precision and reduced harmonics of both grid current and grid voltage. The THD value of (ig) is 2.87% and that of (vg) is 0.48%.

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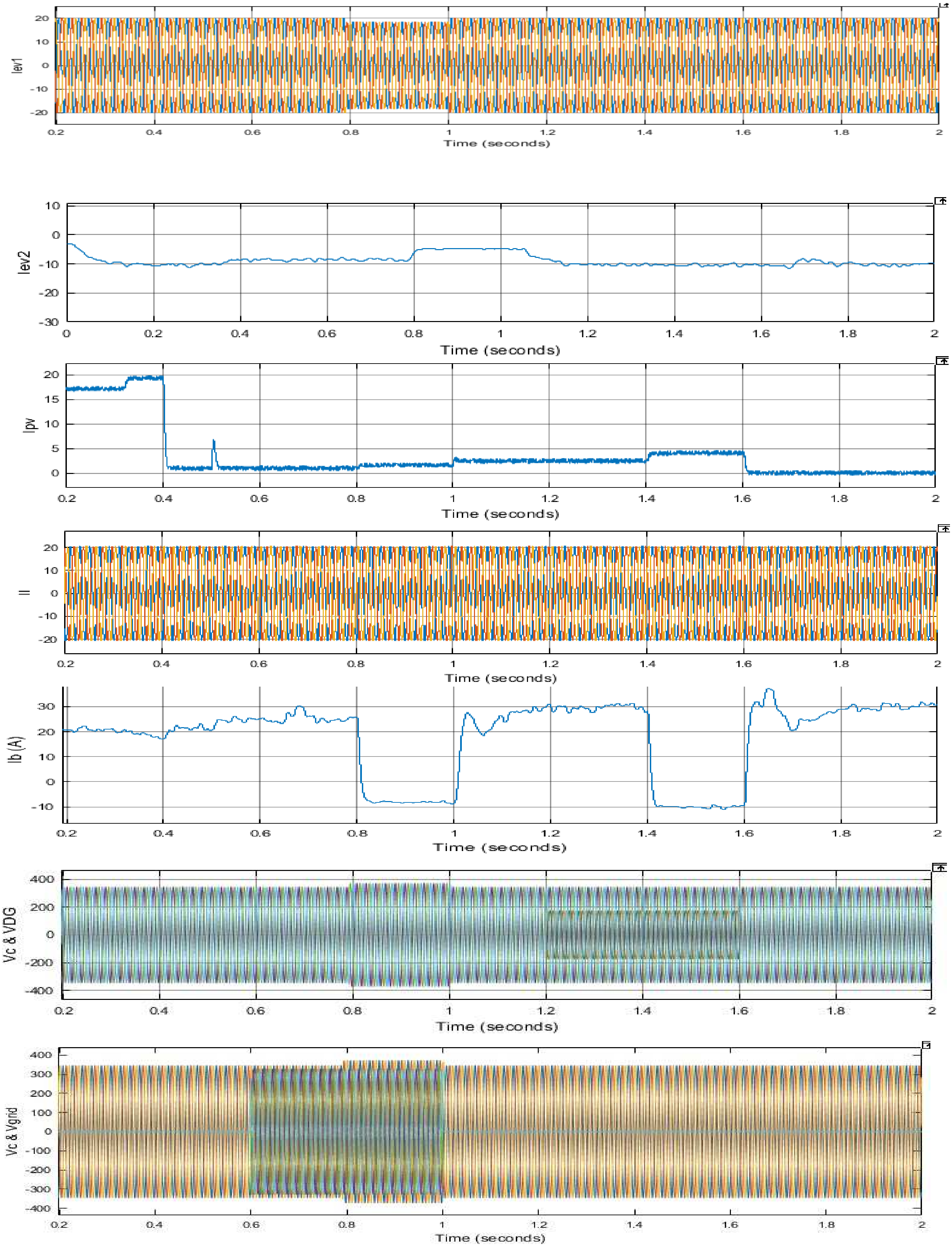

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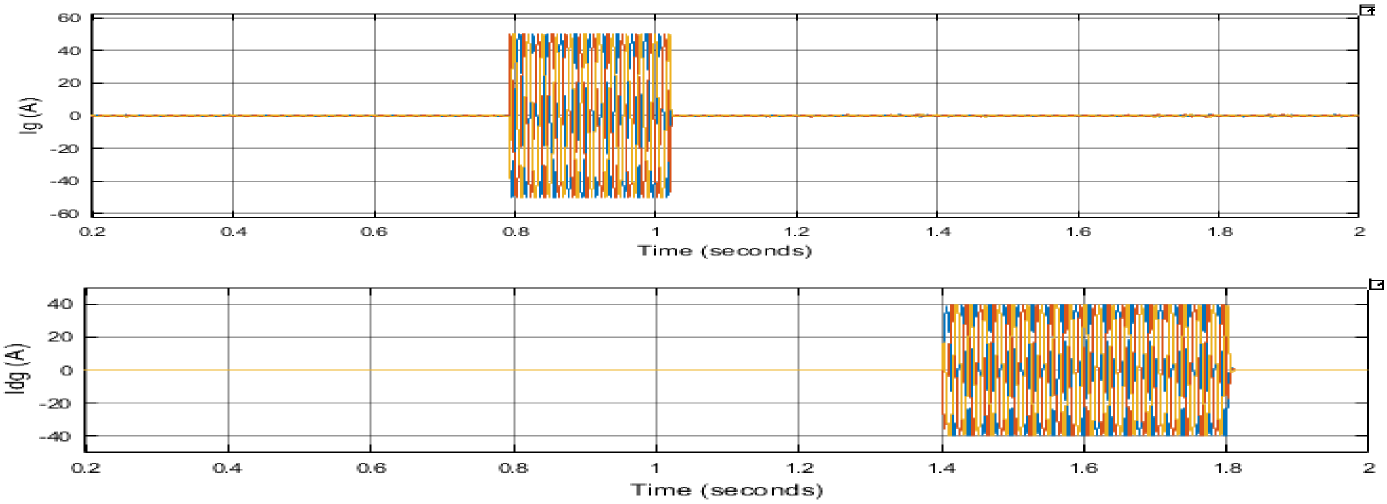

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Fig. 4. Simulations result of various modes of operation

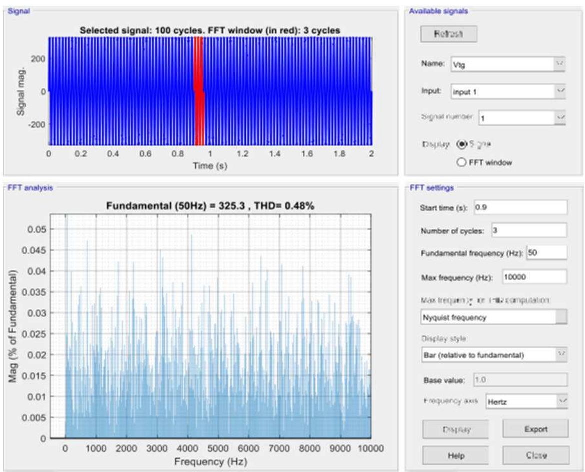

Fig. 5a. THD of Vg

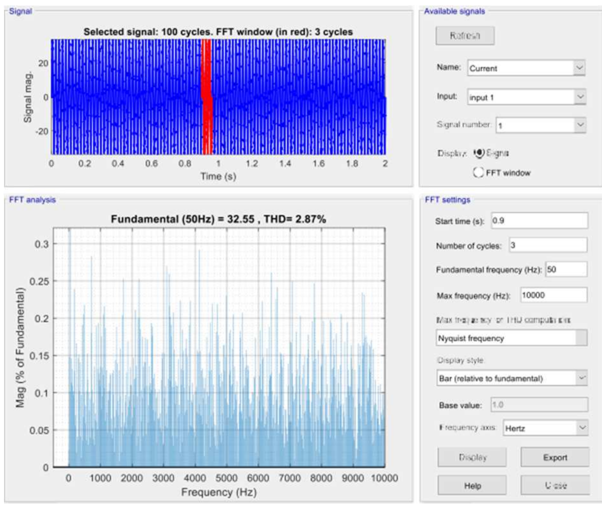

Fig. 5b. THD of Ig

V. CONCLUSION

The implementation of electric vehicle charging stations has been carried out utilising various sources of energy such as solar photovoltaic systems, storage batteries, the grid, and distributed generation sets. The findings presented herein have validated the utilisation of an ANFIS controller in the development and implementation of a Solar PV-Battery and Diesel Generator-Powered Electric Vehicle Charging Station. The utilisation of the ANFIS controller is aimed at optimising the charging process of electric vehicles, with the objective of achieving efficient charging while minimising the adverse effects on the grid. The successful accomplishment of this project has the potential to inspire forthcoming initiatives pertaining to electric vehicle charging stations, mitigate greenhouse gas emissions, and promote the adoption of more sustainable energy sources.

VI. FUTURE WORK

The Anfis controller is replaced with a multilayer converter or a neural network controller to increase the performance of the controller.

VII. REFERENCES

[1] IEA (2022), Electric Vehicles, IEA, Paris https://www.iea.org/reports/electric-vehicles, License: CC BY 4.0

[2] X. Zhang, F. Gao, X. Gong, Z. Wang, and Y. Liu, ‘‘Comparison of climate change impact between power system of electric vehicles and internal combustion engine vehicles,’’ in Advances in Energy and Environmental Materials. Singapore: Springer, 2018, pp. 739–747

[3] S. Bhadra, P. Mukhopadhyay, S. Bhattacharya, S. Debnath, S. Jhampati and A. Chandra, "Design and Development of Solar Power Hybrid Electric Vehicles Charging Station," 2020 IEEE 1st International Conference for Convergence in Engineering (ICCE), Kolkata, India, 2020, pp. 285-289, doi:10.1109/ICCE50343.2020.9290651.

[4] S. K. Ram et al., "Analysis of Interleaved DC-DC Converter using ANFIS Control for EV Charging Applications," 2021 6th International Conference on Inventive Computation Technologies (ICICT), Coimbatore, India, 2021, pp. 374-378, doi: 10.1109/ICICT50816.2021.9358606.

[5] K. Chaudhari, A. Ukil, K. N. Kumar, U. Manandhar and S. K. Kollimalla, “Hybrid Optimization for Economic Deployment of ESS in PV-Integrated EV Charging Stations,” IEEE Trans. Ind. Informat., vol. 14, no. 1, pp. 106-116, Jan. 2018

[6] D. Schürmann, J. Timpner and L. Wolf, “Cooperative Charging in Residential Areas,” IEEE Trans. Intelligent Transportat. Sys., vol. 18, no. 4, pp. 834-846, 2017.

[7] N. Saxena, I. Hussain, B. Singh, and A. L. Vyas, “Implementation of a grid-integrated PV-battery system

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for residential and electrical vehicle applications," IEEE Trans. Ind. Electron., vol. 65, no. 8, pp. 6592–6601, Aug.

[8] G. R. Chandra Mouli, J. Schijffelen, M. van den Heuvel, M. Kardolus, and P. Bauer, "A 10 kW solar-powered bidirectional EV charger compatible with chademo and COMBO," IEEE Trans, Power Electron., vol. 34, no. 2, pp. 1082–1098, Feb. 2019.

[9] V. Monteiro, J. G. Pinto, and J. L. Afonso, "Experimental validation of a three-port integrated topology to interface electric vehicles and renew ables with the electrical grid," IEEE Trans. Ind. Inform., vol. 14, no. 6, pp. 2364–2374, Jun. 2018.

[10] S. A. Singh, G. Carli, N. A. Azeez, and S. S. Williamson, "Modeling, design, control, and implementation of a modified Z- source integrated PV/Grid/EV DC charger/inverter," IEEE Trans. Ind. Electron., vol. 65, no. 6, pp. 5213–5220, Jun. 2018

[11] B. Singh, A. Verma, A. Chandra and K. Al-Haddad, "Implementation of Solar PV-Battery and Diesel Generator Based Electric Vehicle Charging Station," 2018 IEEE International Conference on Power Electronics, Drives and Energy Systems (PEDES), Chennai, India, 2018, pp. 1-6

[12] R. R. Deshmukh and M. S. Ballal, "An energy management scheme for grid connected EVs charging stations," 2018 International Conference on Power, Instrumentation, Control and Computing (PICC), Thrissur, 2018, pp. 1-6.

[13] Darvill, A. Tisan and M. Cirstea, "An ANFIS-PI based boost converter control scheme," 2015 IEEE 13th International Conference on Industrial Informatics (INDIN), Cambridge, 2015, pp. 632-639

[14] U. A. Shaikh, M. K. AlGhamdi and H. A. AlZaher, "Novel product ANFIS-PID hybrid controller for buck converters," in The Journal of Engineering, vol. 2018, no. 8, pp. 730-734, 8 2018.

[15] A. Saware, N. Gavkar, S. Shinde and P. Kulkarni, "Performance Improvement of PID Controller for PMSM Using ANFIS Controller," 2022 International Conference on Intelligent Controller and Computing for Smart Power (ICICCSP), Hyderabad, India, 2022, pp. 1-6, doi: 10.1109/ICICCSP53532.2022.9862372.

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