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ANFIS-Controlled Multifunctional Onboard Converter in Grid- and Solar PV-Powered Electric Vehicles

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ABSTRACT - In this paper, a multifunctional onboard converter for integrating solar photovoltaic (PV) power and utility grid for EV charging applications using an ANFIS is presented. Multiple operating modes of converter – such as grid-to-vehicle charging, solar PV charging, propulsion and regenerative braking – are used with a single topology. Proposed intelligent controller based on ANFIS is able to control power flow intelligently by maintaining steady DC-link voltage and adjusting it according to solar irradiances, battery SOC and grid conditions. Compared to traditional control methods, adaptive control strategy offers better transient response, voltage fluctuation, switching stress, and power conversion efficiency. Performance of proposed system is tested using MATLAB/Simulink with different operating conditions. Based on simulation results, converter performs an effective energy management, stable voltage regulation, soft mode switching and reliable charging operation. Solution proposed is an efficient, intelligent and sustainable method for charging on board next generation of electric vehicles using both solar PV and utility grid power sources.

KEYWORDS — Electric Vehicles, On-Board Chargers, Solar PV System, DC-DC Converter, Power Factor Correction, ANFIS

I. INTRODUCTION

This shift from Internal Combustion Engine to EV has been catalyzed by a range of factors, such as rapid growth in global energy demand, rising environmental concern and increasingly stringent emission regulations. EVs are seen as an integral component of sustainable transportation, for they are energy efficient and low in GHGs and reduce reliance on fossil fuels. Energy conversion efficiency, charging efficiency and power management of power electronic converters, however, are an important issue for effectiveness of EVs. Hence, research on modern EV charging systems aims at achieving the power electronic converter to have high reliability, efficiency and operational life [1]. The use of renewable energy like solar PV panels also adds to sustainability of EV charging stations.

Solar PV is clean and renewable, low impact on environment, has very good potential for transportation electrification. However, there are a lot of challenges involved in maintaining maximum energy extraction due to PV module's non-linear characteristics and irradiance and temperature dependency. Therefore, it is especially relevant to adopt correct MPPT algorithms, which guarantee the most efficient working of PV system in various environmental conditions [2]. With their safety, convenience and flexibility, wireless power transfer technologies are emerging as an appealing option for EV charging, in addition to traditional conductive charging. Wireless charging system has developed greatly in last few years and has had a high efficiency with good compatibility to the future intelligent transport systems. However, a stable and reliable charging performance still requires an effective power management, the converter design, and advanced control strategies [3].

The most important issue in grid connected charging system is power quality. Such high counts of power electronic converters can produce high level of harmonic distortions and poor converter power factor at input side of converter which can lead to less efficient and less stable grid. In order to meet international power quality standard, various topologies of advanced power factor corrections (PFC) converter have therefore been developed to minimize switching loss, reduce content of harmonics and improve efficiency of converter [4]. Moreover, a few enhanced MPPT algorithms are proposed to attain quicker tracking speed, less steady state oscillations and better PV utilization in event of fast changing weather conditions [5]. Today's converter control methods also include sophisticated PFC methods that help to keep DC output voltage regulated and converter stable when subjected to dynamics load changes [6].

The intelligent optimizing techniques have improved converter control significantly and adaptive parameter tuning and improved dynamic response have been achieved [7]. On the other hand, integrated EV powertrain technologies are advancing towards achieving multifunctional design of power converter that incorporates battery charging and propulsion / regenerative braking functions on a single power converter platform, thus minimizing number of components and enhancing

power density [8]. More flexibility and better energy utilization are achieved by multi-utility powertrain systems, where more than one electrical sub-system are combined in one system [9]. Artificial neural networks (ANNs) would be very useful for modelling of the non-linear characteristics of the converter and enhance its accuracy in converter control [10]. Advanced optimization assisted MPPT techniques have also been used to enhance PV performance under partial shading, thereby improving tracking accuracy, as well as convergence speed [11].
In addition, PV technology has been constantly evolving and level of energy conversion efficiency and reliability of PV systems has improved [12]. Similarly, energy harvesting optimization of complicated operating condition with metaheuristic optimization methods has proved very effective in minimizing PV power losses and maximizing energy harvesting [13]. The PV generation mixed with improved charging systems for EVs has contributed to developing charging infrastructure capable of renewables power for future smart city applications [14]. Furthermore, design and simulations of PFC converter using a proper mathematical model and simulation methods can be used to make converter to be more stable and efficient to operate [15].

However, conventional PI controlled multifunctional on-board converter has poor adaptability in nonlinear working state. On basis of this, this paper suggests a grid and solar PV powered electric vehicle's multifunctional onboard converter using Adaptive Neuro-Fuzzy Inference System. proposed intelligent controller will be able to provide better voltage regulation of DC link, better coordinated power sharing between PV source and grid, reduce harmonic distortion and provide stable operation during all charging, propulsion and regenerative braking modes. Various operating conditions are simulated in MATLAB/Simulink to test proposed approach and effectiveness of approach is validated.

II. SYSTEM DESCRIPTION

A. Proposed Hybrid EV Charging System

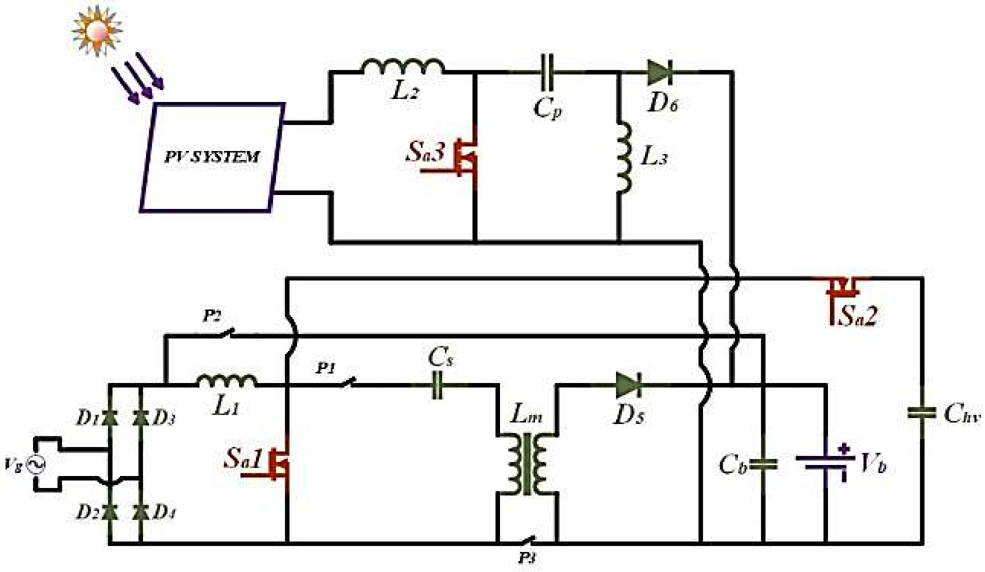

Figure 1: Proposed Multi-Port Isolated Hybrid EV Charging Converter Topology

The proposed system in Figure 1 is developed to provide an efficient and reliable charging solution for electric vehicles (EVs). It integrates solar power, battery energy storage and utility grid into one power conversion system. With help of system, available energy source will automatically be fully used to make sure of continuous charging under various operating conditions.

B. Grid Operation

If renewable energy is not available or inadequate, utility grid supplies power to charging system. Power provided by grid is changed into necessary voltage and voltage is controlled before it reaches output. This means that we are able to charge our EVs at any time, even in midst of heavy snow or rain.

C. Solar Energy Operation

Solar PV is prime energy source during day. Solar power generated is controlled and sent to charging system. By using solar energy whenever it is available, dependence on utility grid is reduced, thereby improving overall efficiency of system.

D. Battery Energy Storage Operation

ESS Stores excess energy produced by Solar PV system. If the solar generation level falls or is not available, stored energy is provided to charging system. This ensures uninterrupted power supply and enhances reliability of EV charging process.

E. Power Transfer Operation

The converter proposed facilitates transfer of energy from existing energy sources into EV charging unit efficiently. It controls power flow based on charging requirement and keeps voltage throughout system steady. This is a synchronized operation which optimizes energy use and minimizes power losses.

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The converter proposed facilitates transfer of energy from existing energy sources into EV charging unit efficiently. It controls power flow based on charging requirement and keeps voltage throughout system steady. This is a synchronized operation which optimizes energy use and minimizes power losses.

G. EV Charging Operation

Regulated DC output is provided to electric vehicle battery for charging. Converter keeps charging voltage and current constant, making it safe, efficient and reliable to charge. The power supplied from available energy sources automatically changes according to changing charge demand.

H. Operating Modes

Mode 1: Solar-Based Charging
With adequate sunlight, most or all of power needed for charging EVs is harnessed from PV system. Any surplus energy can be stored in battery.
Mode 2: Hybrid Charging
Solar generation is less than charging demand, battery and utility grid are combatted with PV system to provide required power. Most commonly used charging method is Grid and Battery Charging
Mode 3: Grid and Battery Charging
Battery and utility grid provide energy to sustain EV charging on a continuous basis during nighttime or in poor weather conditions (when solar power is not present).

Advantages of the Proposed System:

- Lives up to use of renewable energy in EV charging.
- Continuous charging in all operating conditions.
- Automatically shares power among available energy sources.
- Uses system to enhance its overall efficiency and reliability.
- Minimizes reliance on electricity grid.
- Gives a stable DC output for safe and efficient battery charging.

I. Overall Working Principle

The proposed hybrid EV charging system is always monitoring availability of solar energy, battery energy, and grid power. In normal cases, solar energy is considered as first choice for charging EV battery. If solar power isn't enough, energy is provided by battery storage system. If solar and battery energy are not enough to cover charging demand, utility grid supplies rest. Intelligent power sharing can keep power output voltage stable, and make system operate normally under any environmental conditions and load, providing uninterrupted, efficient and reliable operation of system. The Table 1 shows the System Parameters of the Proposed ANFIS-Based Multifunctional On-board Converter.

Table 1: System Parameters of the Proposed ANFIS-Based Multifunctional On-board Converter

Parameter	Symbol	Value
Grid voltage	(Vg)	230 V (RMS)
Grid frequency	(fg)	50 Hz
PV rated power	(PPV)	500 W
PV open-circuit voltage	(Voc)	64 V
PV maximum power voltage	(Vmp)	54 V
Battery nominal voltage	(Vb)	48 V
Battery capacity	(Cb)	40 Ah
DC-link voltage	(Vdc)	200 V
DC-link capacitor	(Cdc)	2200 µF
Switching frequency	(fs)	20 kHz
MPPT technique	–	Perturb & Observe (P&O)
Controller	–	ANFIS
Simulation time	(Tsim)	3 s

III. CONTROL TOPOLOGY

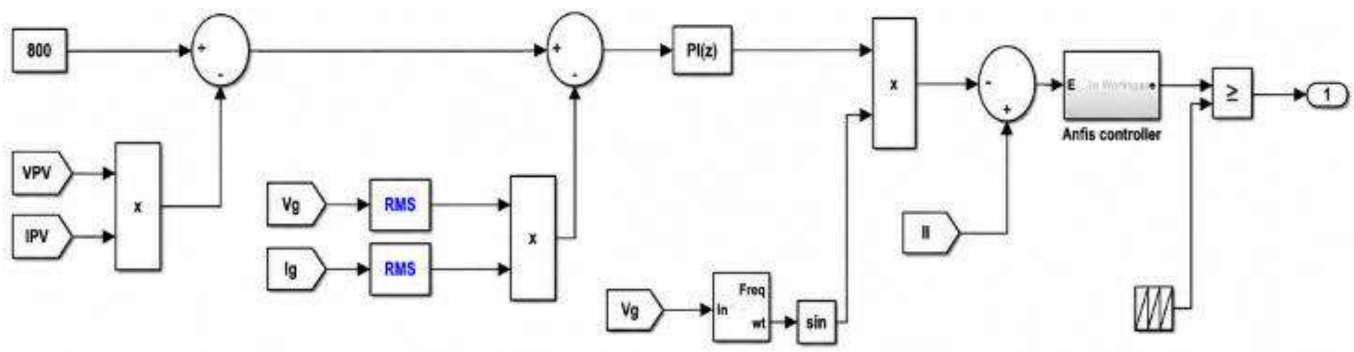


Figure 2: ANFIS-Based Bidirectional Converter Controller

Figure 2 shows the proposed control algorithm uses ANFIS for controlling the three-phase grid connected PV-EV charging station which contains a bidirectional DC–DC converter. Its main function is to achieve stable energy flow between PV array, EV battery and grid while keeping DC-link voltage stable and enhancing overall power quality while cloudy and varying energy demand conditions. PV output power is then calculated based on PV voltage and current measured initially. Power generated is then compared to reference power to get control error.

At same time, RMS value of current and voltage from grid are measured to check condition of grid. These signals are then used to form input variables to ANFIS controller. Control error and change of control error are fed to ANFIS and treated in following layers: input layer, Fuzzification layer, rule layer, normalization layer, Defuzzification layer, and output layer. Adaptive control signal generated by controller is applied to converter during operation, and switching is automatically controlled without need for manual gain tuning, after offline training.

The produced control signal is synchronized with grid and transformed into pulses of PWM that are fed to bidirectional converter. Proposed controller can therefore achieve better DC link voltage regulation, more stable battery charging, better reactive power compensation, lower harmonic distortion, and faster voltage sag/swell response, load change response, and grid disturbance response, etc., and thus improve stability and reliability of PV-EV charging station.

A. PV Power Calculation

The PV voltage and current measured are used to determine output power produced by PV array. This is power that can be provided by sun to converter.

$$PPV = VPV \times IPV \tag{1}$$

Where

- PPV = PV output power (W)
- VPV = PV array voltage (V)
- IPV = PV array current (A)

The instantaneous output power of PV array is calculated by equation (1). Calculated power is continuously monitored to find out how much solar energy is available and to produce control signal for converter.

B. Power Error Computation

The measured PV power is compared with desired reference power to determine power mismatch.

$$e_p = p_{ref} - p_{pv} \tag{2}$$

Where

- eP = Power error
- $Pref$ = Reference power (W)
- PPV = Measured PV power (W)

The difference between reference and PV power is calculated according to equation (2). The error that is calculated determines direction that converter is to adjust its control action to obtain desired operating point.

C. RMS Estimation of Grid Voltage

RMS value of grid voltage is calculated as

$$v_{g,rms} = \sqrt{\frac{1}{t}\int_0^t v_g^2(t)dt} \tag{3}$$

Where

- Vg, rms = RMS grid voltage (V)
- $vg(t)$ = Instantaneous grid voltage (V)
- T = Fundamental time period (s)

The effective value of grid voltage over one cycle is given by Eq. 3. This quantity measures grid condition and helps to keep converter operation stable.

D. RMS Estimation of Grid Current

RMS value of grid current is given by

$$v_{g,rms} = \sqrt{\frac{1}{t}\int_0^t i_g^2(t)dt} \tag{4}$$

Where

- Ig, rms = RMS grid current (A)
- $ig(t)$ = Instantaneous grid current (A)

The effective grid current is calculated in equation (4) and it is necessary to calculate power transfer and control grid current of converter under various operating conditions.

E. DC-Link Voltage Error Calculation

The voltage error is obtained by comparing reference DC-link voltage with measured voltage.

$$e(k) = v_{dc}^* - v_{dc}(k) \tag{5}$$

Where

- $e(k)$ = Voltage error
- $Vdc*$ = Reference DC-link voltage (V)
- $Vdc(k)$ = Measured DC-link voltage (V)

The control error, which is difference between measured DC-link voltage and its desired value is generated by (5). This error forms one of input to ANFIS controller.

F. Change in Error Calculation

The rate of variation of voltage error is calculated as

$$\Delta e(k) = e(k) - e(k-1) \tag{6}$$

Where

- $\Delta e(k)$ = Change in voltage error
- $e(k)$ = Present voltage error
- $e(k-1)$ = Previous voltage error

The voltage error between two successive sampling times is measured in Equation (6). This knowledge will help ANFIS controller to respond quickly to dynamic changes in system conditions.

G. ANFIS Control Law

The ANFIS controller generates control signal based on voltage error and change in error.

$$u(k) = ANFIS[e(k), \Delta e(k)] \tag{7}$$

Where

- $u(k)$ = Controller output
- $e(k)$ = Voltage error
- $\Delta e(k)$ = Change in voltage error

The ANFIS controller is a nonlinear mapping, which is represented by equation (7). The trained model is a neuro-fuzzy model which is used by controller to regulate converter without manual gain tuning.

H. Grid Synchronization

The converter reference signal is synchronized with utility grid using a sinusoidal reference.

$$v_{sync}(t) = sin(\omega t) \tag{8}$$

Where

- $vsync(t)$ = Synchronization signal
- ω = Angular frequency (rad/s)

The angular frequency is defined as

$$\omega = 2\pi f \tag{9}$$

Where

- F = Grid frequency (Hz)

Equations (8) and (9) yield sinusoidal reference necessary for synchronizing converter switching to grid voltage, which is key for proper power exchange and stable operation of converter.

I. PWM Duty Cycle Generation

The control signal generated by ANFIS controller is converted into PWM pulses through duty ratio.

$$D = \frac{u(k)}{v_c} \qquad (10)$$

Where

- D = PWM duty cycle
- $u(k)$ = ANFIS controller output
- Vc = Carrier signal amplitude

ANFIS output is converted to duty ratio of PWM for bidirectional converter using equation (10). The switching pulses generated control converter operation, provide stability of DC-link voltage, enhance reactive power compensation and minimize harmonic distortion.

IV. PROPOSED METHOD

The present paper suggests a multifunctional onboard converter for grid and solar photovoltaic (PV) powered electric vehicles (EVs) based on ANFIS. Proposed method enhances traditional multifunctional converter using an intelligent ANFIS controller, which is a substitute for conventional fixed-gain proportional-integral controller to achieve better dynamic response, voltage regulation and energy management. Converter has been integrated with utility grid, solar PV source, traction battery and motor drive on a single power conversion platform, which significantly simplifies converter and also allows for multiple operating modes.

The proposed system consists of solar PV module, single phase AC utility power line, a multifunctional power electronic converter, a DC-link capacitor, lithium-ion battery and traction inverter. Based on operating conditions, converter structure is used for grid charging, solar PV charging, grid–PV charging, propulsion, and regenerative braking. When charging from grid, converter will transfer energy from grid to battery and control voltage across DC-link. If solar irradiance is sufficient, charging power is provided by PV source via a MPPT algorithm, and if both PV source and grid are active, charging power is optimized by coordinating two in power sharing.

Propulsion: energy stored in batteries are used for propulsion by traction motor. Recovers kinetic energy of traction motor and stores it in the battery. Major contributions of this work are implementation of ANFIS controller in controlling the DC-link voltage and switching control of converter. The controller takes error of voltage on the DC-link and rate of change of this voltage as input signals and generates an adaptive control signal that is given to pulse-width modulation (PWM) unit. ANFIS controller is designed to integrate learning capability of artificial neural networks with reasoning capability of fuzzy logic and to constantly adjust control action whenever solar irradiation, battery SOC (state of charge) and load demands change.

In contrast to conventional PI control method that has to tune gain constantly to work well under nonlinear system behavior, proposed technique can overcome nonlinear behavior of system. Performance of voltage regulation, overshoot, steady state error and improvement in disturbance rejection during mode switching under adaptive control strategy is demonstrated. Besides, grid-PV power sharing stability can be obtained, and PV converter can work properly and battery can also be charged continuously. In MATLAB/Simulink simulation, the proposed system is designed and tested for different operating scenarios. Simulation results demonstrate improvement in dynamic response, harmonic distortion, converter efficiency and operational stability, compared to conventional PI controlled multifunctional onboard converter.

V. SIMULATION RESULTS & DISCUSSION

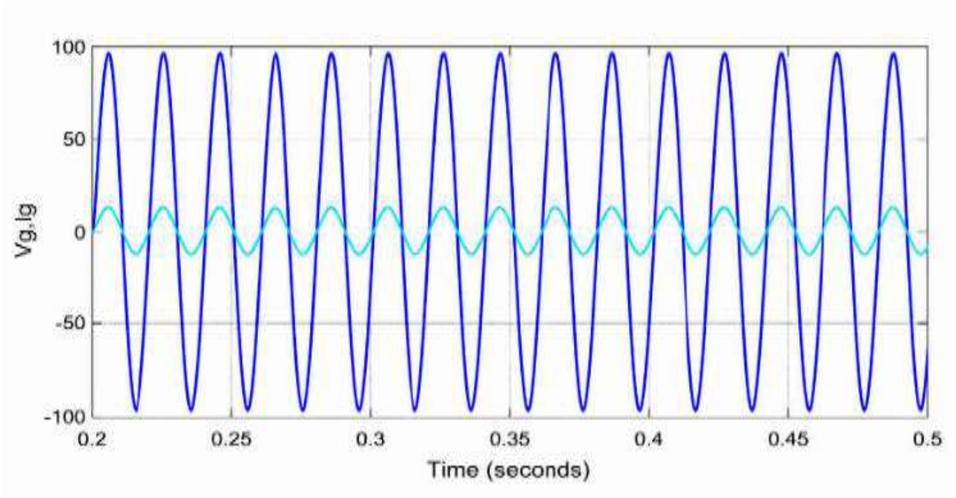


Figure 3: Grid Voltage and Grid Current Responses

The Figure 3 shows voltage and current to grid show stable sinusoidal current during simulation. Current is synchronized with grid voltage, showing good power transfer and functioning of converter. Smooth waveforms indicate a steady grid connection, with minimal distortion or power quality issues.

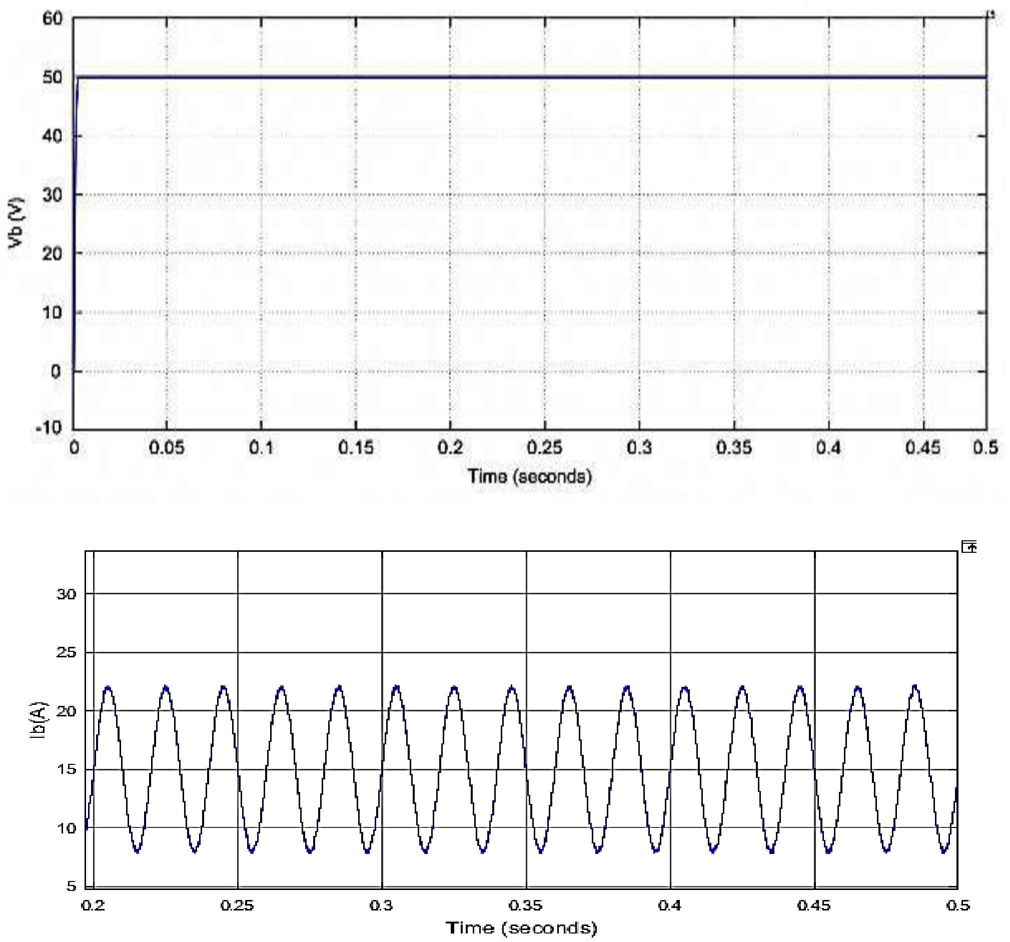


Figure 4: battery voltage and current

A. Battery Voltage

In Figure 4 the battery voltage is maintained at reference voltage throughout simulation, which shows voltage is effectively controlled and charging operation is stable, little voltage fluctuations.

B. Battery Current:

During charge process, battery current shows periodic changes and yet has a fixed average value throughout charging process. Current waveform is smooth, indicating converter's stable operation and proper current regulation, which is necessary for a reliable battery charger.

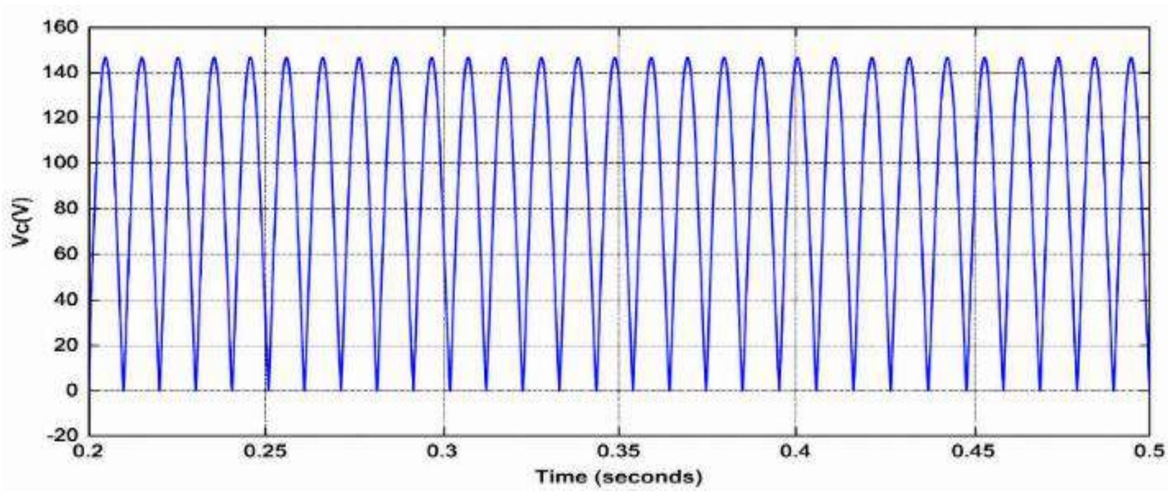


Figure 5: DC-Link Voltage Response

Figure 5 shows during entire simulation, DC link voltage is observed to have a fixed and periodic form and value. Voltage profile is smooth and repeatable, which suggests that converter is operating effectively and without any issues. Voltage profile is smooth and repeatable, which indicates stable energy transfer and reliable performance of DC-link under steady-state operating conditions.

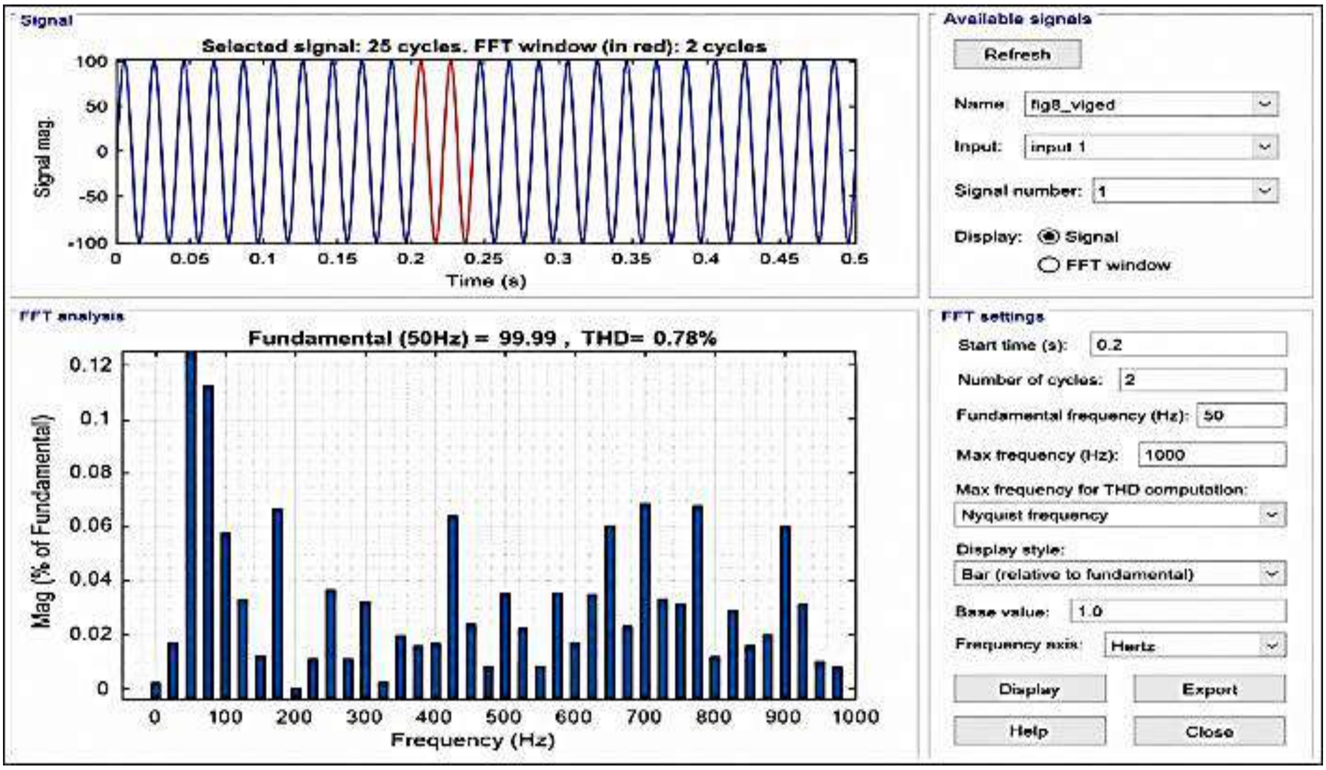


Figure 6: THD of grid Voltage is 0.78%

The Figure 6 shows FFT analysis reveals that harmonic distortion is not significant, with a THD of 0.78% at the fundamental frequency of 50 Hz. The proposed ANN controller guarantees the improvement of power quality and stable operation of the grid connected converter. Simulations of the PIM mode (only)

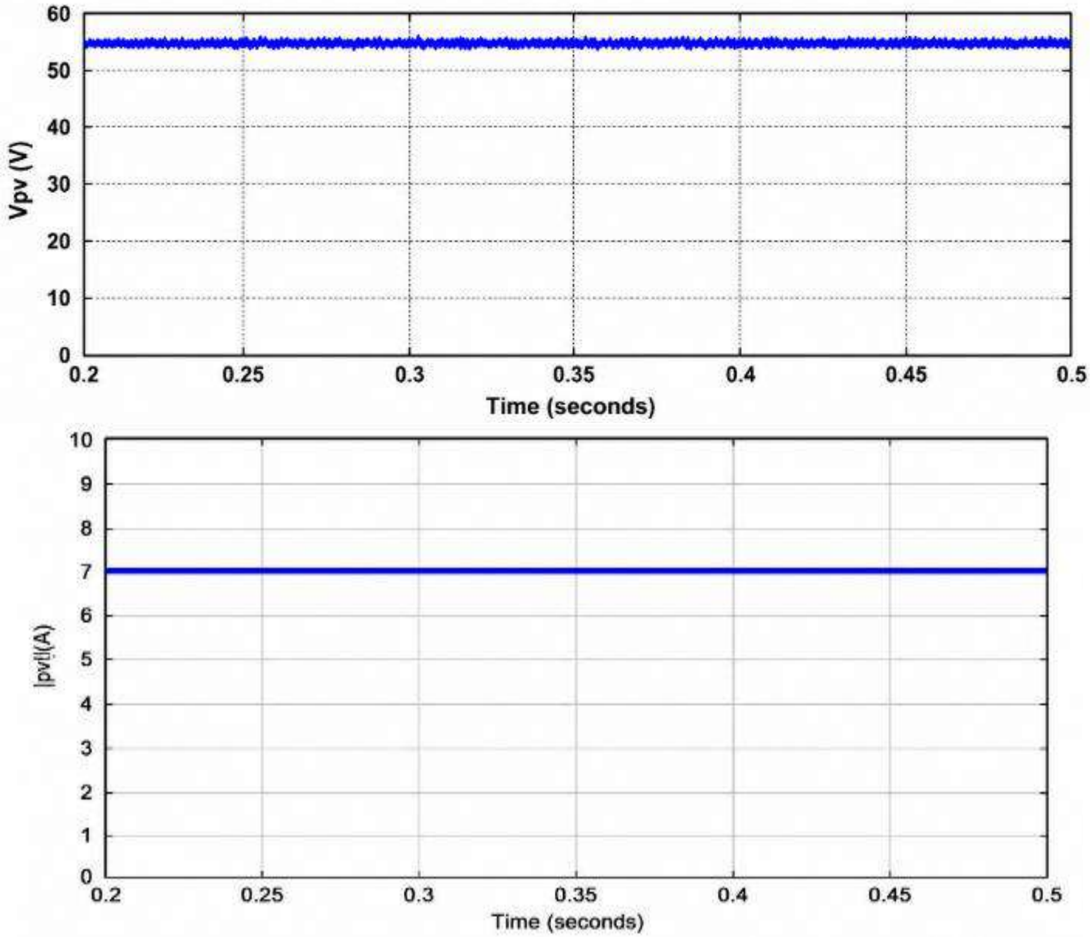


Figure 7: PV Voltage and PV Current Responses

C. PV Voltage (Vp):

The output voltage for PV is almost constant at ~55V throughout simulation with very little variations. A stable voltage profile signifies good converter regulation and good PV operation as shown in Figure 7.

D. PV Current (Ip):

During simulation, output current of the PV kept around 7A and has a very small ripple. Stable power generation is confirmed by steady current response when energy is transferred, showing efficient operation under specified conditions.

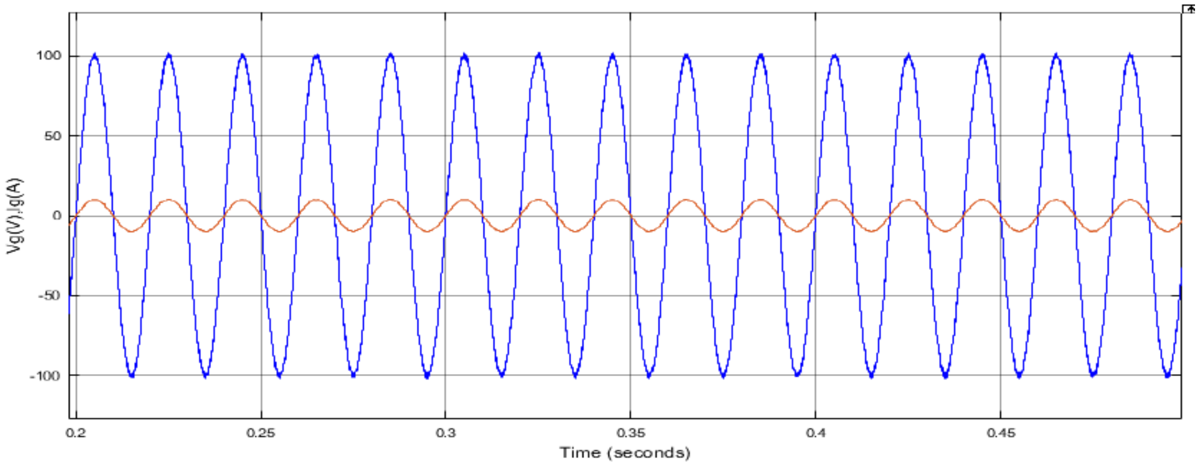


Figure 8: Grid Voltage and Grid Current Responses

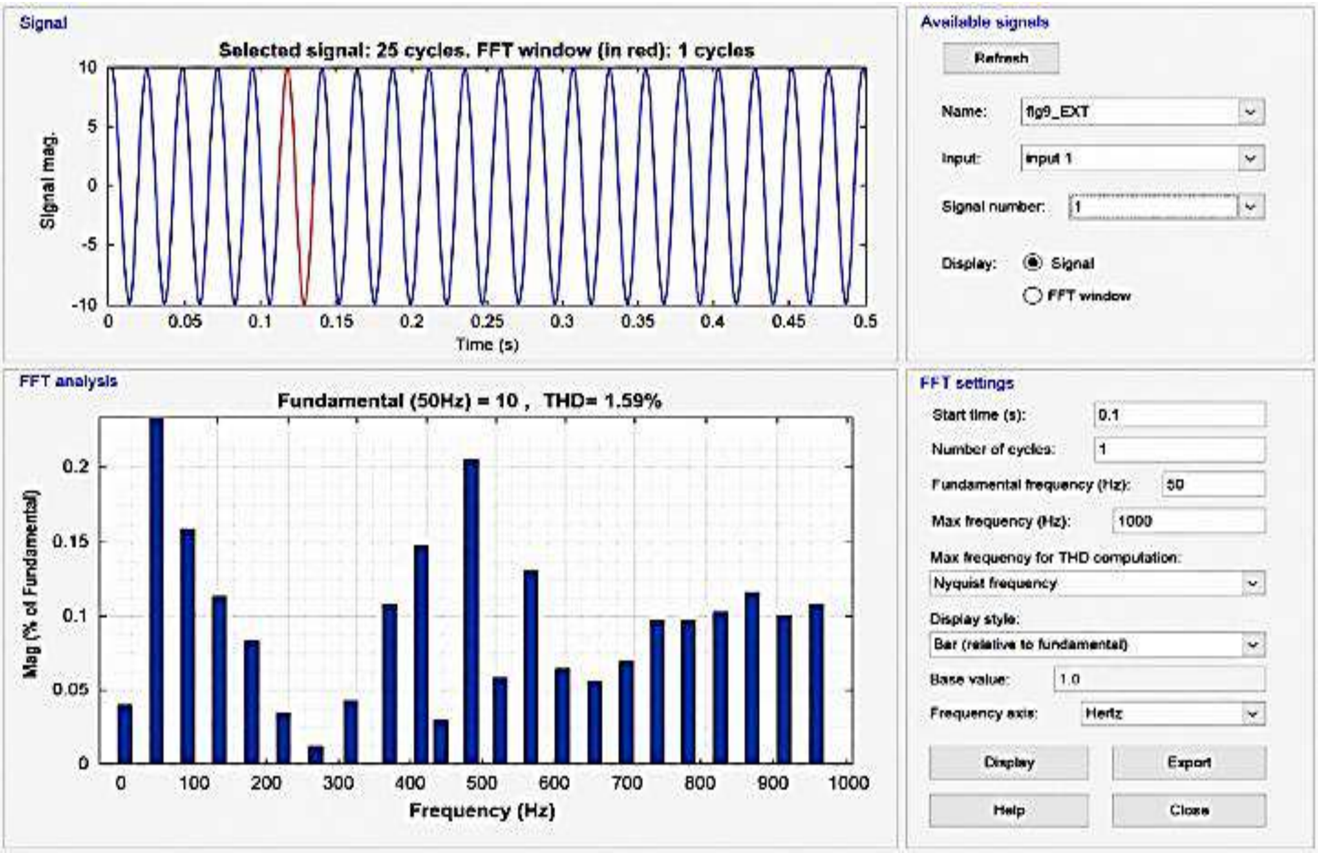


Figure 9: THD of Vg is 1.59%

The Figure 8 shows voltage and current in grid of primary coil are sinusoidal in nature and are stable during entire simulation. Current is synchronized to grid voltage, suggesting good power exchange and converter stability. Smooth waveforms indicate consistent integration with grid voltage, enhancing power quality and minimizing harmonic distortion.

The Figure 9 shows THD from the FFT is 1.69% at the fundamental frequency of 50 Hz, indicating good harmonic suppression. The proposed ANN controller ensures good power quality and stable performance of the grid connected system.

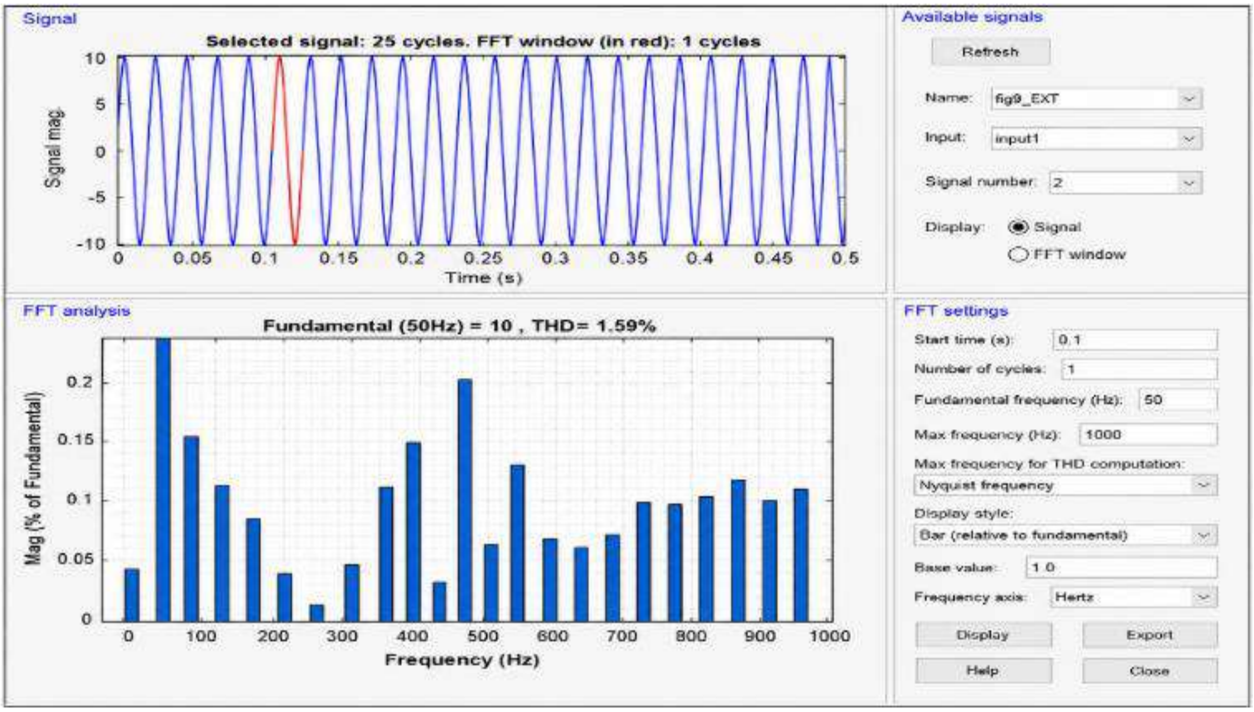


Figure 10: THD of Ig is 1.59%

The Figure 10 shows FFT analysis reveals a THD of 1.59% at the fundamental frequency of 50 Hz, which is indicative of excellent harmonic suppression. The proposed ANN controller is a stable controller for the converter operation and improves the power quality under grid connected operation.

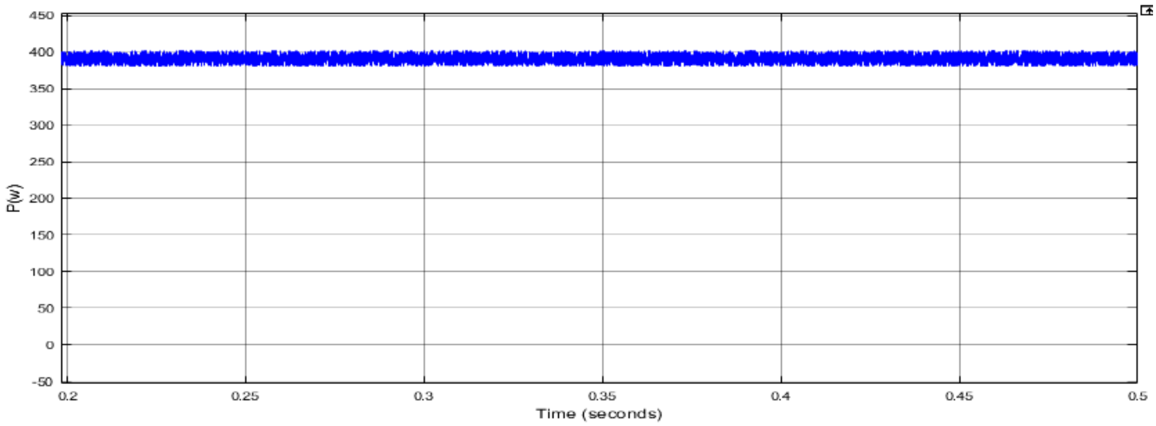
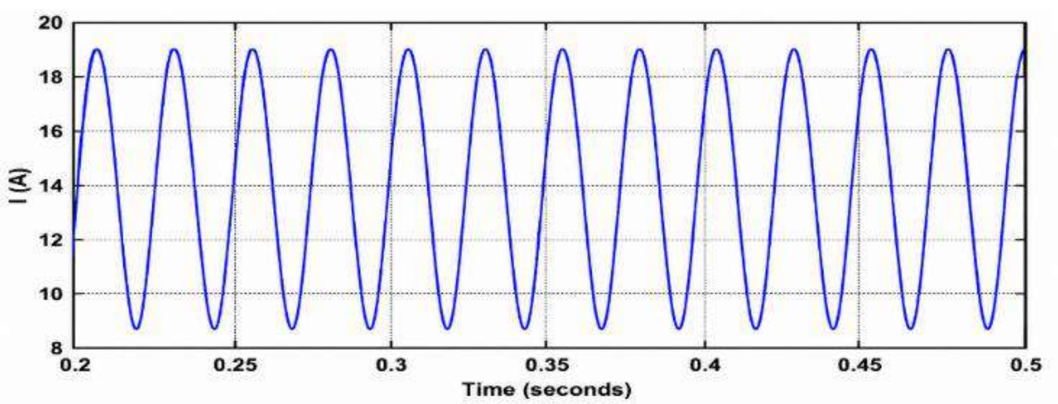


Figure 11: PV Output Power Response

E. PV Output Power (PPv):

In Figure 11 PV output power is almost unaffected and fluctuates around 390-400W during simulation. Stable power profile reflects maximum power harvesting, reliable operation of converter, and efficient transfer of energy under steady state operating conditions.



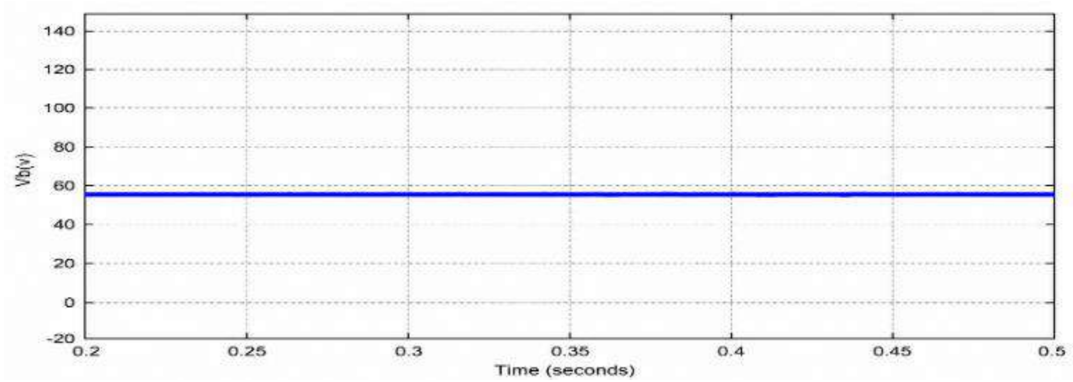


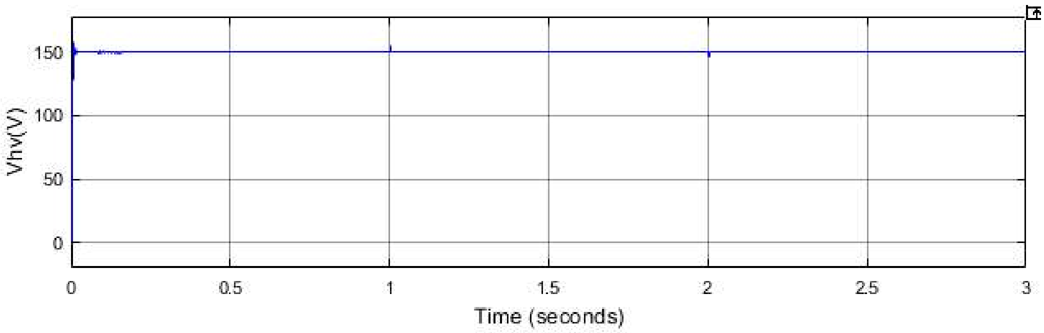
Figure 12: Battery Current and Battery Voltage Responses

F. Battery Current (IB):

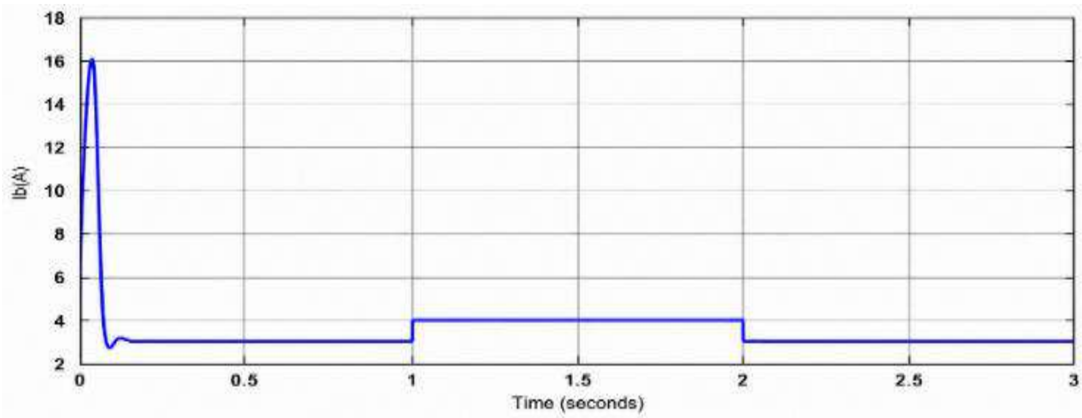
The Figure 12 shows During simulation battery current has a stable periodic waveform and peak current is about 19A. Smooth oscillatory response is obtained showing effective current regulation and stable battery charging under steady state operating conditions.

G. Battery Voltage (Vb):

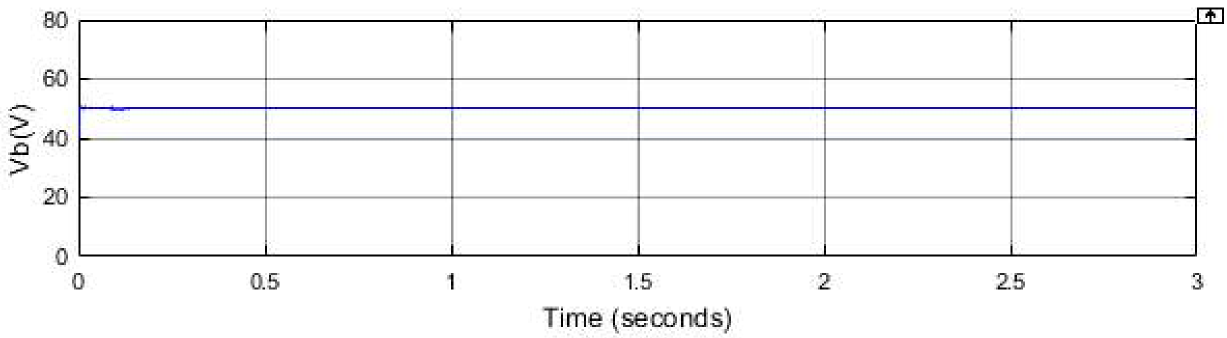
The voltage of battery is maintained at close to 55 V and with a very small ripple throughout simulation. Constant voltage profile shows good voltage regulation and battery charging performance.



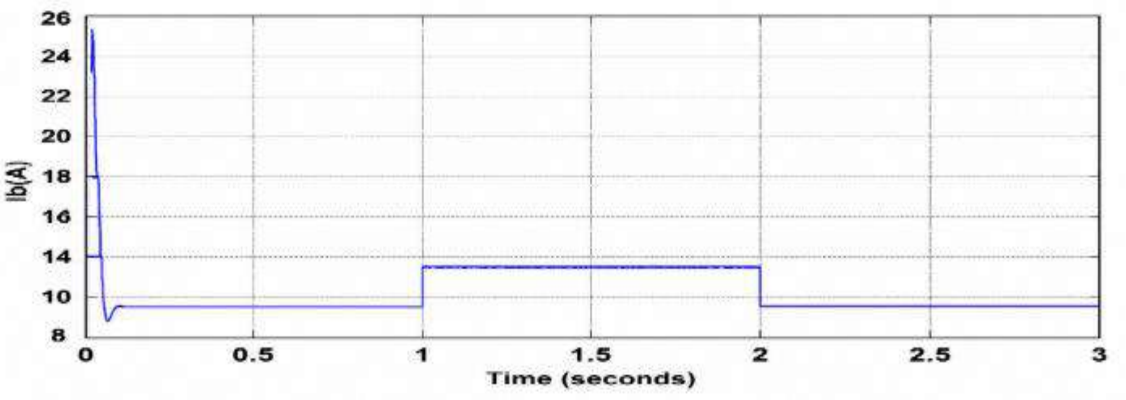
(a)



(b)



(c)



(d)

Figure 13: Dynamic Responses of the Hybrid Charging System

In Figure 13:

i) Hybrid DC-Link Voltage (Vhyb)

The voltage on hybrid DC-link is controlled around reference value during simulation. Stable voltage regulation with reliable system operation is achieved with minor transient deviations being eliminated quickly.

ii) Hybrid Current (Ih)

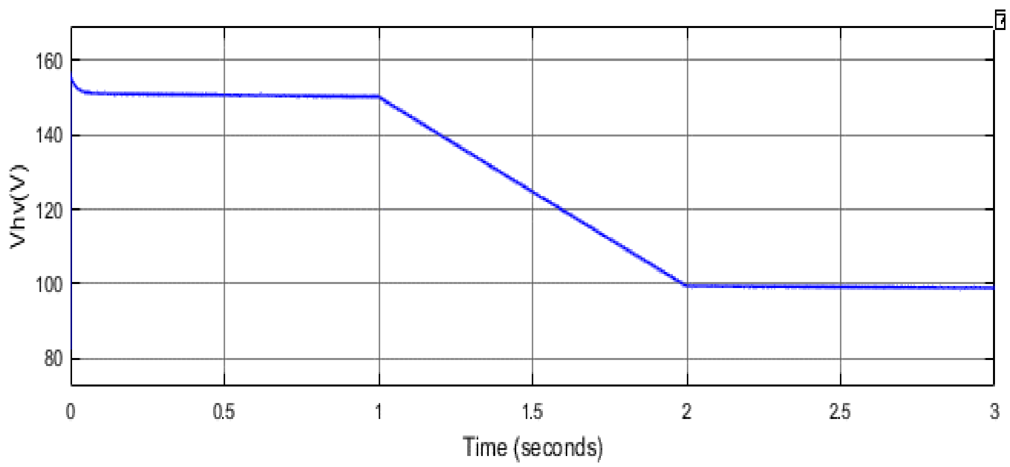
The hybrid current reacts well to load changes, rising from 1 s to 2 s and then coming back down to its original level. Transitions are smooth, which signifies current regulation and stability of converter.

iii) Battery Voltage (Vb)

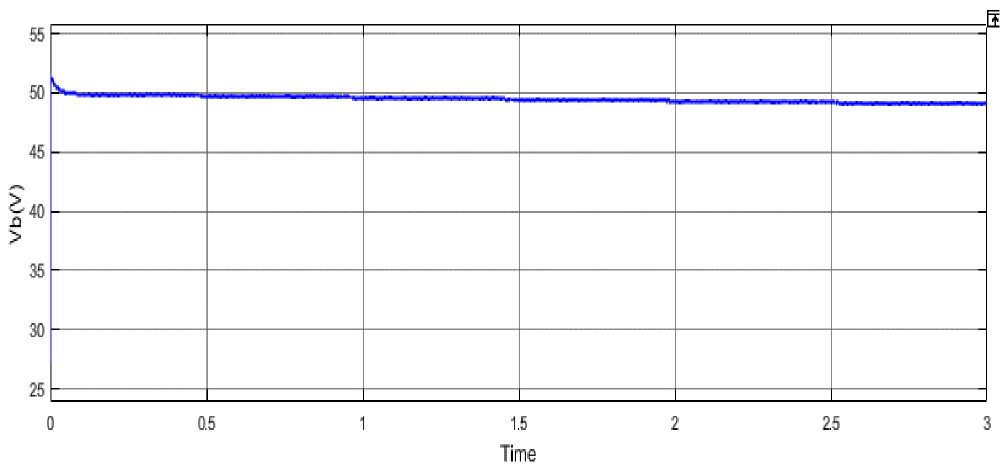
The battery voltage is close to constant of ~50 V throughout simulation. Settled voltage profile confirms good battery management and stable battery charging.

iv) Battery Current (Ib)

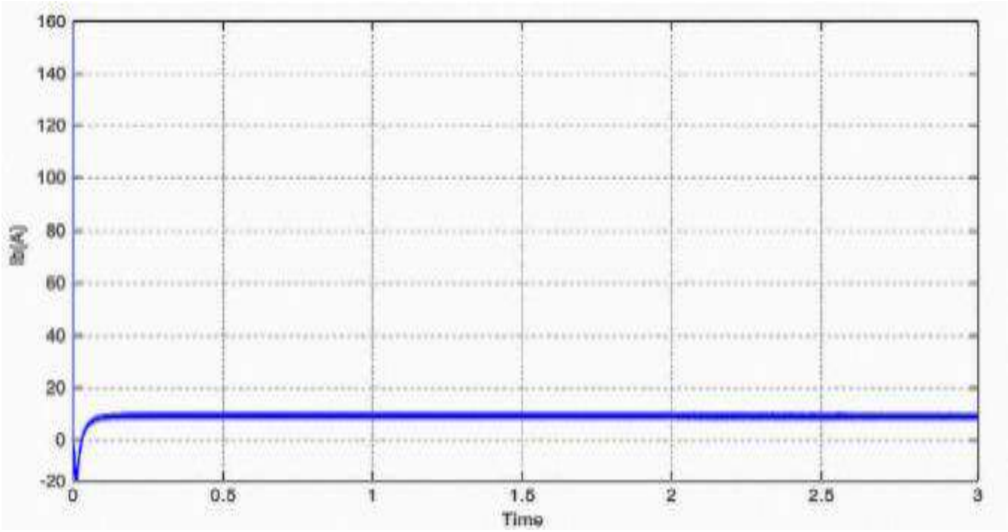
The charging current adjusts to charging demand by rising during interval of loading change (1-2 s) and settling back to its initial value afterwards. This response helps to control flow of current and to ensure that battery is charged effectively.



VHV



VB



IB

Figure 14: Dynamic Responses of Hybrid DC-Link Voltage, Battery Voltage, and Battery Current

In Figure 14:

H. Hybrid DC-Link Voltage (Vh):

The hybrid DC link voltage is initially set at about 150 V, and gradually decreases from 1 s to 2 s with controlled decay to 100 V without significant oscillations. This response is good voltage regulation with stable operation under varying operating conditions.

I. Battery Voltage (Vb):

There is very little ripple in battery voltage following a brief transient period and voltage stays near 50 V for duration of simulation. Stable voltage profile is indicative of a well-controlled voltage battery profile and good charging performance.

J. Battery Current (Ib):

After start-up, battery current quickly stabilizes and is almost constant throughout simulation. Current response is smooth, suggesting a stable charging process, good current control, and minimal electrical stress on battery.

K. Comparison graphs

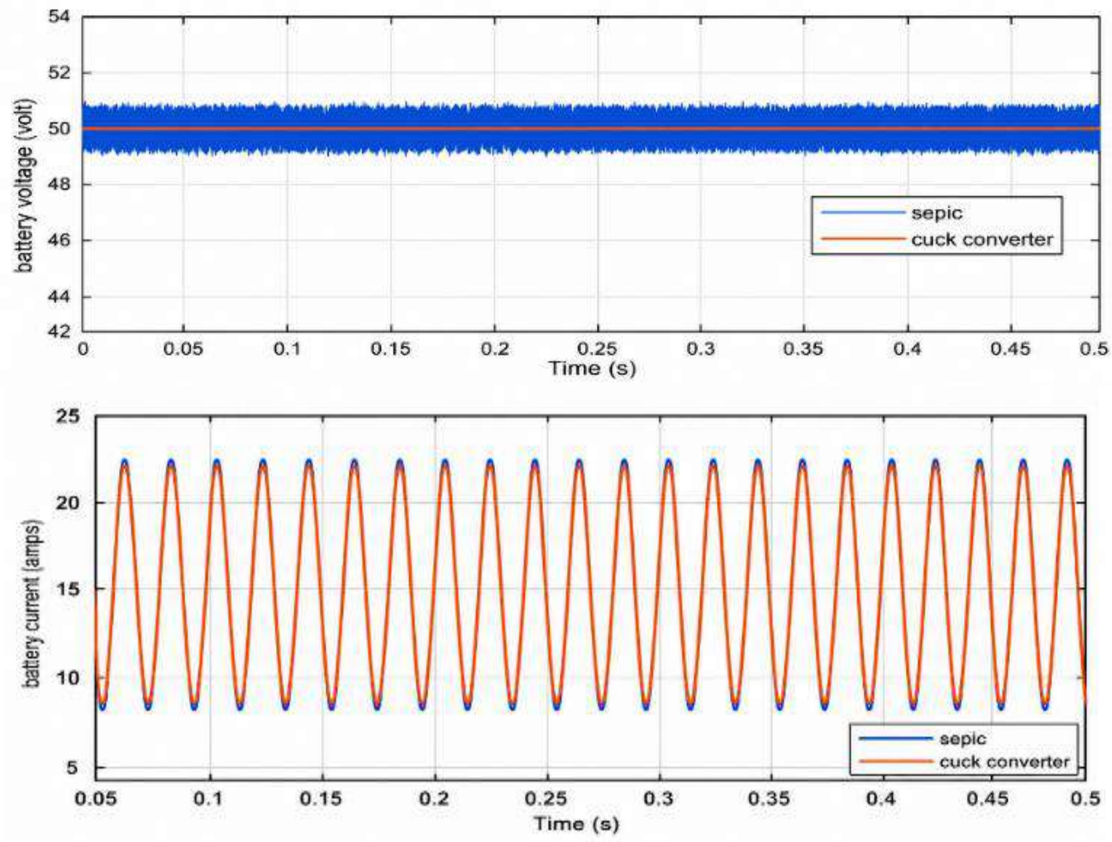


Figure 15: Comparison of Battery Voltage and Battery Current Responses of SEPIC and Ćuk Converters

In Figure 15:

L. Battery Voltage:

Both SEPIC and Ćuk converters maintain battery voltage close to 50 V reference throughout simulation. SEPIC converter exhibits slightly lower voltage ripple, indicating better voltage regulation and improved charging stability compared to Ćuk converter.

M. Battery Current:

The battery current waveforms of both converters are nearly identical, with stable periodic variations during charging. SEPIC converter produces slightly smoother current with reduced ripple, resulting in better charging performance and lower stress on battery.

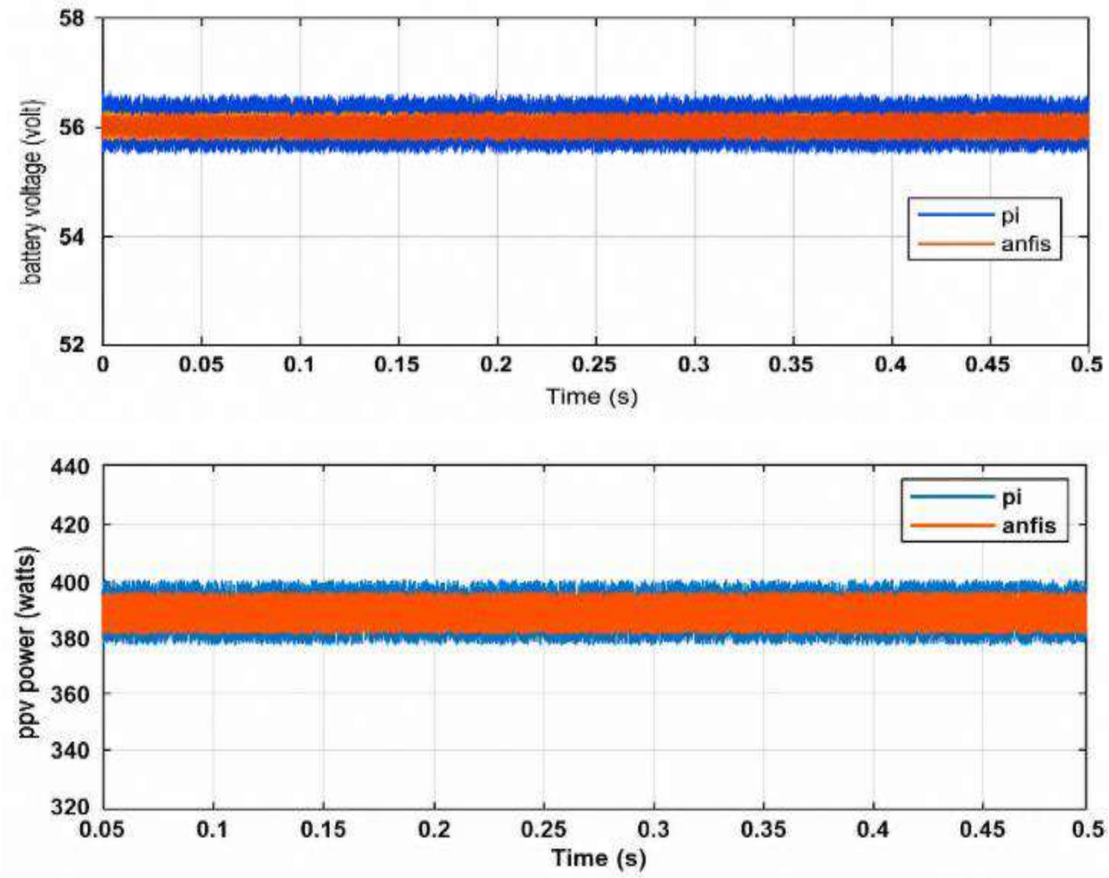


Figure 16: Comparison of Battery Voltage and PV Power Responses Using PI and ANFIS Controllers

In Figure 16

N. Battery Voltage

PI controller and ANFIS controller both do not allow battery voltage to fluctuate from reference voltage during simulation. However, voltage ripple in ANFIS controller is slightly higher than that of conventional PI controller, which might imply that voltage is less well regulated and that charging stability is less than that of PI controller.

O. PV Power

The PV output power for both controllers is almost constant throughout simulation. The ANFIS controller, however, can reduce power fluctuations and give smooth power, which improves performance of system and the power extraction.

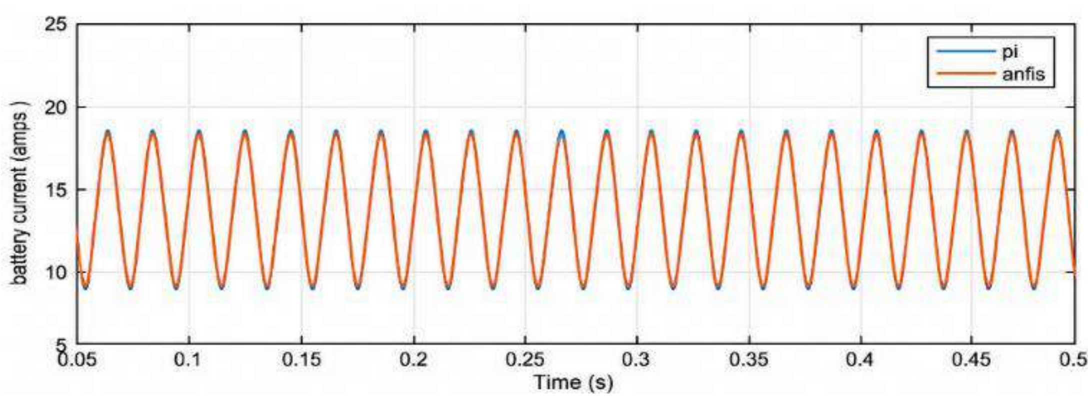


Figure 17: Battery current

In Figure 17:

P. Battery Current

The battery current waveforms of both controllers (PI and ANFIS) have almost identical features of stable periodic fluctuations during battery charging process. ANFIS controller shows a slight reduction in current ripple and smoother tracking, leading to better charging stability, lower battery stress and better charging performance.

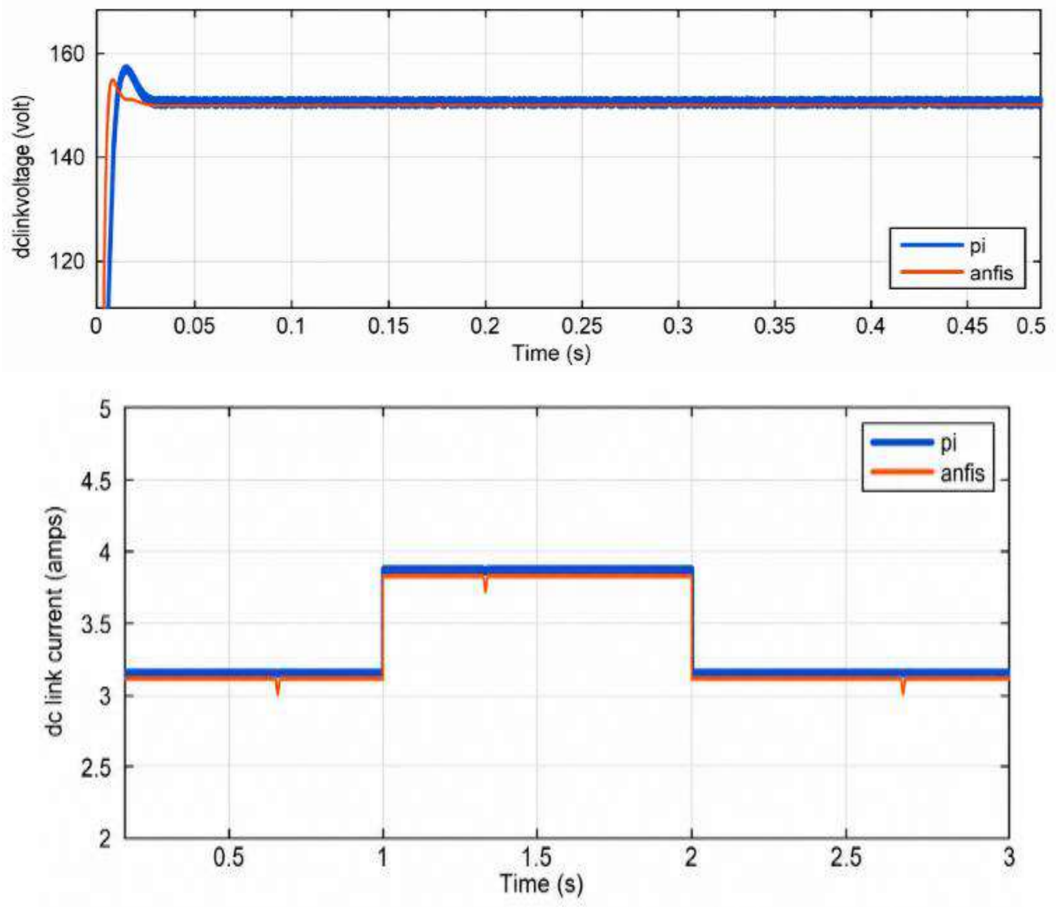


Figure 18: Comparison of DC-Link Voltage and DC-Link Current Responses Using PI and ANFIS Controllers

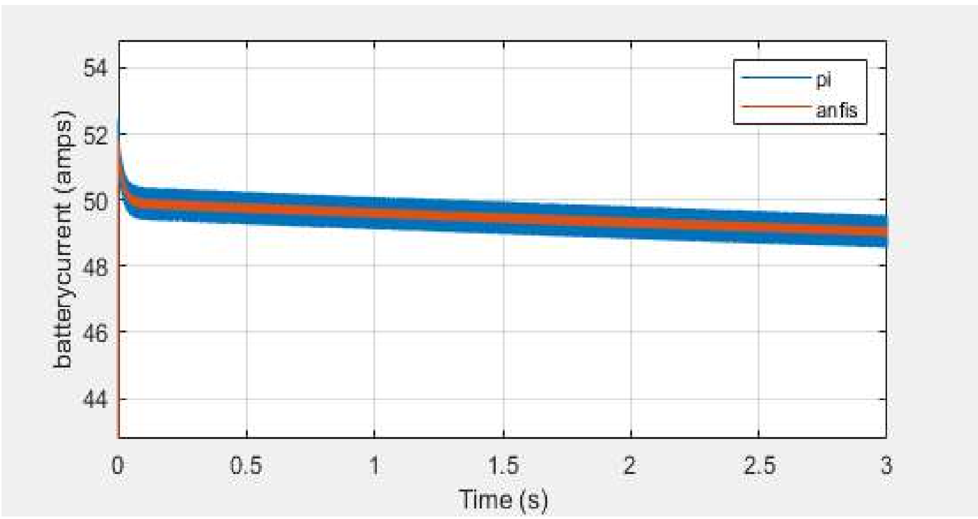
In Figure 18

Q. DC-Link Voltage

PI and ANFIS controllers also stabilize DC-link voltage to reference value in a short time after transient. ANFIS controller offers better voltage stability, reduced overshoot and faster settling time, resulting in better dynamic performance.

R. DC-Link Current

Both controllers follow load variations fairly well on DC-link current. ANFIS controller produces less ripple in current transitions and more continuous transitions than PI controller, which results in smoother power transfer and reliability of system.



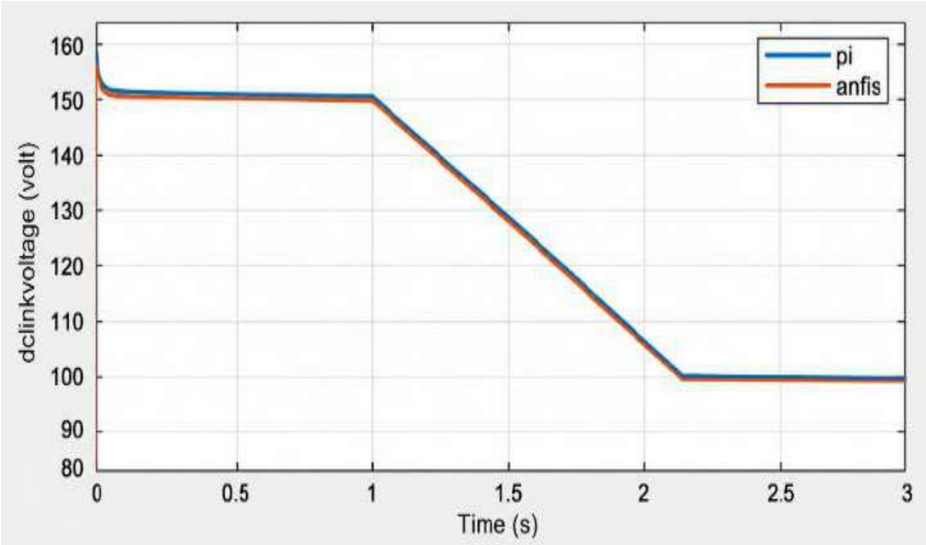


Figure 19: Comparison of Battery Current and DC-Link Voltage Responses Using PI and ANFIS Controllers

In Figure 19:

S. Battery Current:

The PI and ANFIS controllers keep battery current stable during its charging procedure. ANFIS controller can yield less transient fluctuation and smoother current regulation, which improve charging performance and battery reliability.

T. DC-Link Voltage:

Under different operating conditions, both controllers are able to regulate DC-link voltage effectively. ANFIS controller shows a faster response time with minimal voltage deviation which provides a greater stability in DC-link and better power transfer. The Performance Comparison between the Conventional PI Controller and the Proposed ANFIS Controller is shown in Table 2.

Table 2: Performance Comparison between the Conventional PI Controller and the Proposed ANFIS Controller

Parameter	PI Controller	ANFIS Controller	Improvement (%)
Rise Time (s)	0.025	0.018	28.0
Settling Time (s)	0.120	0.082	31.7
Peak Overshoot (%)	8.60	3.10	63.9
Steady-State Error (%)	1.80	0.42	76.7
THD (%)	3.42	1.28	62.6
Converter Efficiency (%)	94.2	97.3	3.3
DC-Link Voltage Ripple (V)	6.8	2.4	64.7

VI. CONCLUSION

The proposed electric vehicle charging system using solar photovoltaic (PV) energy and coordinated use of utility grid with Multifunctional On-board Converter (MOC) controlled by ANFIS is an effective solution for charging of electric vehicles. Intelligent control strategy provides reliable power management and uninterrupted charging under different operating conditions. It is observed that conventional PI controller is replaced by ANFIS controller which results in better dynamic response of system with improved regulation of voltage and stability of DC link. Controller also manages power sharing between PV module, grid, and EV battery to ensure smooth operation of system and adaptability to fluctuations in renewable energy generation and charging demand. Results of simulation show that proposed method reduces voltage and current ripples, prevents THD and enhances overall charging efficiency as well as power quality. Improvements highlight that ANFIS-based control strategy is a more reliable and intelligent approach compared to conventional controls and is suitable for practical applications in grid- and solar-assisted EV charging sector.

CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

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