Intelligent Energy Management System for Electric Vehicle Charging and PMSM Operation using Solar, Wind, and Battery Power with ANFIS Control

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Abstract - The future power demand for electric vehicles (EVs) is expected to rise due to decreasing nonconventional energy generation and increasing maintenance costs. This presents a risk as EV owners may charge batteries on demand, potentially increasing power demand. The demand for sustainable transportation and renewable energy sources has led to the development of innovative solutions that integrate multiple technologies. The intelligent ANFIS control system aims to optimize the charging process of electric vehicles by integrating solar, wind, and battery technologies. This system can reduce reliance on traditional power grids and minimize carbon emissions. The system uses the P&O MPPT algorithm to efficiently track and extract maximum power from solar and wind energy sources. The PMSM motor uses an electric vehicle battery for efficient propulsion, while excess energy is stored in the battery for later use. The ANFIS control system continuously adjusts the motor's speed and torque based on real-time data, optimizing power utilization and minimizing energy waste. The proposed energy management strategy involves the interaction between renewable energy sources, battery storage, and the electric vehicle's performance, enabling further improvements in energy management and overall efficiency.

Keywords - Charging facility, electric vehicles, solar photovoltaic (PV) system, wind system, ANFIS controller, P&O MPPT algorithm, Voltage Source Inverter, Permanent Magnet Synchronous Motor.

1. Introduction

The production of renewable energy (RE) and the efficient use of existing energy resources have emerged as a model antidote to the problems of expanding carbon footprints, diminishing fossil fuel supplies, accelerating global warming, and ever-shifting climatic circumstances [1]. Solar and wind energy are the finest forms of RE currently accessible due to their zero-emissions, silent operation, and wide availability even in distant regions [2]. Solar photovoltaic (SPV) and wind power generating systems are a great way to generate electricity since they offer a low initial investment cost, low ongoing maintenance cost, and no operational cost. Solar photovoltaic (SPV) and wind power generating systems are great options for sustainable energy since they need no ongoing costs outside installation and maintenance. The increased efficiency and dependability of SPV and wind power systems due to technological developments has further added to their allure as a sustainable energy alternative [3–4]. Governments, manufacturers, and environmental activists have all made significant strides in promoting the electric vehicle (EV) in recent years, and it has grown more popular as a result [5]. Electric vehicles provide a comprehensive strategy for reducing air pollution and global warming by eliminating the need for fossil fuels. This electric car charging utilising renewable energy sources such as sun and wind is a potential step towards building a sustainable and clean transportation system. Charging electric vehicles with renewable energy decreases pollution and use of finite resources [6, 10]. Renewable energy integration into the charging infrastructure may also contribute to grid stability and increased energy independence. Traditional technologies, such as coal and fueled power plants, contribute significantly to the depletion of nonrenewable energy sources used to power the grid [8]. Nonrenewable energy sources can no longer keep up with the ever-increasing demand for EV charging. Changing to solar or wind power, for example, may lessen our impact on the environment, provide for a brighter future, and open up new employment possibilities. When it comes to getting the most out of solar and wind power, the P&O MPPT control based on ANFIS is the way to go. By using Adaptive Neuro-Fuzzy Inference System (ANFIS) methods, this control system optimises the operation of the Perturb and Observe (P&O) MPPT algorithm, resulting in better energy harvesting capabilities [19]. This cutting-edge method guarantees that solar panels and wind turbines can reliably provide maximum power output. Boost converters are used by renewable energy sources to improve the efficiency and power of the electricity they produce. Boost converters are essential for optimising the use of renewable energy sources like solar and wind by transforming their output, which is often unstable and lower in voltage, into a steady and higher one [13]. The higher power production makes it possible to distribute and use renewable energy more efficiently, leading to a more environmentally friendly and sustainable future. This algorithm constantly modifies the boost converter's operational settings to keep it in the sweet spot where it draws the most power from the renewable supply [14]. The MPPT P&O algorithm improves the overall performance and utilisation of renewable energy sources [15] by dynamically responding to changing environmental circumstances to enhance the efficiency of the boost converter. The MPPT P&O algorithm benefits from ANFIS management. To fine-tune the MPPT algorithm's decision-making, the ANFIS control system employs a fuzzy logic system and a neural network. Improved energy conversion and overall system performance may follow from this [16] because the maximum power point can be tracked with more accuracy and efficiency. However, climate change and variables like cloud cover or wind strength may cause these sources to not reliably provide electricity. By holding extra energy during peak production times and releasing it during low generation, advances in energy storage technologies like batteries may help overcome these issues and provide a more stable and constant power supply for EV charging [11],[12]. The charging and discharging of batteries are two vital processes that need precise regulation. The ANFIS (Adaptive Neuro-Fuzzy Inference System) control-based bidirectional DC-DC converter [24] is one example of such a method. This converter automatically adjusts the voltage and current levels depending on the battery's state of charge, guaranteeing optimum charging and discharge [25]. ANFIS's control algorithm also allows precise prediction and adjustment of battery performance, which extends the battery's life and improves its overall efficiency [26]. The unpredictability of solar and wind power may be mitigated by installing battery energy storage devices that are managed by an ANFIS. By storing energy during times of high production and releasing it at times of low production or high demand, these systems guarantee customers a steady and stable supply of energy at all times.

To reduce their negative effects on the environment, electric vehicles (EVs) may be charged using renewable energy sources or batteries. A 3-phase VSI is utilized to give ac power to the PMSM drive. The electric vehicle motor is managed via an exterior speed control loop and an internal torque controller. As a result, the drive's speed may be modulated. They employ permanent magnet synchronous motor (PMSM) motors, which provide quiet, dependable operation and more efficiency and durability than internal combustion engines [18]. Charging fluid for EVs provides a trouble-free ride and adds to the long-term viability of the vehicles. With the ANFIS control algorithm regulating the speed of the PMSM motor, the motor's performance may be optimized, leading to improved energy efficiency and lower emissions [19]. To further improve the EV driving experience, the ANFIS control algorithm enables accurate and quick speed changes [20]. Due to its high power density and efficiency, the PMSM drive provides the highest performance for an electric vehicle motor drive. It provides accurate regulation of torque and speed, improving efficiency and performance in electric cars. Because of its lightweight and small size, the PMSM drive is well-suited for electric car applications with restricted inside space [21]. In order to provide electric cars' motor drive systems with electricity, the authors of this research suggest an ANFIS-controlled power production, battery charge and discharge system. The Adaptive Neuro-Fuzzy Inference System (ANFIS) is used by the proposed control system to maximise power output and battery life in electric vehicles. Incorporating ANFIS control allows the system to optimise performance and range by adapting power production and battery charge/discharge rates in real time in response to changing driving circumstances. In addition, the ANFIS-based control system can easily adjust to various driving styles and road conditions, making it applicable to a broad variety of electric cars. Modelled and simulated in a MATLAB/Simulink environment, the performance of this energy management system is tested in a number of driving situations [22], [23]. The simulation results indicate the usefulness of the ANFIS control system in boosting energy efficiency and maximising the utilisation of the vehicle's battery capacity.

It is customary in industrialised nations to have two automobiles at home, with one often being used for errands and grocery shopping. Supporting residential solar PV with the EVBs of seldom-driven automobiles is one solution to the problems with electric vehicles, solar photovoltaic, and wind power systems. This lessens the strain on regional power systems and helps stabilise intermittent renewable energy sources like solar and wind. With the right control algorithm, this setup may be integrated into a smart grid or micro-grid. There are several positive aspects to the proposed solar PV-over-EVB energy system, including:

- Charging and running electric vehicles on renewable energy sources like solar and wind reduces dependency on fossil fuels, which in turn reduces carbon emissions and helps prevent global warming.

- Cleaner air and less dependence on finite resources are two benefits of charging electric cars using renewable energy sources, which contribute to a more sustainable transportation system.

- Batteries and other forms of energy storage are used to store surplus energy produced during peak hours and release it during off-peak hours, making for a more stable and dependable power source for charging electric vehicles.

- The battery's lifetime and performance may be optimised with the help of bidirectional DC-DC converters that are controlled by an ANFIS.

- ANFIS control algorithms enhance the efficiency, emissions reduction, and speed control of Permanent Magnet Synchronous Motors (PMSM) in electric cars.

Those objectives may be met by designing a high-tech power conditioning system (PCS) that takes into account charging and discharging control signals from the EV's on-board BMS.

The main contributions of the paper are:

- Using the dc charging connection standard, a new PV-WIND-EVB system is suggested for use in household renewable energy systems.

- The proposed PV-WIND-EVB system's power conditioning technology and its control system are developed on a programmable platform.

- A power management strategy to efficiently utilize the EV battery and the renewable energy system is proposed.

- The application of Adaptive Neuro-Fuzzy Inference System (ANFIS) control-based Perturb and Observe (P&O) Maximum Power Point Tracking (MPPT) algorithms aids to the effective extraction of energy from solar and wind sources, ensuring that maximum power is consistently harvested.

2. System Layout

The system configuration for electric vehicle charging and operation using renewable energy sources is a sustainable solution as shown in Fig.1. It utilizes solar photovoltaic (SPV) panels and wind turbines, which are clean and abundant sources of renewable energy. The system uses Maximum Power Point Tracking (MPPT) algorithms controlled by Adaptive Neuro-Fuzzy Inference System (ANFIS) to extract maximum power. Boost converters are employed for stability and higher voltage levels, while energy storage is crucial. Bidirectional DC-DC converters with ANFIS control manage battery charge and discharge processes, optimizing battery performance and lifespan. The electric vehicle components include Permanent Magnet Synchronous Motors (PMSM) for precise control over torque and speed as shown on Fig.2. The system is underpinned by ANFIS control algorithms, optimizing various aspects of the system, including MPPT control, boost converter operation, and battery management. Charging infrastructure, such as EV charging stations, is equipped with ANFIS-controlled power generation and battery charge/discharge systems. The system is modeled and simulated in a MATLAB/Simulink environment, demonstrating its potential for sustainable and clean transportation.

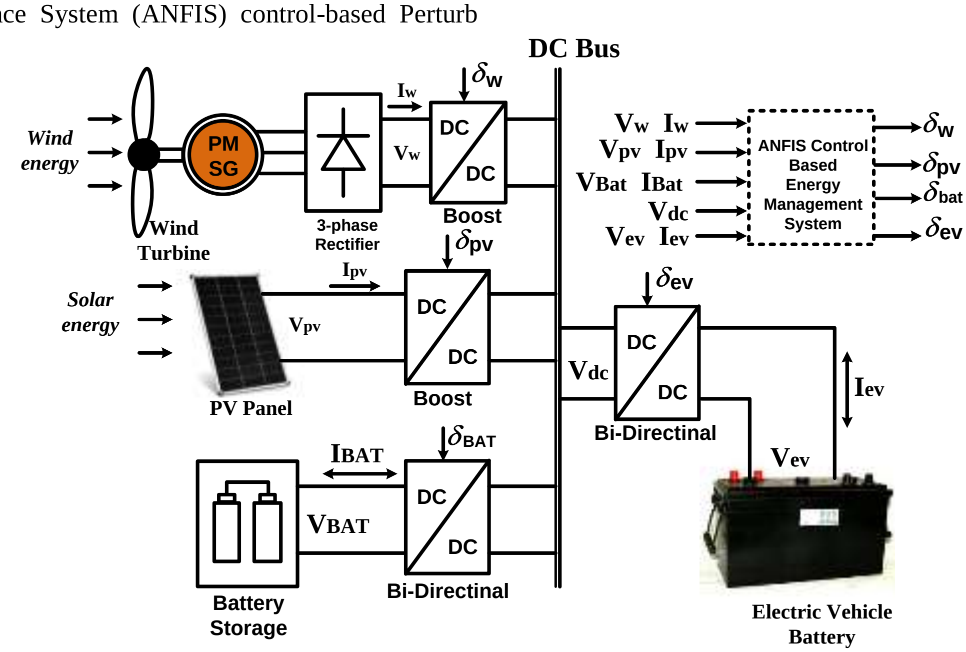


Fig.1 Microgrid components include the proposed EMS for a small-scale wind-solar-battery system.

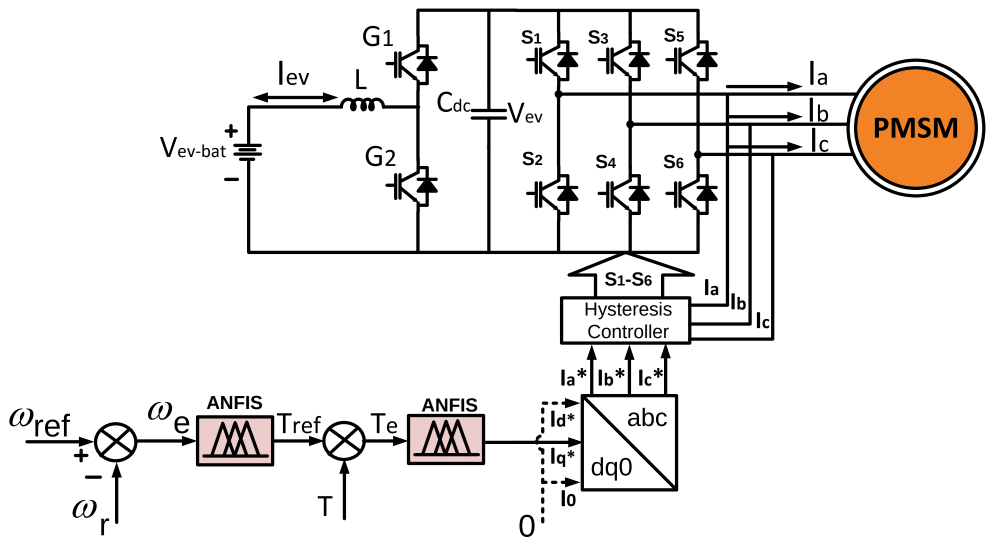


Fig .2 PMSM drive configuration in battery storage system.

3. Solar Energy Conversion System (SECS)

Different The DC-DC boost converter is an essential component in the solar PV system as it allows for the efficient conversion of the generated DC supply to a higher voltage level. This increase in voltage is necessary to ensure optimal power output from the system. The Perturb and Observe (P&O) MPPT algorithm is employed in conjunction with the boost converter to maximize the energy harvested from the solar panels by continuously adjusting the operating point to track the maximum power point as shown Fig.3. The generated power transfer to the DC bus utilizes battery energy storage and electric vehicle charging stations. The battery energy storage system allows for the storage of excess energy generated by the solar panels, which can be used during periods of low sunlight or high demand. Additionally, the electric vehicle charging stations utilize the generated power to charge electric vehicles, further maximizing the utilization of renewable energy sources.

Fig. 4 depicts the solar panel's P-V curve as a function of irradiance. Characteristics are shown for a range of irradiance levels from 400W/m2 to 1200W/m2 at a constant temperature of 25^0C. At 150 V, 3 kW is the maximum power that may be applied to 1000 W/m2. In order to maximize electricity production from the solar panel, this data is helpful in calculating the ideal operating conditions. It also shows how the MPPT mode is crucial for making the most of solar power and avoiding battery overcharging.

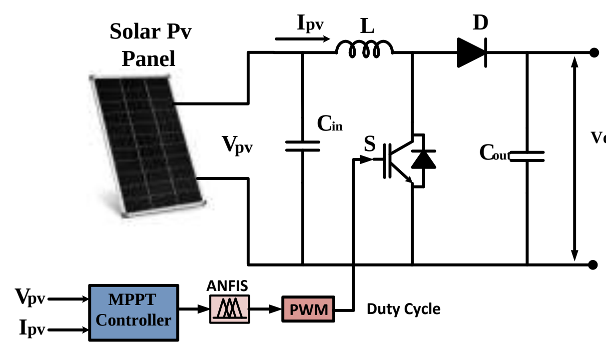


Fig 3. Solar energy conversion system with controller.

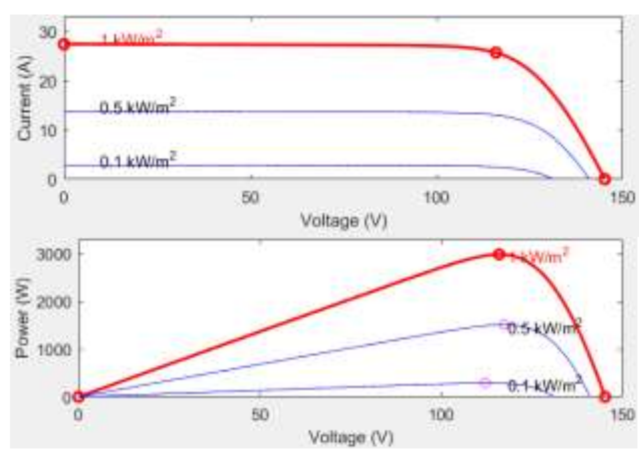


Fig .4 Effect of Irradiance on PV array performance at T = 25^0C.

The power at the PV panel is

$$P_{PV} = V_{PV} \times I_{PV} \quad (1)$$

Where V is the voltage between the PV panel's terminals and I is the current flowing through the panel. Fig. 5 is a flowchart depicting the MPPT algorithm. Using the converter's duty cycle, the MPPT algorithm follows the PV panel's maximum power point in real time. The panel's power output is determined once voltage and current are measured. The data is compared to prior readings to determine whether the duty cycle should be increased or decreased. In order to maximise the PV panel's efficiency, this procedure is repeated until the maximum power point is attained.

The maximum power point tracking (MPPT) algorithm in PV systems ensures that the voltage from the PV panels remains close to the MPP level. Changes in power (ΔP) and voltage (ΔV) are utilised to determine the necessary shift in duty cycle (ΔD) using the P&O technique. At first, we raise or decrease the voltage depending on whether or not the predicted change in output power was positive or negative. This repeated procedure continues until the maximum power point is attained. The P&O approach is popular because it is easy to apply and accurate in determining the MPP in a variety of climates.

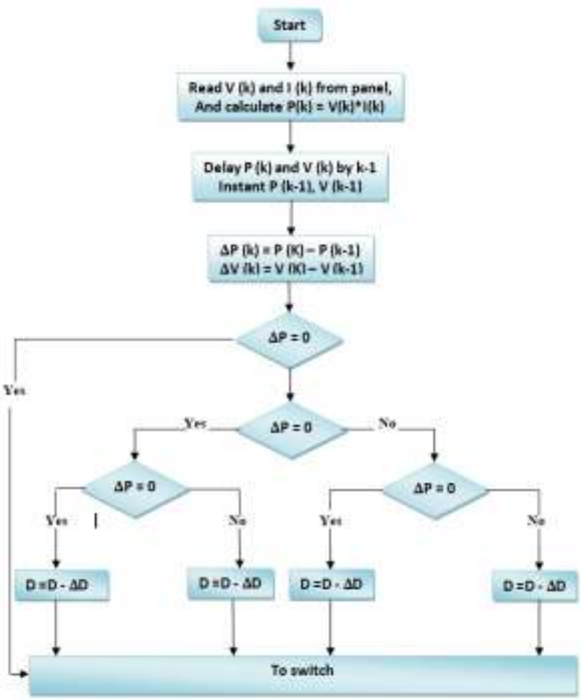


Fig .5 MPPT algorithm flow chart.

4. Wind Energy Conversion System (WECS)

Using Permanent Magnet Synchronous Generators (PMSG) to create electricity from wind is a common and effective strategy for doing so. PMSGs are well-suited for use in wind turbines of varying sizes because to their increased power density in comparison to other kinds of generators. The use of permanent magnets has been shown to improve efficiency and decrease maintenance by eliminating the need for an external power source to generate a magnetic field. Wind turbines' permanent magnet synchronous generators (PMSGs) produce three-phase alternating current, which is rectified into direct current. A DC-DC boost converter is used to further enhance the DC power output as shown in Fig.6. The MPPT algorithm with perturb and observe (P&O) technique is used to optimise the conversion process. This Maximum Power Point Tracking (MPPT) algorithm maintains the wind turbine at its optimum power point, maximizing energy harvesting. The total efficiency of the wind turbine system is increased and energy output is increased as a consequence [27]. Electricity can be efficiently transmitted and distributed to battery storage and electric car systems thanks to this conversion. Furthermore, PMSGs give improved control over power production, allowing efficient utilization of wind resources and enhancing the stability of hybrid renewable energy storage system.

The kinetic energy of the wind is given by

$$KE = 0.5\, \rho\, A\, V^3 \qquad (2)$$

Where KE is the kinetic energy of the wind (in watts, or joules per second), ρ (rho) is the air density (in kilograms per cubic meter), A is the swept area of the rotor blades (in square meters), and V is the wind speed (in meters per second).

The power extracted by the wind from the turbine's rotor blades is given by

$$P_{wind} = 0.5\, \rho\, A\, V^3\, C_P \qquad (3)$$

Where P_{wind} is the power extracted by the wind (in watts), C_P is the power coefficient, representing the efficiency of the wind turbine in converting wind energy into mechanical energy.

The mechanical power input is the power transferred from the rotor blades to the turbine's drive train and is given by

$$P_m = 0.5\, \rho\, A\, V^3\, C_P \qquad (4)$$

This setup employs a wind turbine with a changeable rotational speed. Wind speed and pitch angle, as well as the size of each blade, are important factors to consider when designing a wind turbine as shown Fig.5. For its low running cost and minimal maintenance requirements, a permanent magnet synchronous generator is used. The output of the generator is proportional to the wind velocity. With a variable-speed wind turbine, the blades' rotating speed may be adjusted according to the wind conditions, allowing for maximum energy harvest. This provides the highest levels of productivity and energy production. The permanent magnet synchronous generator is an excellent option for this setup because of its great dependability and efficiency.

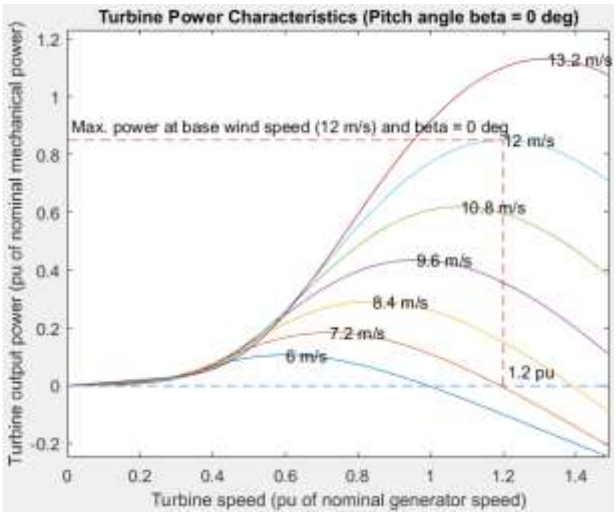


Fig .5 Mechanical characteristics of wind turbine for different wind speeds.

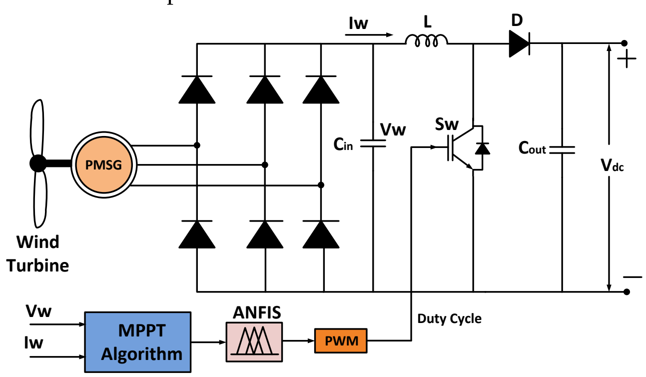


Fig .6 Wind energy conversion system with controller.

5. Battery Storage System (BSS)

Lithium-ion batteries are widely used because of their high energy density and extended cycle life, making them an attractive option for energy storage. The DC-DC bidirectional converter is essential because it regulates the battery's charge and discharge for optimal performance as shown Fig.7. In addition to facilitating the incorporation of renewable energy sources, this method also aids in grid stability by supplying instantaneous power on demand. The ANFIS controller regulates the battery's voltage and current while charging and discharging to maximise its capacity and service life. To ensure reliable and efficient energy transmission, this controller employs an adaptive neuro-fuzzy inference system to track and alter the converter's performance in real time. By installing an ANFIS controller in the DC-DC bidirectional converter, the lithium-ion battery system may achieve optimum efficiency and dependability in numerous applications, from electric automobiles to renewable energy storage systems. The battery's charging and discharging operations may be precisely regulated and optimised thanks to the outer ANFIS controller, which regulates the DC bus voltage, and the inner ANFIS controller, which regulates the battery current.

This dual-controller configuration keeps the battery within its safe working limits while optimising energy transfer, which in turn increases the battery's longevity and boosts the system's overall performance. With its real-time monitoring and adaptive control, ANFIS technology is also well-suited to dynamic load circumstances and intermittent spikes in energy use.

The rate of change of charge (Q) is provided by $Q(t) = \int i(t)$ with regard to time (t) utilised, where $i(t) = \frac{dQ}{dt}$ is the charging or discharging current flowing through the battery. The voltage (*V*) across a battery is related to the State of Charge (*SoC*) through an integral or a derivative, depending on the direction of the relationship:

$$SoC(t) = \frac{1}{Q_{total}} \int i(t)\,\mathrm{d}t \tag{5}$$

$$V(t) = E(t) - \frac{1}{C} \int i(t)\,\mathrm{d}t \tag{6}$$

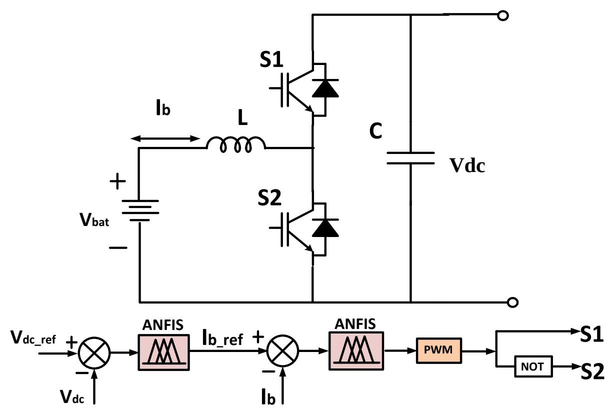


Fig .7 Battery Energy Storage System with ANFIS controller.

Where *E* (*t*) is the electromotive force or open-circuit voltage at time (t), *C* is the battery capacity, Q_{total} is the total charge capacity of the battery.

Battery performance is measured in terms of Columbic Efficiency (CE):

$$CE(t) = \frac{\int i_{b-charge}(t)\,\mathrm{d}t}{\int i_{b-discharge}(t)\,\mathrm{d}t} \tag{7}$$

The ratio of the actual capacity delivered by the battery to the theoretical capacity it should deliver. CE is an important metric as it indicates how efficiently a battery can convert stored energy into usable electrical energy. Additionally, high Columbic Efficiency is desirable as it ensures that the battery can provide consistent and reliable power over its lifespan.

6. Electric Vehicle Battery System (EVBS)

The system configuration for electric vehicle charging and operation using renewable energy sources is a sustainable solution as shown in Fig.1.

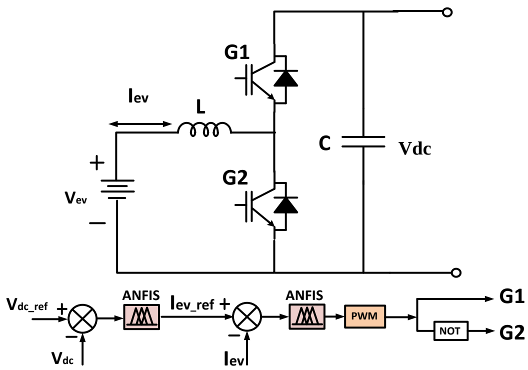


Fig .8 Battery Energy Storage System with ANFIS controller.

- **Bidirectional DC-DC Converter Power Flow:** The bidirectional DC-DC converter is a component that controls the flow of power between the electric vehicle battery and the charging system as shown in Fig.8. During the charging process, the power flowing through the converter (P_{flow}) is determined by the product of the charging current ($i_{ev-charge}$) and the voltage across the converter ($V_{ev-converter}$).

This equation $P_{flow}(t) = V_{ev-converter}(t) \times i_{ev-charge}(t)$) describes how the power is exchanged between the converter and the battery as part of the charging process.

- **ANFIS Controller Adjustment of the bidirectional converter:** The ANFIS controller is an adaptive system that continuously adjusts the operation of the bidirectional DC-DC converter. It does so by monitoring the error between the desired charging power ($P_{desired}$) and the actual power flow (P_{flow}). The adjustment is represented by the rate of change of power flow with respect to time ($\frac{dP_{flow}}{dt}$).

This equation ($\frac{dP_{flow}}{dt}$ =ANFIS ($P_{desired} - P_{flow}$)) expresses how the ANFIS controller dynamically adapts the power flow to align with the desired charging power, ensuring efficiency and adaptability.

- **Energy Supplied with ANFIS controller to the required loads:** The total energy supplied to the battery during charging, considering the ANFIS adjustment, is determined by integrating the adjusted power flow over time.

This equation ($E_{supplied}(t) = \int P_{flow}(t)$ +ANFIS ($P_{desired} - P_{flow}$)) dt) describe a measure of the energy transfer to the battery, accounting for the real-time adjustments made by the ANFIS controller.

- **State of Charge (SoC) regulate with ANFIS controller:** The State of Charge (SoC) of the battery, taking into account the ANFIS adjustment, is related to the total charge capacity (Q_{total}) and the integrated charging current.

This equation describes ($SoC(t) = \frac{1}{Q_{total}} \int i_{ev-charge}(t) + ANFIS\ (P_{desired} - P_{flow}))\, dt$) how the battery's state of charge changes during the charging process, incorporating the influence of the ANFIS controller.

7. PMSM Drives with Battery Storage System

The speed and torque of the PMSM (Power Management Synchronous Motor) are regulated by a three-phase inverter using a pulse width modulation (PWM) approach as shown Fig.9. The PMSM may now be powered by a standard household battery or power source thanks to this arrangement. Power conversion efficiency and noise-free PMSM operation are guaranteed by the ANFIS management of the battery bidirectional converter and the three-phase inverter. The driving experience and battery life are both improved by this all-encompassing control method, which maximises energy efficiency, enhances dynamic responsiveness, and lengthens runtime. The electric vehicle's battery may be charged and discharged using renewable energy sources, and the control system manages both processes.

The DC power supply from battery can be can be expresses as

$$P_{dc} = V_{dc} \times I_{dc} \tag{8}$$

The bidirectional dc-dc converter is responsible for controlling power flow between the vehicle's battery and the 3-phase inverter. In this way, the battery may charge the inverter during acceleration and regenerative braking, maximising the effectiveness of both processes. The battery may be charged by the inverter while braking or when there is spare energy thanks to the bidirectional dc-dc converter. The inverter is crucial in regulating the PMSM's rotational velocity and torque for optimal performance. The optimum operation of the motor is guaranteed by the fact that it controls the AC power's voltage and frequency.

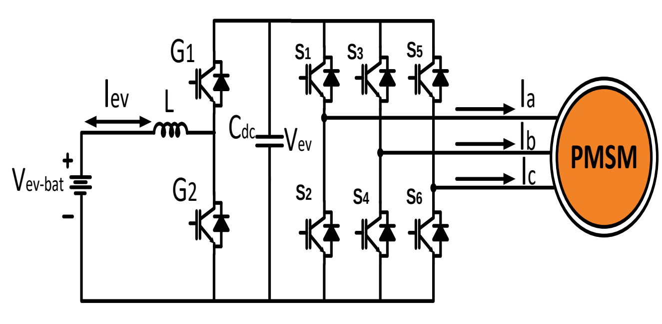


Fig .9 Electric vehicle drive with battery energy storage system.

The three phase inverter converting expresses as

$$P_{ac} = \sqrt{3} \times V_{rms} \times I_{rms} \times \cos(\theta)$$

(9)

Where V_{rms} the root mean square value of the AC voltage is, I_{rms} is the root mean square value of the AC current, and θ is the power factor angle. This type of motor uses permanent magnets to create a magnetic field for the rotor. It offers high efficiency and power density. Due to the constant magnetic field that the permanent magnets generate, this type of motor also offers smooth and precise control in addition to its high efficiency and power density. This makes it ideal for applications that require accurate speed and position control, such as robotics or electric vehicles.

The mechanical power developed by the motor (P_{mech}) can be expresses as

$$P_{mech} = \omega_m \times T_m \qquad (10)$$

Where ω_m is the angular velocity of the motor and T_m is the torque developed by the motor. The electrical power (P_{elec}) can be related to mechanical power can be expresses as

$$P_{elec} = P_{mech} \times \frac{1}{\eta_{motor}} \qquad (11)$$

The motor torque (T_m) is related to the motor current (I_{motor}) given by

$$T_m = \frac{3}{2} \times \frac{P_{elec}}{\omega_m}$$

(12)

8. Proposed ANFIS Control Strategy

The methodology begins with the explicit definition of the control problem, aiming to predict a single output y based on a solitary input x. Fuzzy membership functions, denoted as $A_i(x)$, are meticulously chosen and initialized, such as Gaussian or triangular functions, to encapsulate the linguistic terms related to the input variable [28],[29].

$$\left(\mu_{A_i}(x) = A_i(x)\right) \qquad (13)$$

Fuzzification ensues, transforming crisp input values into fuzzy representations through the application of these membership functions [30]. Fuzzy if-then rules are then formulated, expressing relationships between input and output based on fuzzy set memberships.

$$w_i = \prod_{j=1}^{m} \mu_{A_i}(x_j)$$

(14)

Normalization follows, ensuring that the firing strengths collectively sum to 1.

$$\alpha_i = \frac{w_i}{\sum_{i=1}^{n} w_i} \qquad (15)$$

The consequent parameters of each rule are subsequently adjusted to optimize the system's output, often via a least squares method.

$$\theta_{ij} = \frac{\sum_{k=1}^{P} \alpha k \cdot yk \cdot B_{ij}(x)}{\sum_{k=1}^{P} \alpha k \cdot \left(B_i(x)\right)^2} \qquad (16)$$

Training involves iterative adjustments to minimize the error function, where $\hat{y}_l$ represents the predicted output.

$$E = \frac{1}{2} \Sigma_{1=1}^{q} \left(yl - \hat{y}_l\right)^2 \qquad (17)$$

The model is then validated on a separate dataset, and its performance is tested on additional data. If employing MATLAB for simulation, functions and optimization tools within MATLAB can be applied in various steps of the methodology, enhancing computational efficiency and accuracy in parameter adjustments. The results of training and testing are presented and analyzed, providing insights into the accuracy and effectiveness of the SISO ANFIS control system. The conclusion summarizes the key findings, underscoring the success of the proposed methodology in training a SISO ANFIS model for control applications.

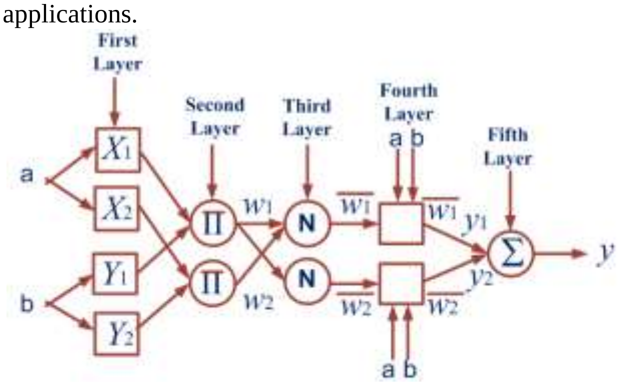


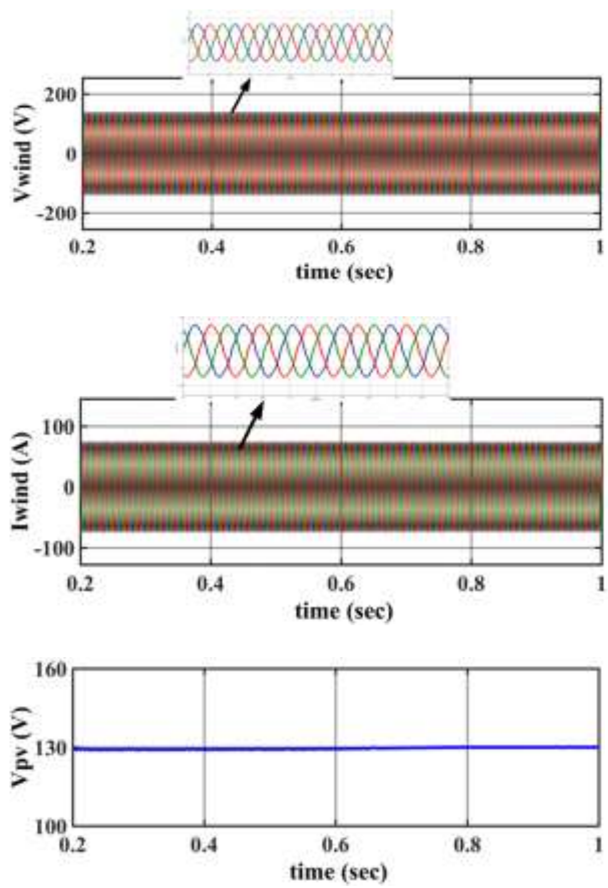
Fig .10 Typical architecture of ANFIS

9. Results and Discussion

Results illustrating suggested control power production using MPPT (Maximum Power Point Tracking) algorithms from renewable energy sources like solar and wind are shown in this section. An MPPT algorithm was constructed and evaluated on a prototype system consisting of a few solar panels and a wind turbine. The results prove that the suggested control works to optimize power production from RE sources. With the suggested ANFIS controller, the energy produced from renewable sources may be stored in batteries and utilised to power a wide range of devices and systems. The renewable power sources not only store energy in the form of electricity, but they also provide electricity to the charging station for the electric cars. The Permanent Magnet Synchronous Motor (PMSM) used to propel electric vehicles is driven by the efficient charging and discharging made possible by this ANFIS controller. We can reduce our reliance on fossil fuels and our environmental effect by operating electric cars more efficiently and for longer with this cutting-edge control system that incorporates renewable energy sources. With ANFIS control, PMSM motors may be operated with accurate and efficient speed and torque management. The many modifications of circumstances presented in this section include the capacity to produce high power density, increased energy efficiency, and decreased maintenance needs. Because of its increased dependability and longevity, PMSM technology is also a good fit for use in electric vehicles.

9.1. Steady state condition renewable energy sources at maximum capacity

Here, we optimise the maximum energy conversion process utilising the ANFIS control algorithm and the MPPT algorithm to produce power from renewable sources. The battery energy storage system will be utilised to store electricity generated from renewable sources for usage during times of high energy demand or when renewable energy production is at a low. Figure 11 depicts the maximum irradiation of 1000 w/m2 from the sun and the maximum wind speed of 12 m/s. The maximum power point tracking (MPPT) algorithm guarantees that the solar panels and wind turbines are operating at peak efficiency. The most energy possible from renewable sources can be stored in batteries and electric car batteries.



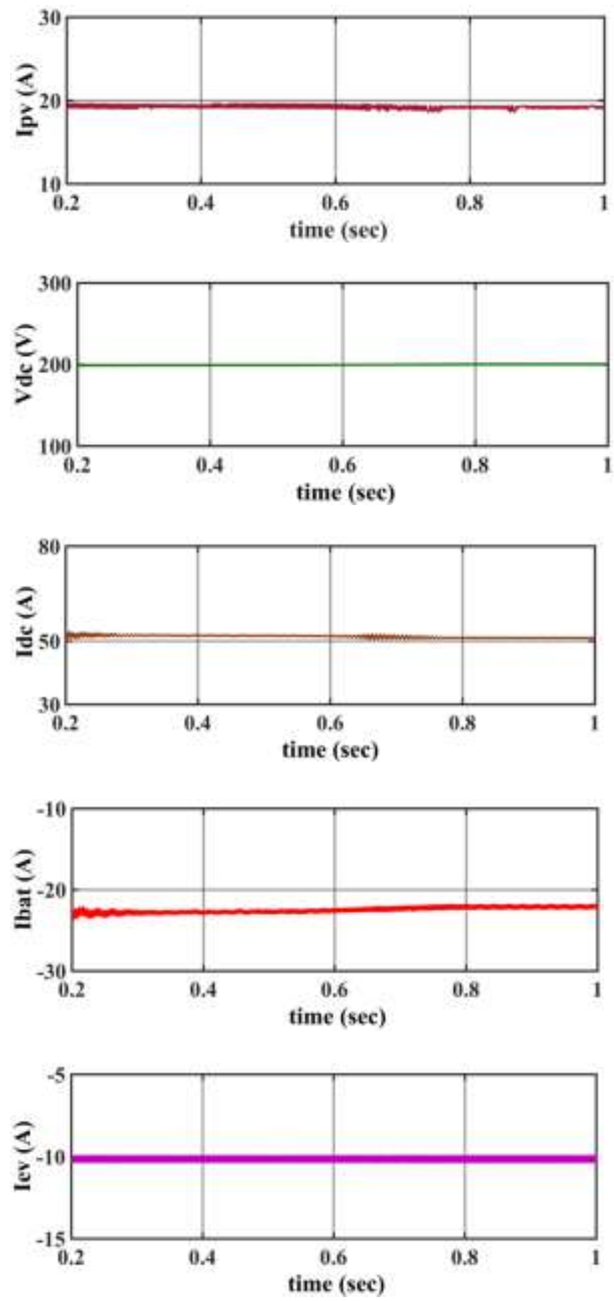
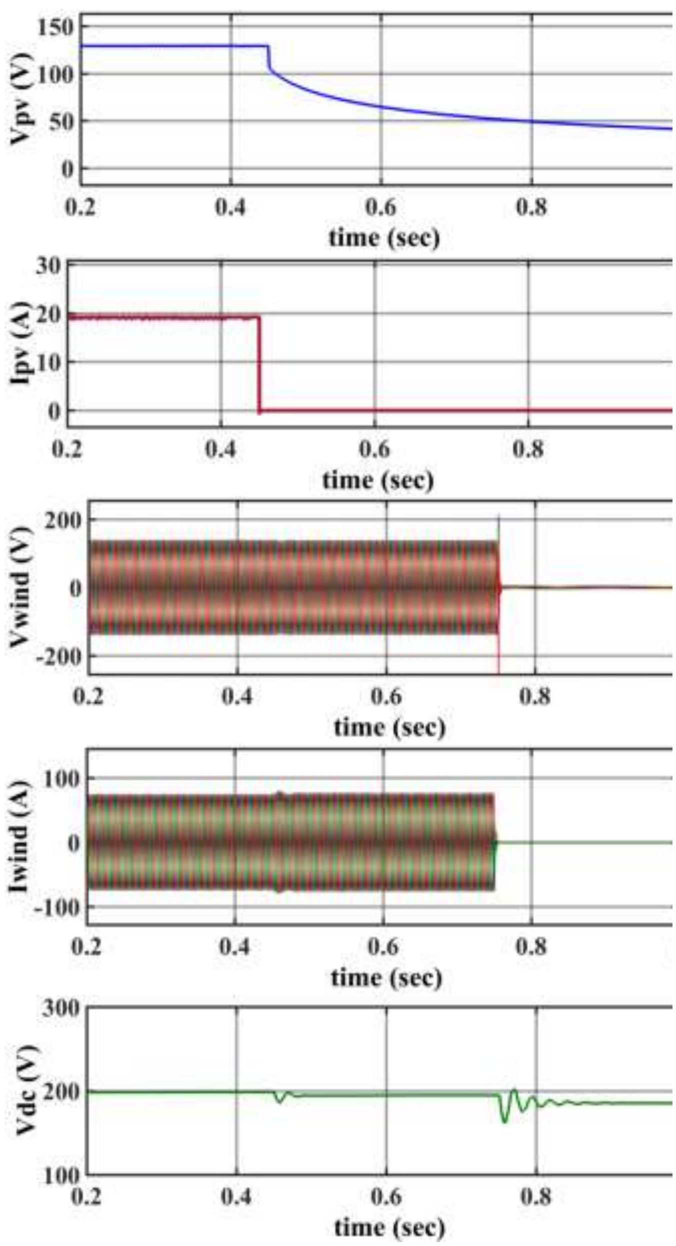


Fig .11 steady state operation of Renewable energy storage system

9.2. Dynamic performance of renewable energy sources with climate changes

The climate is not constant at all; it varies with respect to time and location. It is affected by a wide variety of variables, including solar radiation, wind speed, and the balance of gases in the atmosphere. From 0.2 seconds at 1000 w/m2 to 0.45 seconds at 0 w/m2 is the range of solar irradiation in this region (Fig.12). The local climate and weather may be profoundly affected by variations in sun irradiation. Winds will increase from 0.75 seconds to 1 second at 12 m/s to 0 m/s. The development of weather systems like storms and calm situations may be substantially influenced by these shifts in wind speed. These variations in solar irradiance and wind speed may have an impact on the charging and discharging of the battery system in relation to renewable energy output as a result of climate change. With less sunlight available, renewable energy sources may not be able to replenish the battery system as quickly. The ability of a battery system to release stored energy during times of low renewable energy output might be negatively impacted by a drop in wind speed, for example. Therefore, it is vital to consider climate change while building and operating battery systems for renewable energy integration.



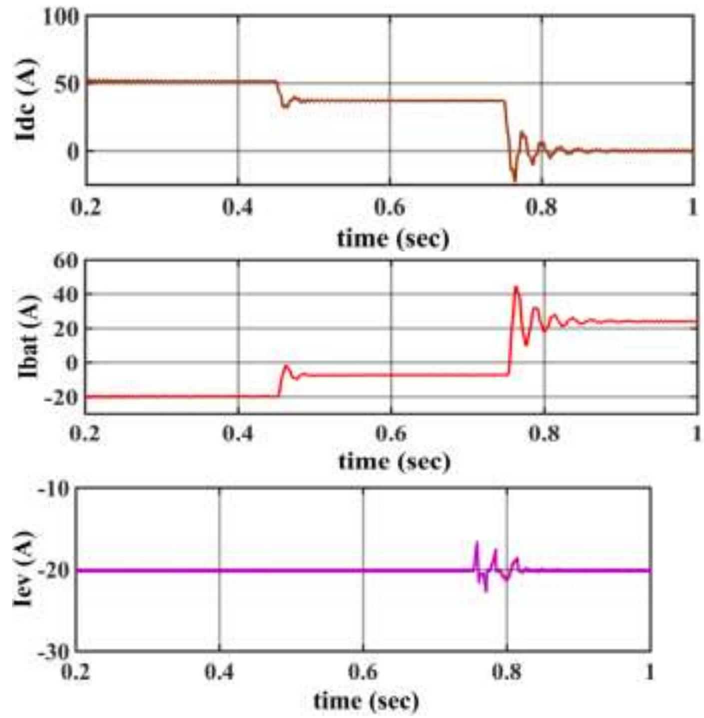


Fig .12 dynamic performance Renewable energy storage system

9.3. A battery storage system can charge an electric vehicle battery without renewable energy.

No renewable energy sources are used to generate electricity in this segment. The battery storage system is an integral part of a safe and dependable electrical grid. In times of heavy demand or when renewable energy sources are not providing power, the battery storage system may release the extra energy that was produced during peak production periods. The battery may also power an electric vehicle's battery storage system, making eco-friendly mobility possible. Intermittency problems are reduced thanks to the battery storage system, which guarantees a steady flow of electricity even when there are changes in generation (see Fig. 13). The electric vehicle battery storage technology allows for a variety of stated electric vehicle ranges. Because of this adaptability, a wide range of charging alternatives are now available for EV drivers.

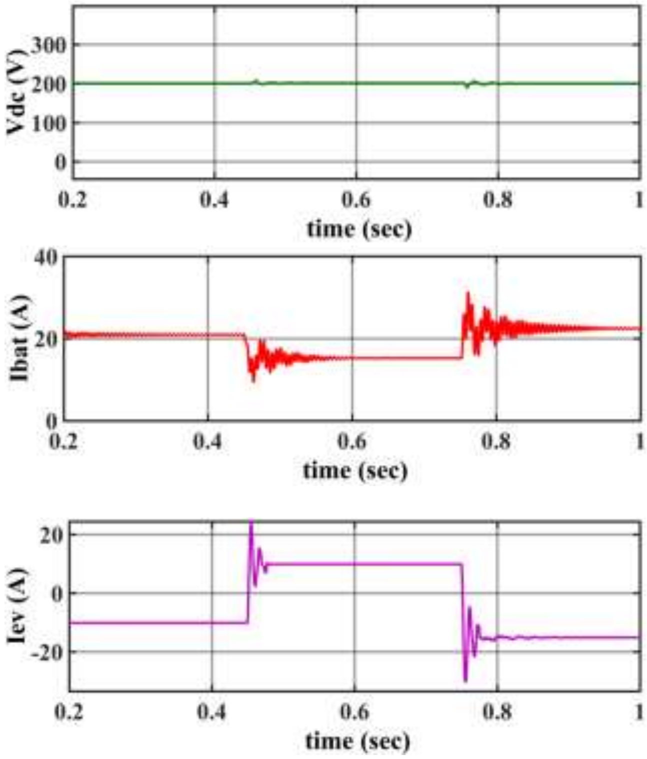
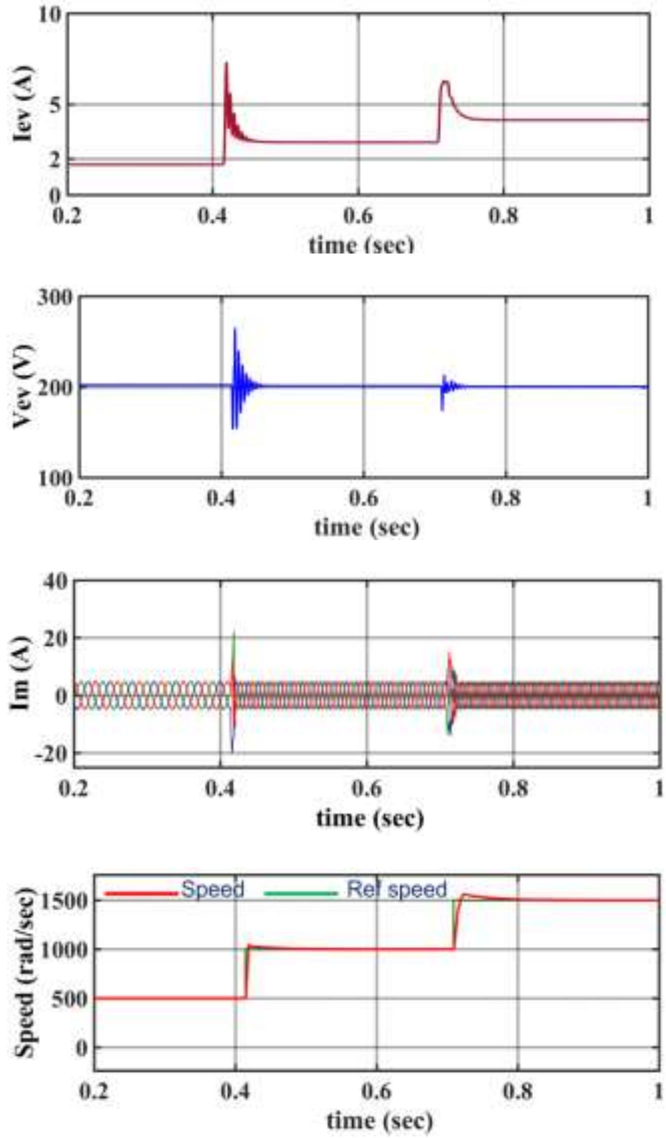


Fig .13 dynamic performance of battery storage system without Renewable energy sources

9.4. PMSM electric vehicle drive with battery storage

As can be seen in Fig. 14, this evaluation and analysis of the electric vehicle battery may be performed at varying speeds and loads. The battery's effectiveness may be evaluated by measuring its efficiency, range, and total power production in a variety of driving situations. Better energy management and battery life may be achieved with the help of the bidirectional dc-dc converter that is based on the ANFIS control system. In addition to improving the electric vehicle's overall performance, PMSM drives provide more torque density and efficiency than conventional induction motors.



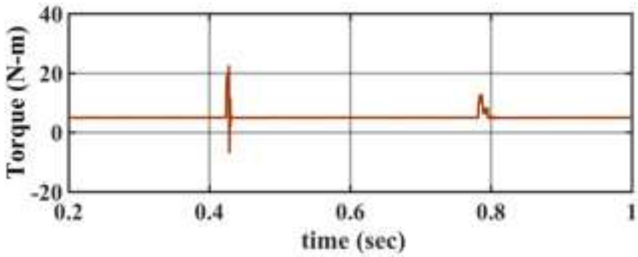


Fig .14 Electric vehicle drive performance with battery energy storage system

10. Conclusion

The proposed system utilizes ANFIS control, a power generation method, to optimize the use of renewable energy sources like solar panels or wind turbines. The system controls the battery system voltage and current, as well as the electric vehicle energy storage voltage and current, to ensure optimal energy utilization. For electric vehicle drives using a battery storage system, ANFIS control can control the power sent to the PMSM through a 3-phase inverter, converting DC power from the battery system into AC power for the vehicle drive. This optimizes the power delivery to the motor, ensuring optimal performance and energy efficiency. This control strategy enhances the driving experience and extends the battery life.

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