



ANFIS-Based Intelligent Control of Solar-Powered DC Motors: A Simulation Approach

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Abstract-The increasing adoption of renewable energy systems has created a need for intelligent control techniques to improve the performance of solar-powered DC motors. This study presents a simulation-based investigation of an Artificial Intelligence (AI)-driven Adaptive Neuro-Fuzzy Inference System (ANFIS) controller for enhancing motor speed regulation and energy utilization. The proposed controller is designed to adapt to variations in solar irradiance, load disturbances, and operating conditions, thereby ensuring stable and efficient motor operation. A detailed simulation model is developed to evaluate the performance of the ANFIS controller and compare it with conventional control methods. The evaluation is based on performance indices such as speed tracking accuracy, response time, energy efficiency, and system robustness. The simulation results demonstrate that the ANFIS-based control strategy provides improved dynamic performance, higher reliability, and better adaptability under varying environmental conditions. The proposed approach contributes to the development of efficient and intelligent solar-powered motor drive systems for sustainable renewable energy applications.

Keywords-ANFIS Controller, Artificial Intelligence, Solar Photovoltaic (PV) System, DC Motor, Renewable Energy, Intelligent Control, Energy Efficiency, Solar Irradiance, Fuzzy Logic, Sustainable Energy.

I. INTRODUCTION

The growing emphasis on sustainable energy sources has led to increased interest in solar power as a viable alternative to traditional fossil fuels. Solar energy, abundant and renewable, offers significant potential for powering various applications, including but not limited to transportation, agriculture, and industrial processes. In particular, solar-powered DC motors have emerged as a promising solution for diverse applications, [1] offering efficient and environmentally friendly means of converting solar energy into mechanical power. However, the effectiveness of solar-powered DC motors hinges not only on the availability of solar irradiance but also on the efficiency of control mechanisms governing their operation. Traditional control methods, while effective to a certain extent, often struggle to adapt to the dynamic and nonlinear nature of solar power systems. This limitation has spurred the exploration of advanced control

techniques, particularly those based on artificial intelligence (AI), to enhance the performance and efficiency of solar-powered DC motors and electric motors. Specifically, a three-phase squirrel cage induction motor functions as the driving force behind the EV. To oversee the dual active bridge converter, an artificial intelligence-based adaptive neuro fuzzy inference system (ANFIS) controller is employed. [2-10]

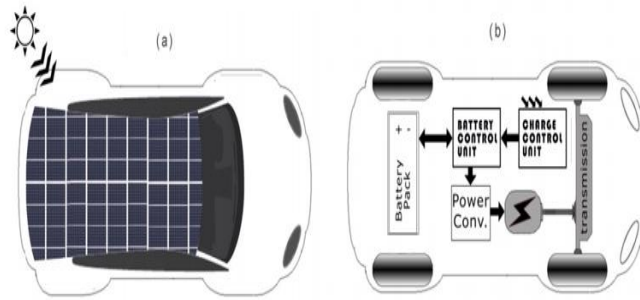


Figure .1. Diagram of Solar EV

Solar-powered DC motors are becoming increasingly popular for various applications, such as electric vehicles, unmanned aerial vehicles (UAVs), and water pumping systems. However, controlling the speed of solar-powered DC motors is challenging due to the intermittent nature of solar power and the nonlinear dynamics of the motor-battery system.

However, these controllers require accurate mathematical models of the system, which are often difficult to obtain for solar-powered DC motors. Moreover, PID controllers may not be able to adapt to changes in the operating conditions, such as variations in solar irradiance.[4]

ANN offer a promising alternative to traditional control techniques for controlling solar-powered DC motors. ANNs can learn and adapt to complex nonlinear systems without requiring a mathematical model of the system. Among different ANN architectures, adaptive neuro-fuzzy inference systems (ANFIS) have gained significant attention in recent years due to their capability to integrate the benefits of both neural networks and fuzzy logic systems.[12]

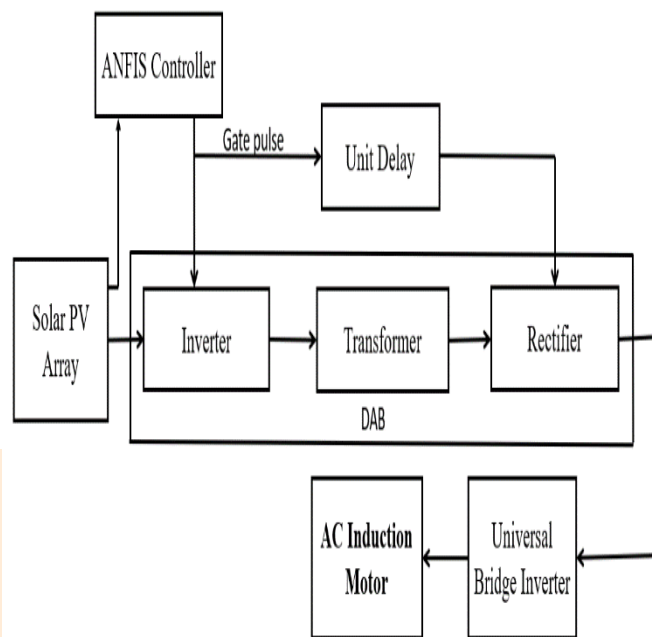
ANFIS can automatically extract knowledge from input-output data, making them suitable for applications where a mathematical model of the system is unavailable or difficult to obtain. In this study, we propose controlling solar-powered DC motors using ANFIS technology.

The amount of power generated by a solar panel depends on several factors, including sunlight intensity, panel temperature, and panel orientation. This means that the voltage and current coming from the panel will fluctuate, which can be problematic for a DC motor, which typically requires a constant voltage or current to operate smoothly.[6]

Most DC motors require a regulated power supply to maintain a constant speed and torque. This is because the speed of a DC motor is directly proportional to the voltage applied to it, and the torque is proportional to the current.

II. APROCH IN PROPOSED SCHEME

The solar photovoltaic (PV) array serves as the primary source of energy generation in this system, producing direct current (DC) electricity. Its efficiency is optimized by the maximum power point tracking (MPPT) algorithm. The generated DC electricity is then fed into an inverter, which converts it into alternating



current (AC) electricity. This conversion is essential for compatibility with most electrical systems and appliances. [9,10]

Figure. 2. Diagram of Controlling in Solar-Powered Dc Motors using Ai-Based ANFIS Technology

It may step up or step down the voltage to suit the requirements of the DC motor driver. The rectifier then reverses the process, converting the AC electricity back into DC, specifically tailored for the DC motor's operation and transformer adjusts the voltage level as necessary for the subsequent components.

The DC motor driver plays a crucial role in controlling the DC motor's speed and direction. It amplifies the control signal received from the Adaptive Neuro-Fuzzy Inference System controller, which adjusts the motor's speed based on various inputs, including the motor's current speed and solar panel voltage/current. This integration of multiple inputs allows for precise and dynamic control of the motor's behaviour, optimizing its performance under different conditions.

The gate pulse triggers the switching action within the DC motor driver, enabling precise control over the motor's operation. Additionally, a unit delay component introduces a time delay into the system, which can be utilized for stabilization or fine-tuning of control algorithms, ensuring smooth and stable operation. In terms of mechanical output, the AC induction motor receives the DC electricity from the DC motor driver and converts it into mechanical rotation. This conversion process facilitates the utilization of the generated electricity to drive mechanical systems, enabling a wide range of applications across industries.

A. INDUCTION MOTOR

The universal bridge inverter provides flexibility in converting DC electricity into AC and vice versa. This capability is particularly useful for applications like regenerative braking or grid interconnection, where energy needs to be efficiently managed and utilized. By enabling bidirectional power flow, the universal bridge inverter enhances the system's efficiency and effectiveness, allowing for seamless integration with external power sources or grids. Overall, the integration of these components forms a comprehensive and adaptable system for energy generation, conversion, and utilization. From harnessing solar energy to driving mechanical systems, each component plays a crucial role in optimizing performance and ensuring efficient operation across various applications. Through advanced control algorithms and versatile converters, the

system offers flexibility and scalability, capable of meeting diverse energy needs while maximizing efficiency and sustainability. [2]

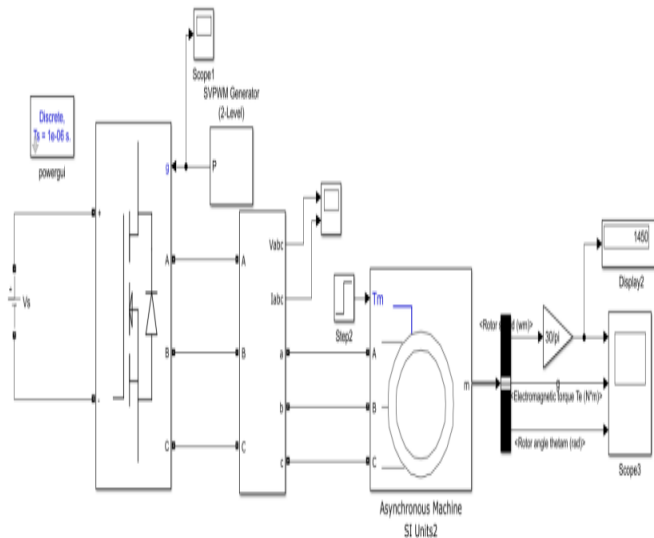


Figure 3. Three-Phase Squirrel Cage Induction Motor in EV

Electric Vehicles (EVs) employ induction motors, relying on electromagnetic induction between a stationary stator and a rotating rotor. The stator, connected to an AC power source, produces a rotating

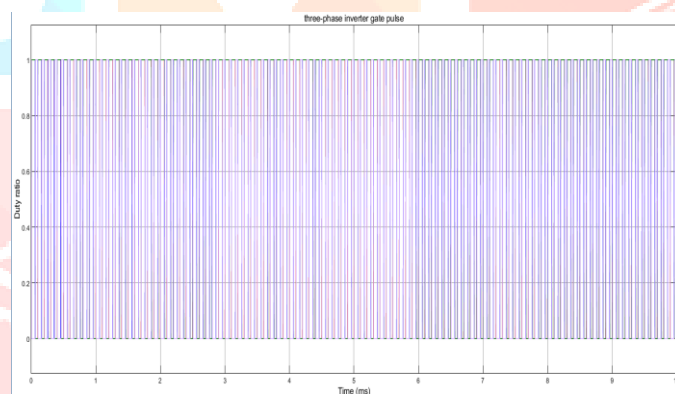


Figure 4: Controlled Gate Pulse of 3 Phase Inverter using SVPWM Generator

thus, producing torque and rotor movement. Control electronics manage speed and torque. Induction motors are favored in EVs for their simplicity, durability, and favourable power-to-weight ratio, making them a preferred choice for propulsion systems.

The diagram portrays a three-phase squirrel cage induction motor, providing 116 variable speed, robustness, and cost-effectiveness. Figure 5 showcases the waveform results of the controlled gate pulse generated by a three-phase inverter, which is then directed to the induction motor.[12]

III. SIMULATION MODEL

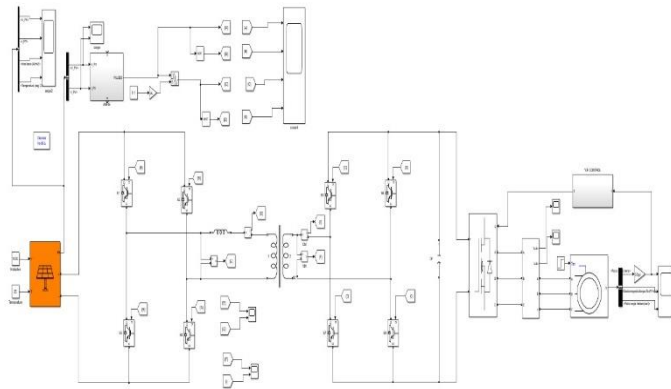


Fig 5: Solar Powered EV Motor using AI Based ANFIS Technology

A. DUAL ACTIVE BRIDGE

The DAB converter, a versatile power electronics network topology commonly found in renewable energy systems like solar inverters, comprises two bridges: an AC/DC input and a DC/DC output, each equipped with controllable switches (typically MOSFETs or IGBTs) and diodes. This converter facilitates bidirectional power flow and boasts benefits such as high efficiency, voltage conversion flexibility, and galvanic isolation. When integrated with solar panels, it efficiently converts the variable DC output into a consistent AC output, suitable for connection to the grid or other applications.

Integrating an Adaptive Neuro-Fuzzy Inference System (ANFIS) for control provides advantages in terms of robustness and adaptability to fluctuating operating conditions. ANFIS controllers leverage a blend of fuzzy logic and neural network principles to dynamically adjust control signals based on input-output data pairs.[12]

D. ANFIS Controller

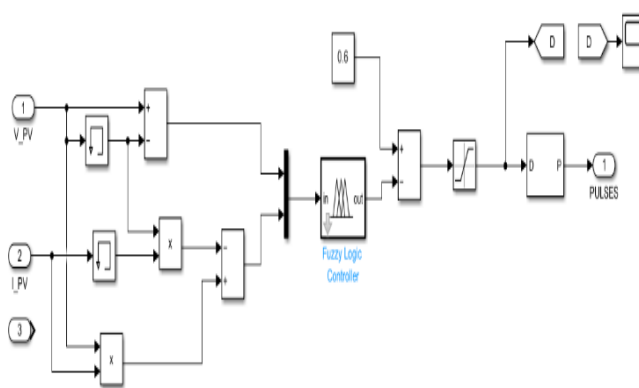


Figure.6. AI Based ANFIS Controller

The ANFIS controller governs the switching signals of the converter's power switches to maintain the desired output voltage and current waveforms. It continually fine-tunes the duty cycles or timing of the switches to enhance performance metrics such as efficiency, output voltage regulation, and reduction of harmonic distortion. Integrating this AI-based ANFIS controller with a Dual Active Bridge converter and solar panels offers an efficient and adaptable solution for power conversion in solar energy systems.[13] [10]

The collaborative operation of the ANFIS controller and the Dual Active Bridge converter alongside solar panels transcends traditional control paradigms. Utilizing sophisticated artificial intelligence methodologies like fuzzy logic and neural networks, the ANFIS controller swiftly adapts to evolving environmental conditions and system dynamics. This adaptiveness ensures optimal performance across diverse scenarios, encompassing variations in solar irradiance and load conditions.

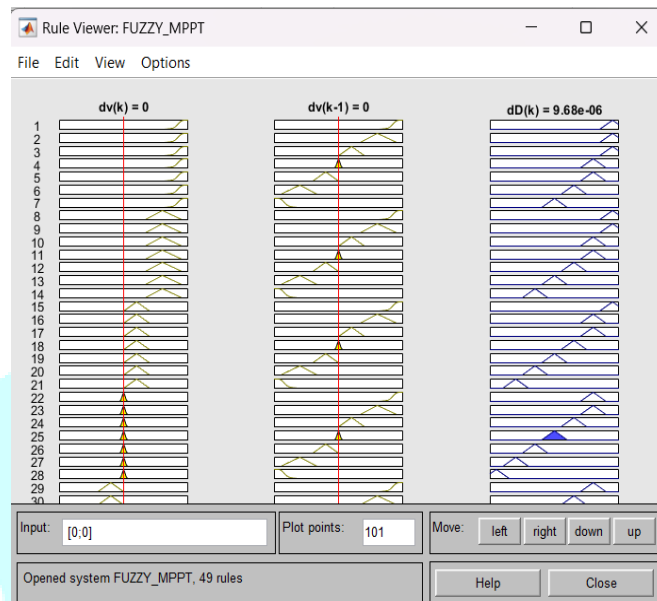


Figure.7. a. Fuzzy in Rules Viewer

Furthermore, the inherent learning capability of ANFIS enables continual refinement of control strategies, fostering heightened system efficiency and reliability over time. Consequently, the integration of ANFIS technology marks a pivotal advancement in bolstering the efficacy and resilience of solar energy conversion system.

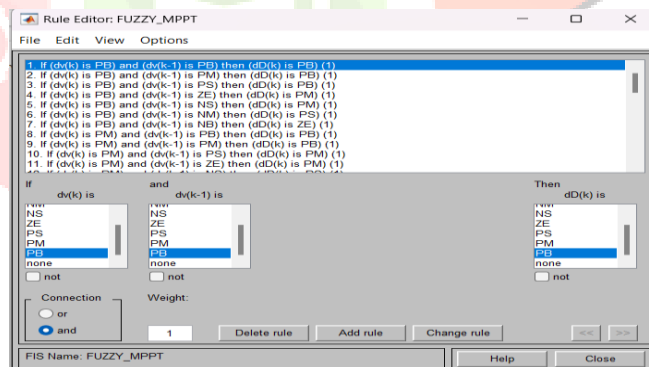


Fig 7. b: Fuzzy 49 Rules Conditions

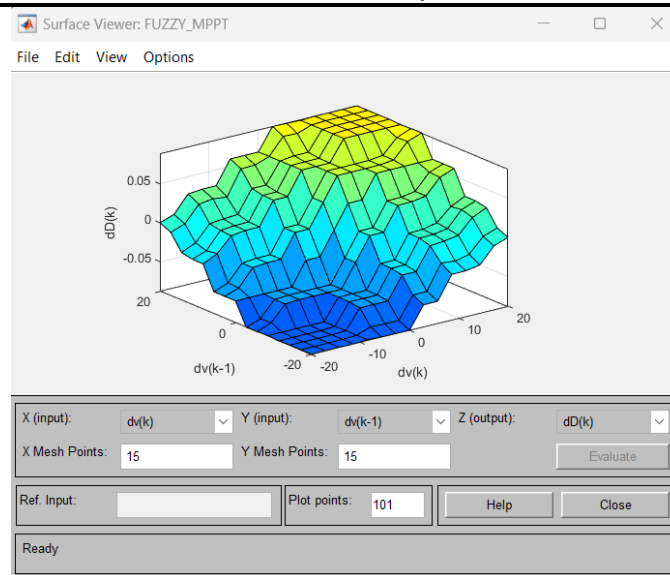


Fig 7. c: Fuzzy in Surface Viewer

IV. RESULTS

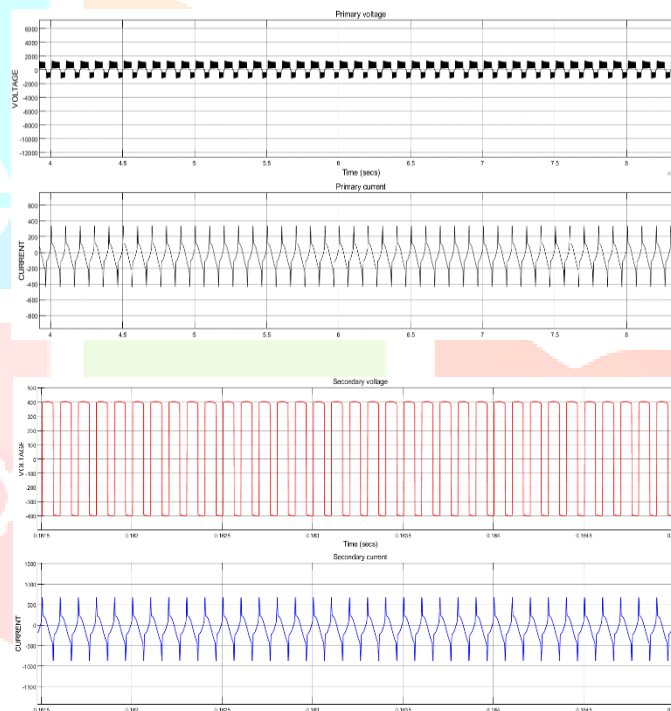


Fig 8. Transmitter Coil/ Primary Winding Voltage and Current

Fig 9. Receiving Coil/ Secondary Winding Voltage and Current

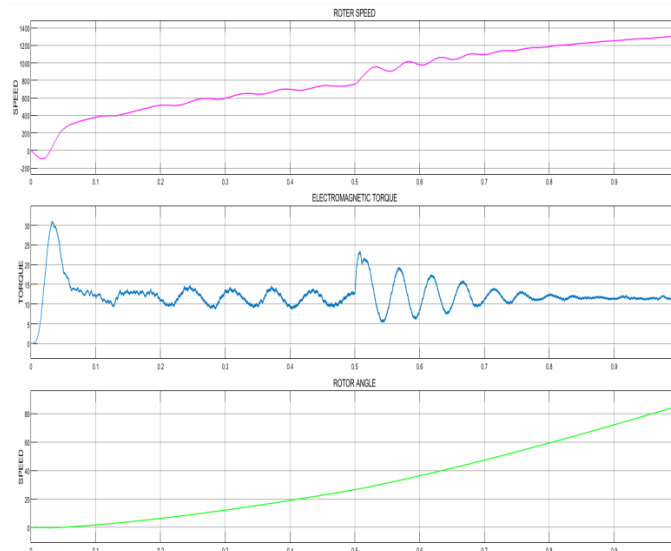


Fig 10. Rotor Speed, Electromagnetic Torque and Rotor Angle

The depicted Figure 10 show cases the rotor speed, electromagnetic torque, and rotor angle of the three-phase induction motor. The results indicate capable operation at the rated RPM of 1400, exhibiting good transient stability and minimal distortions at $t=0.1$ sec. Moreover, the motor can achieve an electromagnetic torque of 10 N-m.

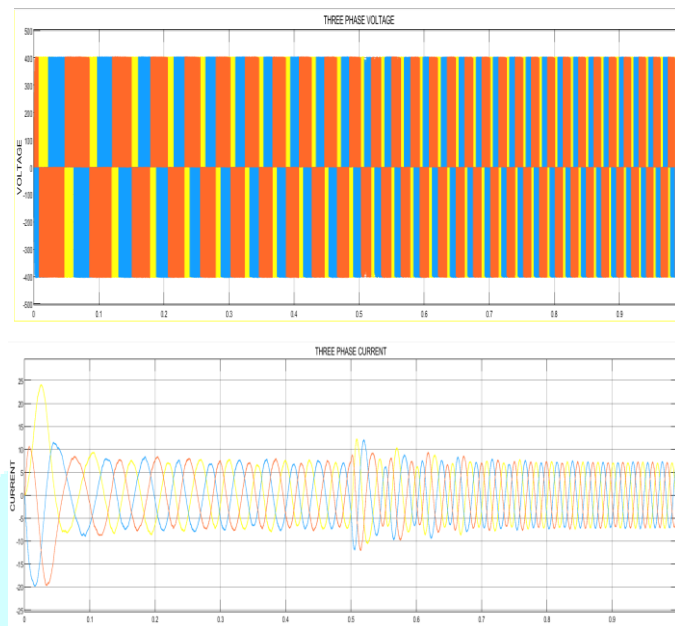


Fig11. Three Phase Voltage and Current from the 3 Phase Inverter

V. CONCLUSION

This study demonstrates the effective integration of solar renewable energy into a DC motor drive system through a wireless power transfer mechanism based on the principle of mutual inductance. A Dual Active Bridge (DAB) converter was utilized to enable efficient bidirectional power conversion and improve energy transfer performance. To achieve intelligent and adaptive control, an Artificial Intelligence (AI)-based Adaptive Neuro-Fuzzy Inference System (ANFIS) controller was implemented. The proposed controller efficiently regulated the DAB converter under varying operating conditions, resulting in improved energy utilization, stable motor performance, and enhanced system reliability. The simulation results confirm that the proposed AI-assisted control strategy offers a promising solution for developing efficient and sustainable solar-powered DC motor applications.

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