MODELING AND ANALYSIS OF RENEWABLE ENERGY AND EV INTEGRATION IN MICROGRIDS USING MATLAB

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ABSTRACT: This study analyzes the impact of integrating Electric Vehicles (EVs) into a renewable energy-based microgrid. Using MATLAB, we model a microgrid that includes a primary hydro generator, a photovoltaic (PV) system, and a Vehicle-to-Grid (V2G) charging station. Energy management is handled by an AI-based Adaptive Neuro-Fuzzy Inference System (ANFIS) controller, which analyzes the EV battery's State of Charge (SOC) to optimize power flow. The research investigates the challenges posed by the non-linear electrical components of EVs and evaluates their effect on the microgrid's voltage profiles, stability, and overall efficiency. The goal is to understand how to effectively integrate the growing number of EVs into modern power systems.

KEYWORDS: renewable energy, grid-to-vehicle, ANFIS, EV.

1. INTRODUCTION

The global transition to Electric Vehicles (EVs) is a vital step toward mitigating air pollution and greenhouse gas emissions. However, the large-scale integration of EVs presents considerable challenges to power grids due to their high, often unpredictable, load requirements and non-linear electronic components, which can distort voltage profiles and compromise system stability.

Microgrids have emerged as a promising solution to manage these complexities. As localized, controllable power systems, they enhance reliability and can seamlessly incorporate diverse energy sources, particularly renewables. This study presents a comprehensive model of a microgrid designed specifically for EV integration, developed in MATLAB/Simulink. The proposed system is powered by a primary hydro generator and supplemented by a photovoltaic (PV) array. A key feature is the inclusion of an EV charging station with Vehicle-to-Grid (V2G) technology, allowing EVs to not only draw power but also supply it back to the grid for support services.

Energy management and load balancing are coordinated by an advanced Adaptive Neuro-Fuzzy Inference System (ANFIS) controller, which optimizes power distribution based on the EV battery's State of Charge (SOC) and other system parameters. The core objective of this research is to thoroughly evaluate the impact of EV integration on the microgrid's operational dynamics. By simulating various scenarios, this work assesses the network's overall performance, stability, and efficiency, offering critical insights into how intelligent control strategies and V2G technology can pave the way for more robust and sustainable energy systems.

2. LITERATURE REVIEW

The integration of electric vehicles (EVs) into the power grid presents significant technical and economic challenges, as highlighted in foundational reviews by Lopes et al. (2011) and Richardson (2013). These studies underscore the necessity for grid reinforcement and sophisticated control strategies to manage the increased load. Comprehensive reviews by Hussain et al. (2021) and Amjad et al. (2018) further detail the primary issues, including voltage dips, load fluctuations, and system losses, recommending demand response and coordinated charging as key mitigation techniques. A major stream of research focuses on optimizing the economic aspects of EV charging, particularly for energy aggregators. James et al. (2016) proposed a model predictive control (MPC) method to maximize aggregator profit, though without assessing the impact on the microgrid's voltage or peak load. Similarly, Vardanyan et al. (2018) developed a stochastic model for optimal aggregator bidding under uncertainty but lacked simulation results on grid performance. The economic focus extends to the consumer, with Gong et al. (2020) designing a dynamic pricing strategy for residential charging to reduce operational costs while maintaining user convenience.

3.METHODOLGYS

A. Hydropower

Hydropower is a renewable energy source that harnesses the energy of moving water to create electricity. It is a reliable and adaptable power source, often favored over diesel generators and wind turbines. Hydropower systems can vary in size from massive dams to small "micro-hydro" setups that can power a few homes.

The fundamental process involves channeling water to turn the blades of a turbine. This spinning turbine drives a generator, which converts the mechanical motion into electrical energy

The amount of electrical power that can be generated from moving water is determined by the following formula:

$$P = \eta * \rho * Q * g * H \qquad (1)$$

Whare
P = Power generated watts (W).
η = The efficiency of the turbine.
ρ = The density of water (kg/m³).
Q = The volumetric flow rate of the water, measured in cubic meters per second (m^3/s).
g = The acceleration due to gravity, (m/s^2).
H = The effective head, measured in meters (m).

B. Solar-power

The renewable energy sources in the microgrid are solar power, generated by a photovoltaic (PV) farm (Fig. 1). Its main function is to convert sunlight into direct current (DC) electricity.

Fig-1 photovoltaic (PV) farm

The energy output of the PV system depends directly on the amount of sunlight it receives, which is influenced by the type of solar panels used and the local weather conditions. According to the study's simulation, the PV farm generates electricity during the daytime, with peak output around noon and no production at night.

In addition to supporting the microgrid’s energy demands, solar generation contributes to environmental protection. However, since solar power depends on weather and daylight availability, it is supported by a hydro power generator to ensure a continuous electricity supply. Using solar energy to charge electric vehicles is also a step toward achieving zero emissions and promoting clean energy usage.

C. Vehicle-to-Grid (V2G) system

The Vehicle-to-Grid (V2G) system is an advanced methodology where Electric Vehicles (EVs) not only consume electricity for charging but can also supply stored energy back to the grid when needed. This system plays a crucial role in energy management and grid stability, especially with the rising integration of renewable energy sources. In V2G mode, EVs act as distributed energy resources (DERs), discharging electricity to support peak load demands, stabilize voltage and frequency, and enhance power quality. The methodology includes coordinated charging/discharging strategies controlled by aggregators—digital platforms that manage the flow of power between EVs and the grid. By implementing optimized charging schedules, V2G reduces stress on the grid, lowers operational costs, and minimizes battery degradation. Additionally, V2G supports ancillary services like secondary frequency regulation, traditionally managed by large power plants. The effectiveness of V2G depends on communication between EVs, charging infrastructure, and the grid, requiring smart charging stations and advanced control algorithms. Overall, V2G presents a mutually beneficial solution, transforming EVs from passive loads to active participants in the power ecosystem.

3.ANFIS CONTROLLER

The Vehicle-to-Grid (V2G) system is an innovative approach where Electric Vehicles (EVs) not only draw power from the grid for charging but can also send electricity back to the grid when required. This helps in managing energy more efficiently and supports the stability of the power grid, especially with the increasing use of renewable energy sources. In V2G operation, EVs act like small energy units that can discharge stored electricity during peak demand times, helping to maintain voltage and frequency levels and improve overall power quality. This process is managed by a digital platform called an aggregator, which coordinates charging and discharging across multiple vehicles. Smart scheduling and control strategies are used to reduce pressure on the grid, cut costs, and limit battery wear. V2G also provides important grid services like secondary frequency control, which is usually done by large power plants. For V2G to work effectively, there must be good communication between EVs, charging stations, and the grid. In short, V2G turns EVs into active energy resources, making the electric power system more reliable and efficient.

A. Fuzzy Inference System (FIS) Structure

The foundation of the controller is a Sugeno-type Fuzzy Inference System (FIS) Fig 3 as it is computationally efficient and well-suited for control applications. The overall structure of the designed FIS, named "pvhydro," is shown below.

- Inputs: The system takes two inputs': The power generated by the photovoltaic array. Hydro: The power generated by the hydro system.
- Output: The system has one output, "output1," which represents the final control signal for energy management.
- FIS Methods: The FIS is configured with standard methods for a Sugeno system: 'prod' for the AND operator, 'wtaver' (weighted average) for defuzzification, 'min' for implication, and 'max' for aggregation.

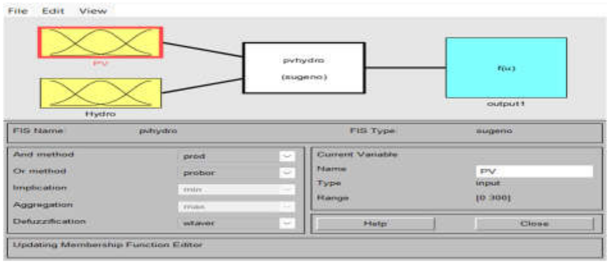

Figure 3: ANFIS model structure with PV and Hydro inputs.

B. Input Membership Functions

To handle the uncertainty and variability of the power sources, the crisp input values (e.g., power in kW) are converted into linguistic fuzzy sets through membership functions Fig 4 and Fig 5. This process is known as fuzzification. Both inputs have a defined range of [0 300] and use three triangular membership functions (trimf) to represent different power levels Fig 5.

- PV Input: The "PV" input is categorized into low, medium, and high-power levels. The parameters for the 'low' membership function are [-125 0 125].

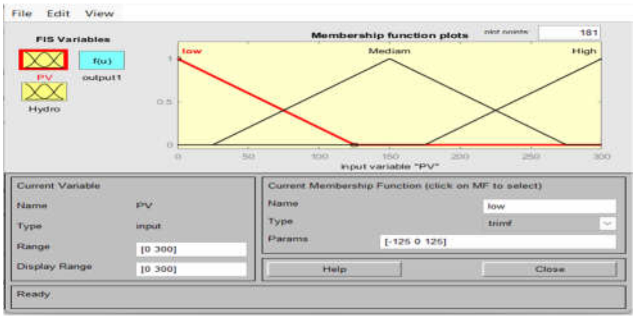

Figure 4: Membership functions for the "PV" input variable.

- Hydro Input: The "Hydro" input is similarly categorized using Low_G, Medium_G, and High_G membership functions. The parameters for the 'Low_G' function are [-125 0 125].

C. Fuzzy Rules and Inference

The core of the fuzzy controller is a set of IF-THEN rules that dictate the output based on the input conditions. With two inputs each having three membership functions, the system is built on a rule base of 3times3=9 rules Fig 6.

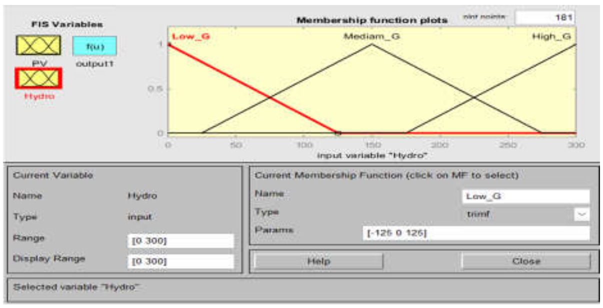

Figure 5: Membership functions for the "Hydro" input variable.

The Rule Viewer shows how these rules are evaluated for a specific set of inputs. For example, when the PV input is 150 and the Hydro input is 150, the controller processes these values through the 9 rules to produce a crisp output of 1. The yellow-highlighted areas on the plots show the degree to which each rule is activated, and the final output is calculated by aggregating these results.

Figure 6: Rule viewer demonstrating the inference process for given inputs.

The Surface Viewer visualizes the complete input-output relationship of the ANFIS controller as a 3D plot Fig 7. The X and Y axes represent the PV and Hydro inputs, respectively, while the Z axis shows the corresponding "output1" value. This surface represents the controller's entire decision-making logic, illustrating how the output signal changes smoothly in response to any combination of input power levels. This final mapping is the result of the defuzzification process, where the aggregated fuzzy outputs are converted into a single, precise control value.

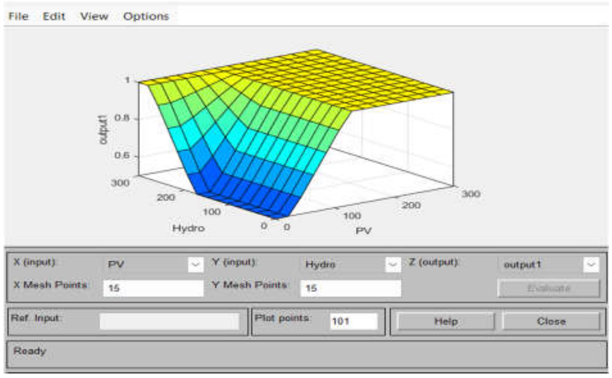

Figure 7: ANFIS controller output surface.

4. SIMULATION & RESULTS

Fig 8 model explores the synergistic operation of renewable energy sources, such as solar and hydro power, with electric vehicles (EVs) within a microgrid system. The simulated environment connects and manages diverse components, including renewable energy generators, EV charging units, energy storage systems (like

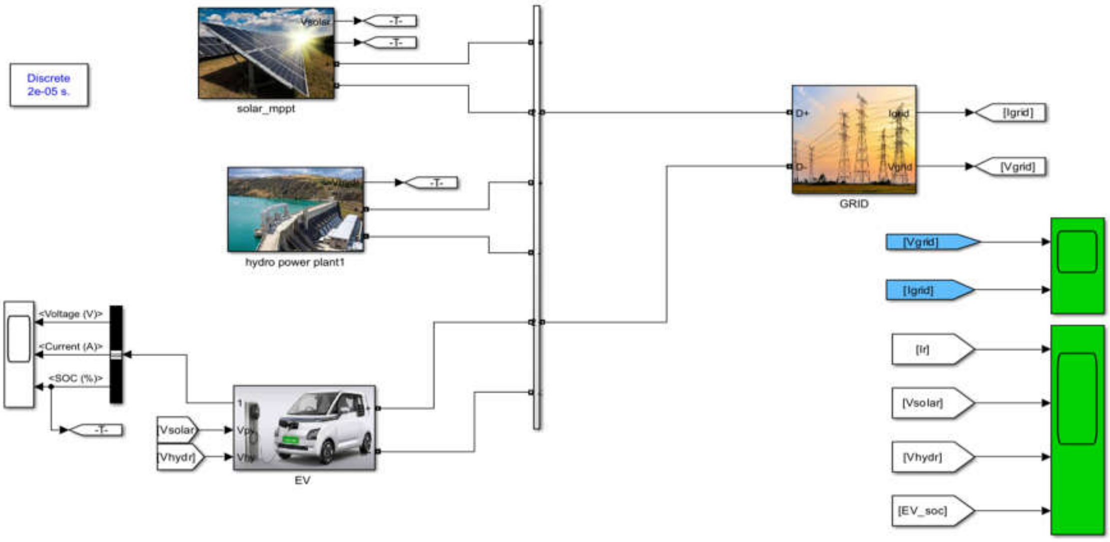

Fig 8 simulation model

batteries), and central control units. the proposed energy management system's dynamic performance over a 1.5-second simulation. The system effectively balances power from solar, hydro, and electric vehicles, ensuring grid stability amidst changing conditions.

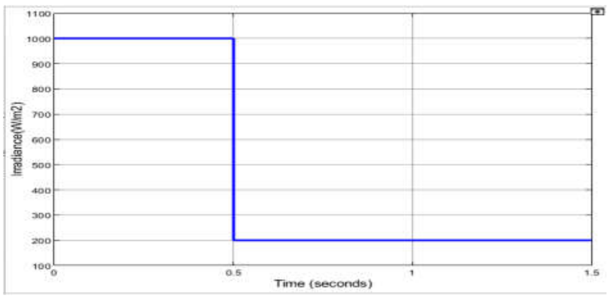

Figure 9: Irradiance

Figure 9 represent Irradiance of input solar array in simulation begins with a high solar irradiance of 1000 W/m2 from 0 to 0.5 seconds. At 0.5 seconds, the irradiance sharply drops to 200 W/m^2 and remains at this lower level until the end of the simulation at 1.5 seconds.

Figure 10 Voltage at Solar PV is Corresponding to the irradiance changes, the solar PV system initially generates power at approximately 175 V. When the solar irradiance drops at 0.5 seconds, the PV system's voltage also significantly falls to about 40 V, reflecting the reduced solar input.

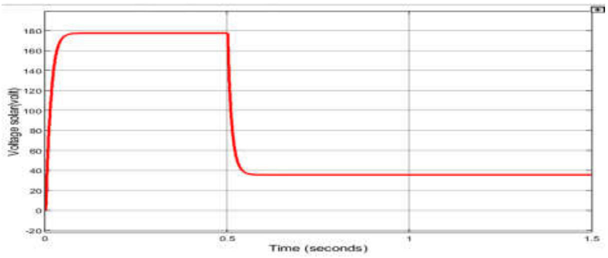

Figure 10 Voltage at Solar PV

Figure 11 Voltage at Hydro of the hydro system consistently supplies power at approximately 175 V for the first 1.0 second of the simulation. This sustained output helps compensate for any initial solar fluctuations and the subsequent loss of solar power. However, at 1.0 second, the hydro system's output voltage also drops significantly to a minimum, indicating a reduction in its power generation.

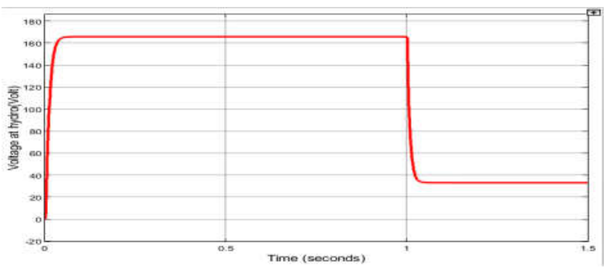

Figure 11 Voltage at Hydro

Figure 12 SOC of Battery: The EV's State of Charge (SOC) steadily increases from an initial 80% up to approximately 81.3% by 1.0 second. This indicates that the EV is primarily in Grid-to-Vehicle (G2V) charging mode during this period, utilizing available power from the solar and hydro systems, a process facilitated by the ANFIS controller. After 1.0 second, as both solar and hydro generation drop to minimum levels, the EV switches to Vehicle-to-Grid (V2G) mode to support the grid, and its SOC begins to decrease, reflecting the battery discharging power back into the system.

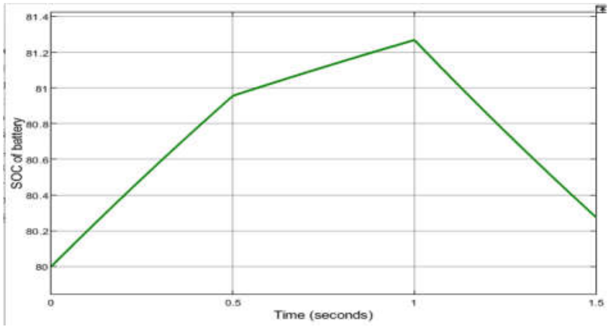

Figure 12 SOC of Battery

Figure 13 displays the grid's voltage and current waveforms throughout the entire 1.5-second simulation. Despite the significant dynamic events, such as the complete loss of solar power at 0.5 seconds and the subsequent drop in hydro power at 1.0 second, the grid voltage and current consistently remain stable and uninterrupted. The waveforms maintain a clean sinusoidal shape, demonstrating the energy management controller's success in seamlessly switching between various power sources (PV, Hydro) and energy storage (V2G) to ensure a reliable and stable power supply to the microgrid. Simulation analysis values present in Table 1.

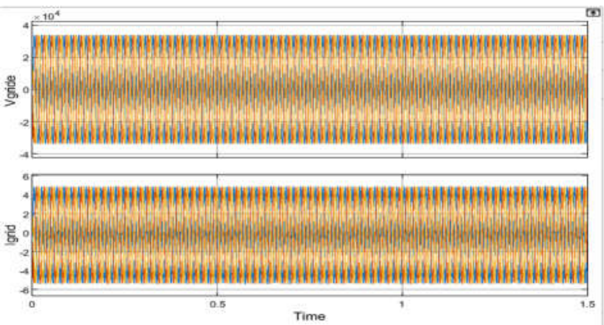

Figure 13 Grid Voltage and Grid Current

Time (s)	Solar Irradiance (W/m2)	Solar PV Voltage (V	Hydro Voltage (V)	EV Operating Mode
0-0.5	1000W/m2	~175	~175	G2V (Charging)
0.5-1	200W/m2	~40	~175	G2V (Charging)
1-1.5	200W/m2	~40	~40	V2G (Discharging)

Table-1

5. CONCLUSION

This paper models and analyzes an EV and renewable-integrated microgrid, highlighting dynamic energy management via an ANFIS controller. This controller intelligently manages EV charging (G2V) and discharging (V2G) for voltage regulation, power loss reduction, and power factor improvement. Simulations confirm grid voltage and current stability despite solar/hydro fluctuations, validating the ANFIS controller's success in seamless power source switching and V2G grid support. Ultimately, ANFIS-based control effectively manages EV integration, optimizing renewables and enhancing grid stability, though further power quality research is needed.

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