International Journal of Applied Electrical and Electronics Engineering
Volume 2 , Issue 1, 2026

Design of Pico Hydro's Battery Energy Storage System (BESS) with Fuzzy Control

Jin, Xie. Department of Electronics Engineering, China

Research Article

Date of Submission: 20-01-2026 Date of Acceptance: 15-02-2026 Date of Publication: 19-03-2026

Abstract—One of the suggested methods for off-grid power supply options for rural communities is the Pico hydro system, which consists of a generator, electronic load controller, and hydro turbine governor. The optimum option for power balancing between power production and load-consuming demand in a traditional hydro system installation is an electronic load controller with proportional-integral-derivative (PID). Nonetheless, electricity demand always peaks during the day, while nighttime energy usage is little. Due to this circumstance, a lot of energy was lost and discharged, and the plant's power stability was not well managed. In order to assess the efficient use of the extra energy, this study sought to build fuzzy logic control (FLC) for an energy system that could satisfy the critical load requirement before being simulated using MATLAB SIMULINK. Implementing a fuzzy logic-based control system using Mamdani's techniques with 25 membership rules may provide effective power flow regulation across situations like discharging, battery backup, and load supply. The outcome shown that using fuzzy control in excess power production from the pico hydro system from 2 to 3 seconds is a better option and more effective system stability and energy delivery.

***Index Terms*—Renewable energy, fuzzy controller, battery storage system, load demand**

INTRODUCTION

Rural electrification is the process of supplying electricity to isolated villages or places, especially those that are distant from cities. These areas often suffer from power outages, which may lead to major problems with power quality and damage to electrical equipment. The mismatch between hydropower production and end-user peak demand is the cause of these problems. To satisfy the demand and guarantee a continuous supply in communities, it is essential to employ sustainable energy via a battery energy storage system that can offer electricity without fail, especially in Sarawak, Malaysia. Ong [1] claims that Malaysia's superior battery energy technology and geographic location make it a chosen clean energy leader in the area. The water turbine speed and different consumer loads will have an impact on the generator's output voltage and frequency. In order to stabilize and sustain the pico hydro system, several electronic load controllers were created many years ago. The possibility of a voltage mismatch between generation and customer demand is reduced by this efficient regulation. In order to maintain a steady output for the system, an electronic load controller employs the dump load technique, which involves consuming surplus power and dumping it into the ballast load [2]. Numerous controller techniques were used to manage the voltage's frequency. To compensate for current and voltage harmonics, Ali et al. [3] developed a revolutionary method called zero switching control. In the meanwhile, Mulyadi et al. [4] presented an integration control method that integrates load control and flow valve control in the pico hydro system. By cutting down on rising, peak, and settling times, this controller will enhance output performance. Similar to human-thinking logic, the Fuzzy Logic Controller (FLC) is a three-stage procedure. They are fuzzy inference, defuzzification, and fuzzification. Because they provide and regulate the output parameters within the allowable limit, these three steps are essential for transforming classical data into fuzzy data. It gives a correct output result, such as partly true instead of true or false, while regulating motor and consumer load [4]. To regulate nonlinear systems and modify PID parameters, Neural Networks Proportional Integral Derivative (PID) was created [5]. This approach has the potential to significantly speed up the learning and control process. Improved momentum helps to boost performance by adjusting external load and parameter fluctuation. The majority of research studies, however, focused only on the controller and did not address the potential for battery charging technology implementation, which would have several advantages for end users, especially during periods of high load demand. Hermann [6] described and examined the technical viability and economic merits of battery charging using minor hydropower resources. In order to provide affordable energy services to the rural region, a variety of battery and charging techniques were found and examined throughout the study. Additionally, a method for figuring out the balance between peak demand and the battery energy storage system was put out [7]. The Peak Reduction Strategy (PRS) is used in the algorithm's equation to calculate the quantity of energy released. The approach is predicated on the equilibrium threshold line parameters and the sum of power for Day-Ahead Load Profiles (DALP). The stored energy will be released

and returned to the system during peak hours. Two battery charging techniques were used in this study: photovoltaic (PV) production and reverse power flow. Nevertheless, only solar PV systems use this battery energy charging mechanism. A novel fuzzy logic controller technique for managing turbine valves and dams via a spillway gateway was presented by Adhikary, Roy, and Mazumdar [8]. The centroid of gravity defuzzification in MATLAB simulation was assessed using the tabu search technique and the Fuzzy Delphi Method (FDM). As an alternative, Subramaniam et al. [9] created the power balancing control technique to distribute power to the battery, load, and grid. Power conditioning systems serve as a bridge between the battery pack, load, and grid. When there is a grid outage, it may either provide electricity to nearby loads or charge the battery. Using Gaussian, triangle, and pi input fuzzy sets, a thorough evaluation of fuzzy controllers' efficacy over traditional controllers was previously carried out [10]. The fuzzy-PID controller performs better than the traditional controller in terms of peak time and overshoot. Nevertheless, the outcome has only been simulated and has not been tested in an actual site installation. In the meanwhile, a Direct Current (DC) DC-DC converter was used as a control mechanism for battery charging and discharging in a PV hybrid system [11]. In order to implement a battery management system, the bidirectional may control other components. However, this study focused on a straightforward control approach that uses a comparison and a converter. Because of its nonlinear characteristics, it is not suitable for use in a pico hydro system. Using the voltage and current from the solar panel and boost converter, Sharom, Josh, and Joseph [12] created a fuzzy controller for PV array battery management. This approach is not appropriate for standalone pico hydro implementation since it just takes into account the input of solar power production. However, the pico hydro system's load power usage fluctuates. The efficiency of a fuzzy controller to regulate power production from a low-energy battery energy storage system in response to frequency fluctuations was shown by Toma, Mihai, and Dobrin [13]. The input of the fuzzy controller is determined by a State of Charge (SOC) and frequency variations. This Battery Energy Storage System (BESS) adds to the main frequency control level due to its lack of coordination. Load demand is not considered in this research. A fuzzy logic-based energy management system comprising fuel cells, supercapacitors, and battery storage devices was described by Baset, Rezk, and Hamada [14]. The load power and SOC are the two inputs of the suggested fuzzy controller, and fuel cell power determines the output. According to their study, the FLC-based management technique ensures fuel efficiency by keeping the battery almost fully charged in addition to supplying the load. Additionally, the power system's operational performance has been enhanced. Nevertheless, it only employs 12 if-then membership criteria. Increasing the number of membership rules might enhance management plan performance and accuracy. Rehman and Riaz [15] used a zero-crossing approach to detect and regulate frequency fluctuation in an electronic load controller. The frequency range is calculated, measured, and compared to a predetermined value. However, the insertion of phantom loads results in energy waste. Thus, in the future, a battery energy storage system may be used.

PICO HYDRO SYSTEM

Fig. 1 depicts the pico hydro system's general block idea. A pico hydro power plant with a battery energy storage system is placed in rural regions to replenish the system's electricity during periods of high load demand. A DC to alternating current (AC) converter was created and attached to the pico hydropower plant since batteries provide energy in DC.



Fig. 1. The whole concept of pico hydro system with battery controller.

To illustrate the effectiveness of the battery energy management system, three main components of the concept—the battery storage system, the DC to AC controller, and the hydropower plant—are created in MATLAB Simulink.

A. Hydro Power Plant

As shown in Fig. 2, a MATLAB model of a pico hydro power plant was created. This model comprises a 200MVA synchronous machine, a 13.8kV excitation system, and a nonlinear hydraulic model of a hydro

turbine governor. The nonlinear hydro turbine governor uses a PID controller and a servo motor. The hydro turbine governor was able to manage the signal and alter the gate opening by using the synchronous machine's speed as a reference speed. Put otherwise, the hydro turbine model will respond to the speed variation of the synchronous machine.

A fuzzy-PID controller was used as a turbine governor in place of a PID controller. The fuzzy-PID controller is selected over other controllers because to its increased stability, reduced steady-state error, and intelligent control. In order to regulate the servo motor and enable the settings to change over time, fuzzy logic was added to the system using Mamdani's fuzzy inference techniques [16].

B. DC to AC Controller

Since this study uses a battery energy storage system, a bidirectional flow is necessary to guarantee the system's stability. A DC to AC converter link in the system is seen in Fig. 3. Inverter control, an insulated gate bipolar transistor with pulse width modulation (PWM IGBT) inverter, and a logic control filter make up the DC to AC converter block.

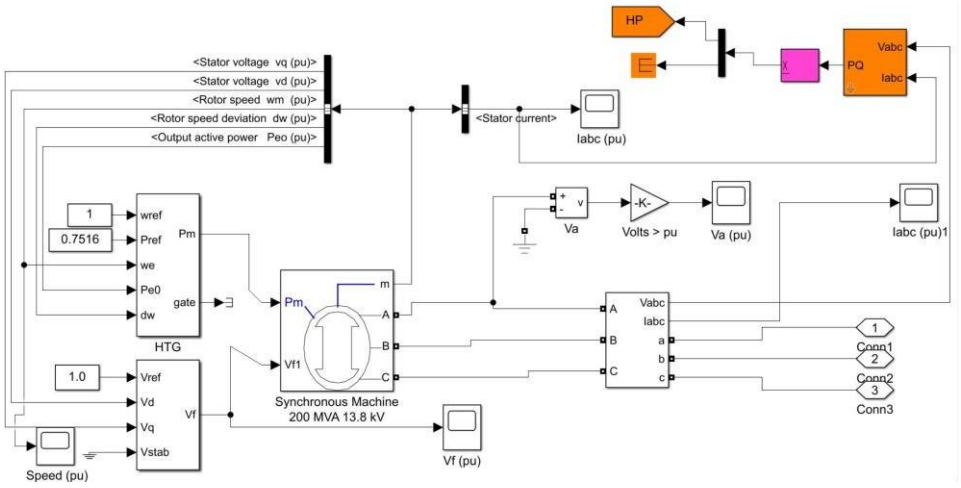


Fig. 2. Circuit modeling for pico hydro system.

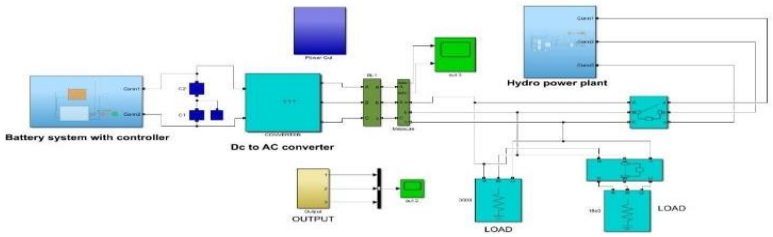


Fig. 3. DC to AC converter in MATLAB Simulink.

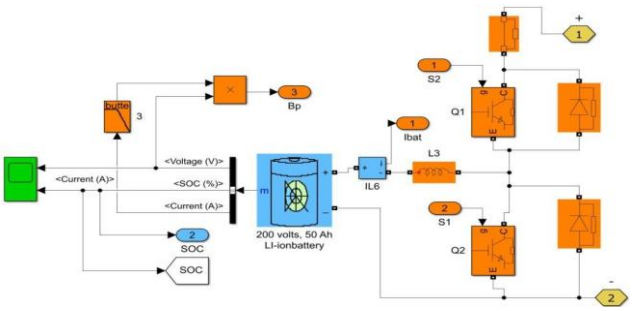


Fig. 4. BESS system with 200V, 50Ah Li-ion battery.

Power may flow as a loaded supply from the battery storage system to the hydropower plant (discharging) or from the pico hydropower plant to the battery (charging status) during periods of high demand. The battery

will store the energy produced by the pico hydropower plant while it is charging, and it will provide a steady output power while it is discharging.

C. BESS

1) Battery implementation

A pico hydro plant must constantly address peak power demand difficulties and energy waste during low power demand in a standard pico hydro system installation. This leads to the overall element of a defective system. The main focus of this study is the BESS, which was created to provide a steady supply of electricity in rural regions. To increase system efficiency, intelligent control techniques like fuzzy logic were used to this system. A battery system constructed using a 200V, 50Ah lithium-ion (Li-ion) battery is seen in Fig. 4.

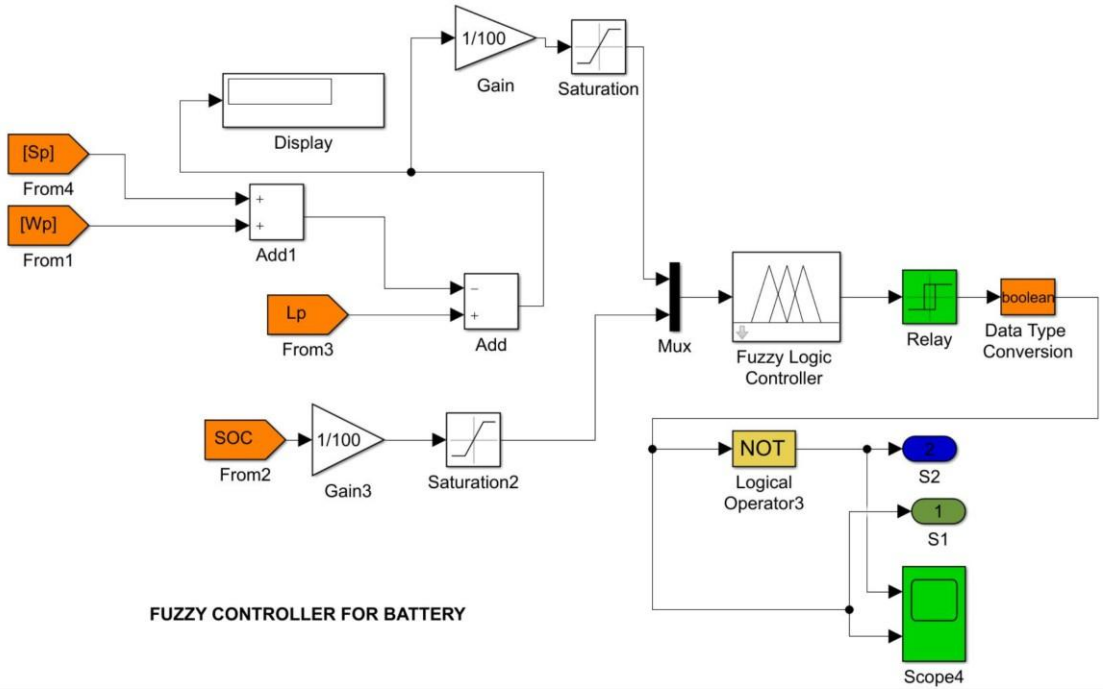


Fig. 5. BESS with fuzzy logic.

Because of its high energy and power density in a variety of industrial applications, including grid and renewable energy storage, Li-ion batteries were selected for this study. The cell is a good alternative to other battery kinds because of its thin, light, and insignificant features. The power output of the charge might be determined using the following equation:

$$\text{Power charging output} = \frac{\text{Capacity battery}}{\text{Charging efficient} \times 24\text{h}}$$

Around 490W output is expected with a minimum 50Ah Li-ion battery, 200V, and 85% charging efficiency. The initial SOC was set to 95%.

2) Battery controller

To regulate the output charging and discharging mode, an intelligent fuzzy was included into the battery controller. The control system for the fuzzy logic model, with two inputs and one output, is shown in Fig. 5.

This work established and built fuzzy logic using Mamdani's approach to regulate the charging process. The fuzzy logic design was divided into three categories: defuzzification, inference system, and fuzzification. The membership function's range and shape dictate fuzzification (Table I).

TABLE I: FUZZY MEMBERSHIP SYSTEM FOR BATTERY CONTROLLER

P/SOC	NB	NS	ZO	PS	PB
NB	PB	PB	PB	PB	PB
NS	PB	PB	PS	PS	PB
ZO	ZO	ZO	ZO	PS	PB
PS	NS	NS	NS	NS	PB

PB	NB	NB	NB	NB	PB

NB = Negative Big, NS = Negative Small, ZO = Zero, PB = Positive Big Medium, PS = Positive Small

The total number of rules used in the rule editor study was 25, where $P^Q = 5^2 = 25$, whereby P is total number of fuzzy sets overlapped and Q is degree of membership for state of charge. Fig. 6 displays the membership function in MATLAB Simulink. The membership function inputs were power and SOC, while the output of the membership function was battery current. For the positive and negative values of the valuables, all of the membership functions were symmetrical. It is classified as negative big (NB), negative small (NS), zero (ZO), positive small (PS), and positive big (PB) (Table I). When the battery current is negative, it indicates that the battery is discharging, whereas when the battery current is positive, it indicates that the battery is charging.

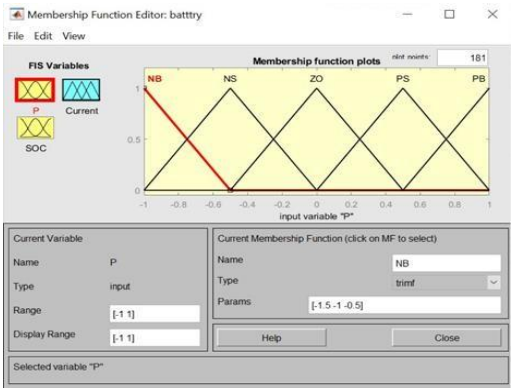


Fig. 6. Membership function for battery controller.

The input from the load power demand and the SOC % will be used to monitor the fuzzy logic battery controller's output. The metal oxide semiconductor field-effect transistor (MOSFET) switch, which controls whether to charge or discharge the battery, will be linked to the battery system. To show that the system is under peak load demand, a three-phase breaker was attached to the additional load (200W) in this study and switched on for two to three seconds. Based on the instantaneous connection of an additional load, the fuzzy logic battery controller will take control action.

PERFORMANCE ANALYSIS

To illustrate effective battery energy management in the pico hydro system, a total simulation period of battery voltage was selected between 0 and 4 seconds (Fig. 7). The LI-ion battery's initial state of charge (SOC) was 95%, which was regarded as almost full capacity. A sharp decrease from 2 to 3 seconds is shown in Fig. 8. When an additional load was applied to the circuit during the time period, this pattern showed that the battery was in draining mode.

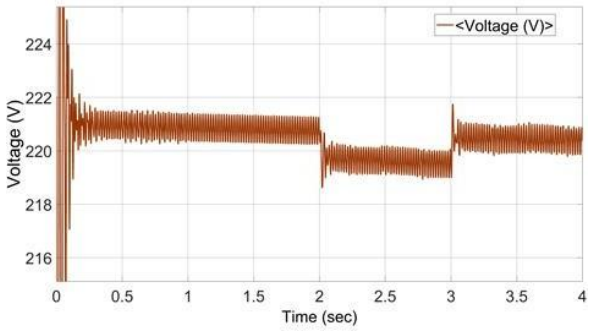


Fig. 7. Simulation analysis for battery voltage.

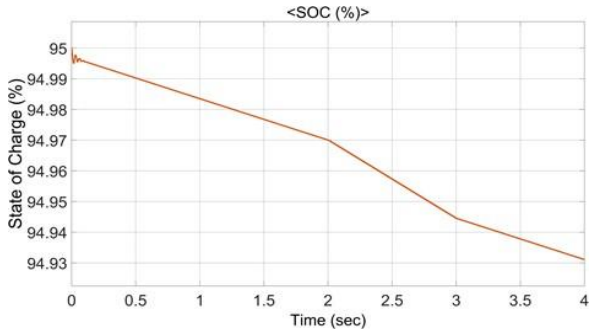


Fig. 8. Simulation analysis for the SOC (%).

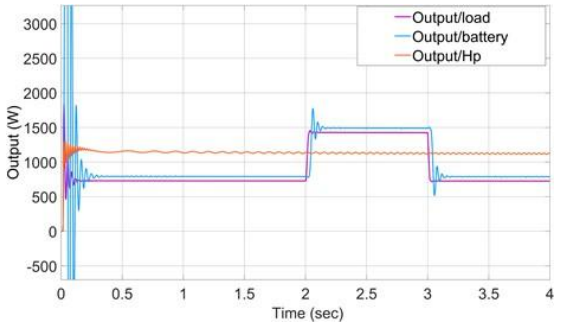


Fig. 9. Output simulation for load, battery, and hydropower.

Because of the additional load during the second and third seconds, the battery voltage decreased from 218V to 217V. The trend showed that the battery controller used SOC and total load power to decide charging and discharging. Under normal load demand conditions, the circuit breaker automatically disconnects after three seconds, allowing the system to resume normal functioning. The output comparison between the battery and the load is shown in Fig. 9.

The power waveforms of the energy storage system, which is made up of a battery and a load, are shown in the waveforms above. The battery is in charging mode at the beginning of the simulation, as seen by the yellow line (output for load) being compensated by battery power. During the simulation, the battery is depleted and electricity is introduced into the system as the load increases from two to three seconds. When the 3-second load drops, the battery goes back to charging mode. This procedure increases the energy management system's efficiency and flexibility when the pico hydro turbine produces excess electricity.

CONCLUSION

This investigation's main goal was to maintain the pico hydro system's functionality and energy delivery even during periods of high load demand, especially in rural regions. One of the greatest methods to guarantee a steady and enough power supply in a pico hydro system is to include battery energy storage. Technical, battery type, and other environmental factors dictate the necessary figures for developing a pico hydro battery energy storage system. Since it guarantees that the system is operating properly, the controller is a crucial component of this study. Battery energy storage devices have used fuzzy logic because of its intelligence characteristic. Mamdani's approach has been put out, and the model is essential. Battery control technology for industrial usage has not yet been developed, despite earlier research on battery charging and discharging procedures. Additionally, some of the batteries are costly and harmful to the environment. To forecast more precise and effective control based on membership norms, this work may be extended by adding other fuzzy-logic-linguistic factors..

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