Optimizing Pico-Hydro Systems in Off-Grid Rural Areas using Adaptive Neuro-Fuzzy Inference System-Particle Swarm Optimization (ANFIS-PSO) with Internet of Things (IoT) Controller

ECIJA, Lois Ivan R.
Electronics Engineering Department
Technological University of the Philippines

PINEDA, Jeremy Paul V.
Electronics Engineering Department
Technological University of the Philippines

REYTOS, Bea Kristine E.
Electronics Engineering Department
Technological University of the Philippines

USON, Chrissia Mae
Electronics Engineering Department
Technological University of the Philippines

ZIPAGAN, Loumeridian T.
Electronics Engineering Department
Technological University of the Philippines

MADRIGAL, Gilfred Allen M.
FACULTY
Electronics Engineering Department
Technological University of the Philippines

Abstract – Electricity is one of the most important resources needed by many humans in the world. In urban areas, having electricity is common; however, in some rural areas, having electricity is still a privilege for some people. The reason might be that their household needs more financial resources, or their location is far away from power generation facilities, making extending to their area expensive for the provider because they need to build many posts and route cables for a small community. Pico-hydro technology will help a community located near running water. But, in normal water turbine systems, the voltage fluctuates and cannot be used by users because it will damage the appliances. The automatic generation controller (AGC) will help the pico-hydro maintain a stable output voltage and frequency. The ANFIS-PSO algorithm will help the stepper motor regulate the output voltage and frequency. With this algorithm, the stepper motor will open and close the gate valve depending on the values. Monitoring the output using their mobile phones will inform the users if the voltage and frequency are still in the desired range.

Keywords – ANFIS-PSO, Pico-hydro power, IoT-based, Automatic generation controller

I. INTRODUCTION

Electricity is certainly necessary for both economic activity and basic human needs, even though it may not be able to produce all the conditions for economic growth on its own. Theoretically, access to electricity can alleviate socioeconomic conditions in developing nations by influencing the environment, health, education, and income—four major factors that contribute to poverty. One of the main barriers to economic development in rural areas is the lack of access to energy, including electricity. Access to power is strongly correlated with poverty in rural areas since it is necessary for engaging in productive activities. Pico-hydroelectric systems that use the power of small water flows are a good option. However, optimizing the performance of these systems is essential to ensure reliable power generation. To address this, the researcher proposes a new approach in our study: an IoT-based automated hydropower generation controller to optimize peak-hydro systems in remote rural areas. This controller features Adaptive Neuro-

Fuzzy Inference System-Particle Swarm Optimization (ANFIS-PSO), a hybrid algorithm that combines the modeling capabilities of ANFIS with the optimization capabilities of PSO. By introducing IoT technology, the operator can monitor and analyze data from pico-hydro systems, promoting intelligent and adaptive monitoring. The research aims to contribute to the energy sustainability of rural off-grid areas, promote renewable energy sources, and promote the socioeconomic development of poor communities.

The Pico-Hydro energy system is a viable and sustainable source of renewable electricity for remote rural communities, leveraging the power potential of nearby water resources. However, optimizing the performance of these systems to ensure energy efficiency poses significant challenges. To address this, researchers have proposed the use of Internet of Things (IoT)-based solar-powered automation for optimizing hydropower plants in remote rural areas. This innovative approach incorporates the advanced capabilities of the Adaptive Neuro-Fuzzy Inference System-Particle Swarm Optimization (ANFIS-PSO) method. By combining neural networks and fuzzy logic, ANFIS enables precise modeling and control, while PSO optimizes system parameters to maximize efficiency. The integration of IoT technology allows for real-time data analysis and remote monitoring of the Pico-Hydro system, ensuring improved performance and power production. This research contributes to the advancement of renewable energy utilization in underserved rural areas, promoting sustainable development and empowering local communities.

II. BACKGROUND OF THE STUDY

Off-grid islands in the Philippines are small, remote islands that frequently rely on extremely expensive and unreliable electricity, assuming they are still in need of electricity. (Delina et al., 2021) Often, remote areas without electricity depend on expensive energy sources like imported fossil fuels or diesel generators. Households and companies are burdened financially by high energy costs, which are largely caused by the costs of fuel purchases and generator system maintenance. Though this expensive electricity supply is available in most parts of the country, many isolated rural areas need access to consistent energy since expanding grid infrastructure is a high cost as well. Residents are consequently compelled to depend on unstable alternative energy sources like kerosene lamps, candles, and improvised diesel generators, all of which are hazardous to their health and safety. Because diesel generators and grid connections are only sometimes dependable, power outages and blackouts are frequent, even in places with access to energy. These disruptions interfere with day-to-day operations, have an impact on enterprises, and impede the socioeconomic advancement of rural communities. By this, the implementation of renewable energy sources, particularly for individuals in rural areas, is essential to the technological advancement of our contemporary world. (Madrigal et al., 2022)

Adaptive Neuro-Fuzzy Inference System (ANFIS) is a controller that is used in several research fields and industries, including automotive. On the other hand, the Particle Swarm Optimization (PSO) is a bio-inspired algorithm that solves the solution of space. According to the publisher of Induction Motor Control Using PSO-ANFIS (Mahapatra et al., 2015), the combination of these control algorithms can provide great performance control, and it can be adjusted. The inputs for this project are the speed, torque, and output firing angle. This study shows that the PSO-ANFIS is the best controller because of its performance with regard to the ANFIS-PSO controller. With the rapid advancement of technology, IoT (Internet of Things) became a transformative opportunity to extend connectivity beyond traditional devices and exchange data over the Internet. IoT facilitates innovative applications in many aspects and areas. It reshapes industries like education, medicine, etc. However, the implementation of renewable off-grid technologies, especially in rural areas, was not considered economically feasible, given the environmental and financial factors. Several advancements and improvements could have been made, and it was gaining momentum but varied greatly depending on the region and specific projects. The IoT-based controllers have become more efficient in managing off-grid, which allows the users to monitor, control, and optimize the resources in terms of solar energy and water.

Integrating the ANFIS-PSO controller with IoT-Based technology, off-grid rural areas can benefit from this project with the improvement of energy efficiency, increased electricity generation, and reduced operational costs. Moreover, the environmental impact of pico-hydro systems can be minimized through proactive operation and management practices.

III. STATEMENT OF THE PROBLEM

The Adaptive Neuro-Fuzzy Inference System-Particle Swarm Optimization (ANFIS-PSO) algorithm is a vast framework pattern that optimizes the ANFIS model for the accurate modeling and control of the system. Integration of IoT solutions ensures accessibility and continuous monitoring management through Mobile Applications. This project aims to improve the stabilization and real-time monitoring of the system. By the integration of ANFIS-PSO and IoT into the system, this study will answer the following questions:

1. How can the system ensure real-time data synchronization without delays in the Mobile Application?
2. Is the ANFIS-PSO algorithm suitable for the stabilization of voltage and frequency compared to other PID controllers and traditional stabilization methods?
3. How can the Mobile Application be user-friendly for a diverse range of users, including non-tech users?
4. Is the robustness of the ANFIS-PSO algorithm present against external disturbances?

IV. RELATED LITERATURE

A. Adaptive Neuro-Fuzzy Inference System-Particle Swarm Optimization control algorithm.

The adaptive neuro-fuzzy inference system (ANFIS) has been determined to be efficient and suitable for regulating the output of the pico-hydro system in terms of the parameters voltage and frequency. However, particle swarm optimization moves in a search space to find a solution suitable to a certain parameter. This algorithm is endowed with self-adaptiveness to improve the performance and accuracy of optimization techniques applied in the domain of water resource management and infrastructure design. (Montalvo, et al., 2010)

The combined controller and algorithm, which is the Adaptive Neuro-Fuzzy Inference System and Particle Swarm Optimization, respectively, has an effective combination in the behavior of the speed of the DC motor. The concept of the Adaptive Neuro-Fuzzy Inference System (ANFIS) is aimed at the automatic acquisition and adaptation of knowledge. Particle Swarm Optimization (PSO) simulates the behavior of swarming particles to search and optimize problem space efficiently. The performance of the combined ANFIS-Swarm satisfied the behavior of the DC motor as it has no overshoot, minimal rise time, and a steady-state error of zero. The control algorithm passed the good quality of robustness. (Allaoua, et al., 2009).

B. Mobile Application (Thunkable)

A mobile application is software that the user uses to monitor parameters. It is the practice of developing an app for mobile devices to create a platform on a specific mobile application. This will be done in the Thunkable environment to create and customize an effective mobile application. It was classified as one of the development platforms for design applications. It concludes that by using drag and drop, the developers will make effective mobile apps. (Joy, 2018).

Thunkable is a user-friendly platform that has garnered attention in the realm of mobile app development due to its intuitive drag-and-drop interface and support for both Android and iOS platforms. The building block of this app is the components, making the user interface (UI) perceive something without the code for creating a mobile app. (Gonzalez, 2024). Moreover, thinkable offers a robust integration capability, which explores the platform's compatibility with various third-party services. By facilitating seamless integration with popular services such as Firebase and Google Maps, Thunkable empowers developers to incorporate advanced functionalities into their applications with ease, enhancing user experience and app functionality.

V. METHODOLOGY

For pico-hydroelectric systems in isolated rural locations, a research study was conducted to develop and evaluate an IoT-based hydropower generation controller using the ANFIS-PSO algorithm. The research involved designing and building the controller and performing experiments to collect performance data. Sensors were deployed to measure variables such as water flow, voltage, and frequency in a real-world setting. The collected data was then subjected to statistical analysis, including the application of a T-test to compare the system's performance with and without the controller. This analysis aimed to assess the effectiveness of the proposed ANFIS-PSO solution in enhancing overall system performance.

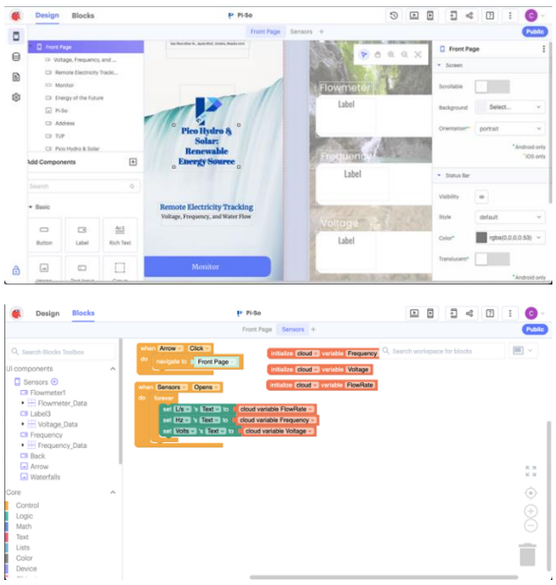

Figure 1. *Mobile Application developer*

Figure 1 shows the mobile app development platform that the researchers used to design the Pi-So mobile application. The initial step in creating the mobile application was to integrate the sensors and Arduino UNO in ESP32. After this, the ESP32 uploads the data to Google Firebase and stores it in Realtime Database. After retrieving the data, the Realtime Database will send it to the mobile application created in Thunkable.

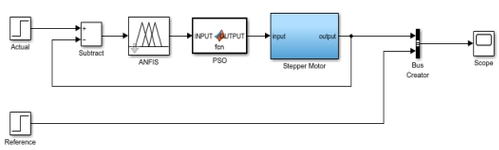

Figure 2. *ANFIS-PSO Model*

The researchers employed ANFIS-PSO as their control algorithm to help the stepper motor control the water entering the system. The Simulink function in Matrix Laboratory (MATLAB) simulated the control algorithm. The primary purpose of this project was to establish a reliable renewable energy source that could be used in off-grid rural areas, especially for those residing beside any flowing water. Researchers focused this evaluation on how fast the ANFIS-PSO could regulate the power produced by the Pico-Hydro generator.

The training data would have two input variables, the voltage, and the frequency, and the output data would be the rotation of the stepper motor; it could be clockwise or counterclockwise as it opens and closes the gate valve depending on the voltage and frequency read by the sensors.

The methodologies employed in this research encompassed the integration of Internet of Things (IoT) technology, the application of the ANFIS-PSO algorithm (Adaptive Neuro-Fuzzy Inference System), and the execution of experimental analysis. Through the integration of IoT technology, real-time monitoring and analysis of pico-hydro systems were made feasible, thereby enabling effective monitoring of the systems. The ANFIS-PSO algorithm, known for its robust modeling and optimization capabilities, was utilized to enhance energy generation in the studied context. A comprehensive experimental analysis was conducted to validate the proposed solution empirically. These selected approaches were carefully chosen to provide a sound and practical framework for maximizing energy production in remote rural locations, thereby contributing to the advancement of renewable energy utilization and promoting sustainable socioeconomic development.

VI. RESULTS AND DISCUSSION

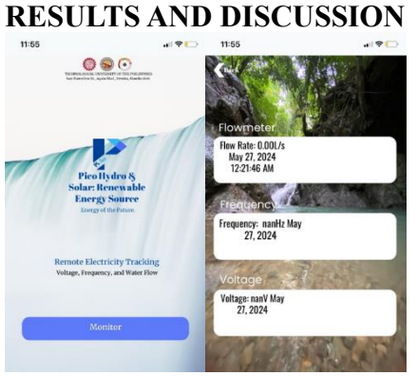

Figure 3. *Mobile Application*

The UI of the mobile application intended for remote Pico-Hydro system output monitoring is shown in Figure 3. With this application, users may monitor voltage, frequency, and flowmeter in real time. The researchers conducted several tests at the deployment site to ensure the application's dependability and validated its functionality and performance. It's probable that the user-friendly design elements of the mobile application interface make it easy to explore and see the system parameters. The studies conducted by the researchers yielded significant insights into the program's functionality across a range of circumstances, demonstrating its efficacy in delivering precise and timely information to users. Additionally, assessing the mobile application in a distant place helps the researchers evaluate its reliability and error-free performance over long distances.

VII. CONCLUSION

In conclusion, the Adaptive Neuro-Fuzzy Inference System-Particle Swarm Optimization (ANFIS-PSO) algorithm was implemented efficiently, optimizing the performance of the Automatic Generation Controller (AGC) in regulating the water flow through the gate valve. This optimization led to improved stabilization of voltage and frequency outputs. Additionally, a wireless mobile application for remote monitoring, developed using Thunkable, enabled real-time tracking of data transmitted from Google Firebase. This mobile application, named "Pi-So," provided an accessible interface for all users, allowing for convenient oversight and management of the system's performance. The integration of these technologies demonstrated significant advancements in the control and monitoring of the AGC, highlighting the potential for further innovations in the field.

VIII. REFERENCES

[1] Madrigal G. A. M., Capulong, T. J. F., Lising, J. A. B., Loyola, B. H. C., Ramirez, A. L., Simpliciano, J. E., Tolentino, L. K. S., Hollman, G. B., Galido, E. A., Fernandez, E. O., Thio-Ac, A. C., & Fortaleza, B. N. (2022, April 1). *Implementation of ANFIS in an Automatic Generation Controller of the Pico-Hydro Power System for Off-grid Rural Areas.* IEEE Xplore.

[2] Mahapatra, S., Daniel, R., Dey, D. N., & Nayak, S. (2015). Induction motor control using PSO-ANFIS. *Procedia Computer Science*, *48*, 753–768.

[3] Montalvo, I., Izquierdo, J., Pérez-García, R., & Herrera, M. (2010). Improved performance of PSO with self-adaptive parameters for computing the optimal design of Water Supply Systems. *Engineering Applications of Artificial Intelligence*, *23*(5), 727–735.

[4] Allaoua, B., Laoufi, A., Gasbaoui, B., & Abderrahmani, A. (2009). Neuro-Fuzzy DC Motor Speed Control Using Particle Swarm Optimization. *Leonardo Electronic Journal of Practices and Technologies*, *15*.

[5] Joy, A. (2018). *Review on different types of drag and drop mobile app development platforms*.

[6] Gonzalez, A. (2024). *Using thunkable basics to build a powerful app (Showcase app included)*.