DESIGNING AN ANFIS-CONTROLLER BASED HYBRID MICRO-GRID SYSTEM FOR SUSTAINABLE ENERGY OPTIMIZATION IN REMOTE AREAS

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Abstract
In order to optimize sustainable energy in remote places,designing a hybrid micro-grid system under the direction of an ANFIS (Adaptive Neuro-Fuzzy Inference System) is the solution. The proposed system combines a variety of renewable energy resources, including solar, wind, and hydropower, with energy storage technologies to deliver dependable and environmentally friendly electricity to rural populations. The results of the simulations show that the hybrid micro-grid system controlled by ANFIS can efficiently manage power flow and optimize energy utilization, delivering a dependable and sustainable energy supply with smooth operation without amplifying any disturbances in remote areas. The suggested method may be a practical way to meet the energy requirements of isolated communities, lessen reliance on nonrenewable energy sources, and advance sustainable development.
Keywords: Microgrid, PV system, Wind, Battery, inverter, Load, fuzzy logic controller, ANFIS controller.

1.Introduction

Because of the negative effects on the environment and the fluctuations in fuel prices, using sustainable power source assets in a power system has received essential consideration. In light of their many points of interest, as well as the administration motivating forces and open supports, sustainable power source assets have therefore emerged as crucial sources to obtain control at the business level [1].

Systems based on Renewable Energy (RES) are utilized to generate power in order to counteract these consequences and lessen reliance on nations that produce most of the world's oil. Hybrid micro-grid systems with electronically managed strategies are made up of numerous distributed resources that are linked in parallel and have the option of adding an isolated mode in addition to grid-connected operation [3].

Microgrids are certain to provide all network administrators and clients with improved power quality and obligation, arrange blockage, diminished power misfortunes, and more efficient and greener energy compared to the energy provided by standard large-scale influence plants because of the proximity of DERs to load in microgrids and as a result of the use of sustainable distributed generators (DGs) [4].

Fuzzy logic (FL) systems and artificial neural networks (ANNs) are strong contenders for the identification and control of nonlinear dynamical systems due to their nonlinear universal function approximation characteristic. As a result, intelligent control systems have emerged as a result of the effective use of these strategies to handle many types of control system design issues[15].

The incorporation of FL systems and ANNs into a single system has gained a lot of interest in the literature as a means of overcoming these disadvantages, which has given rise to the quickly developing field of neuro-fuzzy systems. Additionally, according to the robustness test, this controller has distinguished itself by being able to counteract external disturbances both while they are present and after they have left. The streamlined MIMO ANFIS controller has also demonstrated its advantage in terms of the shorter training time and the control accuracy in comparison to a traditional MIMO ANFIS controller [15].

2.Modelling and System Description

The DC micro-grid includes renewable energy resources such as a PV system, a wind system, a load, and a battery bank. DC boost converters are used to link the PV array to the DC bus. A PMSG is attached to a wind turbine as part of the wind energy system. Through an AC/DC converter, the wind energy system's output power is transformed into DC power for common coupling. For the battery bank to be connected to the common DC bus, a bidirectional buck/boost converter is utilized. The load is given DC control from all of the sources by using an inverter.

2.1: Photovoltaic System

A PV cell is essentially a semiconductor diode with p-n junctions that operate when sunlight strikes it. Solar photovoltaic energy is converted into electricity by PV cells. A PV cell's fundamental operating principle depends on photoelectric impact. When sunlight reaches a photovoltaic cell's surface, some of the sun's orienting energy is therefore trapped within the semiconductor material. The semiconductor's illuminated region is where the sets of gap electrons are produced. The produced electrons in the conduction band are currently permitted to move in this manner. These free electrons are forced to flow in a certain direction by the activity of the electric field present in PV cells [4].

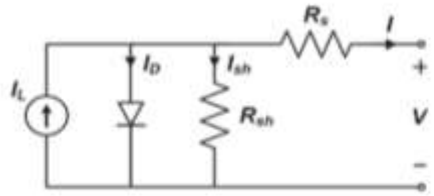

Fig 1: Single diode model of a PV cell

The load current and voltage of a PV cell is expressed as,

$I = I_L - I_D - I_{sh}$(1)

$V_{sh} = V + IR_s$(2)

The shunt branch current and the diode current of the PV cell is shown as,

$I_{sh} = \frac{V_{sh}}{R_{sh}} = \frac{V+IR_s}{R_{sh}}$ (3)The current through the diode is given by

$I_D = I_0[e^{\frac{V_{sh}}{nV_t}} - 1]$(4)

Where $V_t = \frac{KT}{q}$

$I = I_L - I_0\left[e^{\frac{V_{sh}}{nV_t}} - 1\right] - \frac{V+IR_s}{R_{sh}}$(5)

Where,

I_{sh} -Currentthroughtheshuntresistor(A)
I_L-Current generatedbyPV(A)
I –Currentthroughload(A)
I_D-Currentthroughdiode(A)
R_s - Equivalent circuit series resistance(Ω)
R_{sh}- Equivalent circuit shunt resistance(Ω)
V –Voltageacross load(V)
V_{sh}-Shunt voltage(V)
T-Temperature of solar cell (kelvin)

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n-ideality factor of solar cell
k-Boltzmann constant,(k= 1.3806488*10^{-23} J.K^{-1})
q-electron charge,(q =1.602176565*10^{-19} C)

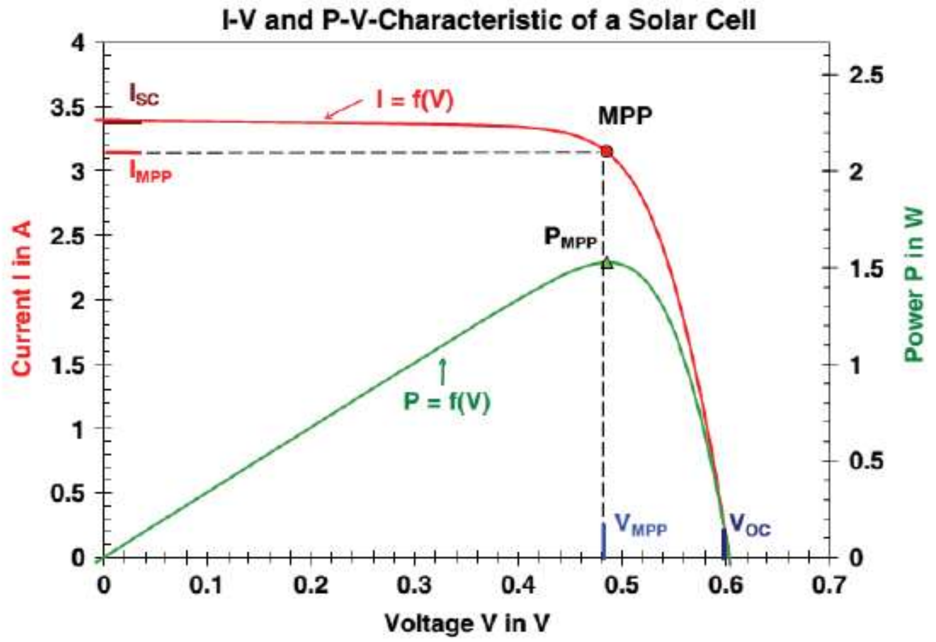

Fig 2:SolarIVandPVcharacteristicswithMPPT

When the current across the load is at its maximum, the power of a PV cell is at its highest. The PV module's efficiency is extremely low and is influenced by the panel's temperature. The effectiveness of the panel decreases as its temperature rises. To determine the maximum power under various environmental circumstances, an MPPT technique is applied.

The best power is produced by the panel when it is operating at the highest voltage and biggest current in the region beneath the I-V bend. With an increase in sun-oriented cell voltage, the region shrinks due to the temperature expanding [10].

2.2: Wind Energy System

With the idea that speed is the active energy of wind, the wind turbine's operational standards can be illustrated. If a wind turbine existed, it would function by separating kinetic energy from the wind that passes past its rotor.

Considering that wind turbines produce electricity from wind, whereas fans produce wind from power. Any strong turbine is capable of having three effectively planned edges. Every time the margins are exposed to wind, it becomes easier to frame a development as a result. The cutting edges turn a pole connected to the generator, generating power as a result.

Therefore, the energy produced by a wind turbine is provided by:

$$P_{wt} = \frac{1}{2} C_p(\lambda, \beta) \rho A v_{wind}^3 (6)$$

Where,

ρ - airdensity(kg/m3)
C_{ρ}- performance coefficient of the turbine
λ - areasweptbyturbine(m2)
β -pitchangleofblade(deg)
A_i-tipspeedratio

2.3: Battery Units

Lithium-ion batteries are utilized in microgrid backup storage units. Batteries are connected in series and parallel based on the required voltage and power. Because they provide more cycles during their lifespan compared to other batteries, lithium-ion batteries are preferred [1].

In the micro-grid, lithium particle batteries are used as support storage. According to the unique voltage and power requirements, these batteries are connected in a configuration and parallel air conditioning. The positive terminal of the Li-ion battery is formed of metal oxide. Carbon serves as the negative anode while lithium salts in organic solvents serve as the electrolyte.

3.Problem Identification

The DC-microgrid depicts a hybrid energy system with wind, solar, and battery energy sources connected to the DC-link by means of their own converters, which have embedded PI Controllers. Both solar and wind energy conversion systems employ the MPPT method. Based on a computation of the amount of energy used and generated, control modes are chosen [23]. When the operation point is outside of a specific radius around the operating point used to design the controllers, the PI-based control system, however, is unable to keep its good responsiveness.The PI based controller cannot guarantee the stability of the system in the entire operating range due to the peculiarities of the hybrid energy system and the microgrid operation, making it an unacceptable choice for this application [14].

4.Proposed Method

ANFIS controller scheme gives better outcome compared to the conventional PI controller scheme. ANFIS controller alters PI parameters in accordance with the change in power system operating condition at the time of disturbance [12]. The DC-microgrid displays a hybrid energy system with wind, solar, and Battery all associated to the DC-link via their own converters, in which ANFIS based Controller is implemented in the control circuit of the wind system which provides stable and smoothness in operation.

4.1: ANFIS Controller

The neural network and fuzzy inference system are combined to form the ANFIS. Fuzzification, defuzzification, and rule base are characteristics of the artificial intelligence subfield known as fuzzy logic. Fuzzy logic takes into account brain networks and language factors. input and output databases are necessary for training. Back propagation networks are typically employed for linear databases, while multilayer feed forward neural networks are chosen for nonlinear databases [12].

The ANFIS controller works by combining the principles of fuzzy logic and neural networks to create an adaptive control system. The ANFIS controller consists of five layers known as fuzzification layer, rule layer, normalization layer, defuzzification layer and learning layer.

The fuzzy rules are used by the ANFIS controller during operation to produce an output value. The system then uses the output value as feedback to modify the input values. The learning layer's updating of the membership functions and fuzzy rules allows the ANFIS controller to adjust to system changes.

Overall, the ANFIS controller employs neural networks to learn and adjust to changes in the system as well as fuzzy logic to capture the uncertainty and imprecision of the system. The ANFIS controller is an effective instrument for controlling complex systems with nonlinear or unpredictable dynamics as a result of this hybrid approach.

4.2: Inputs and Rules in ANFIS

Negative Big (NB), Negative Small (NS), Zero (Z), Positive Small (PS), and Positive Big (PB) are fuzzy subsets of the variables for the input Membership Function (MF).

Input1

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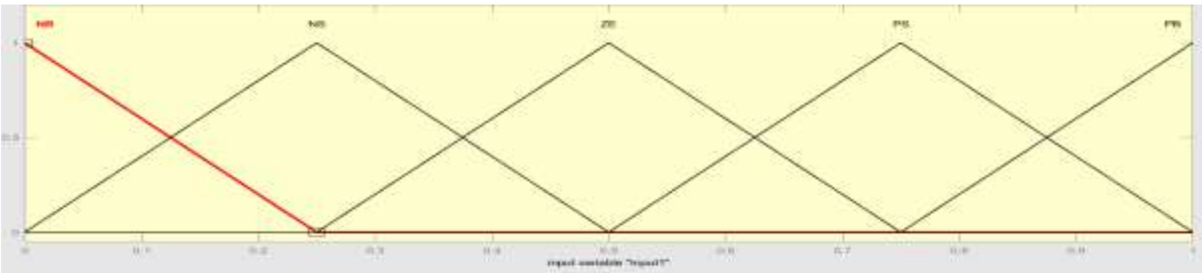

Fig 3: Input1 Membership Function

Input2

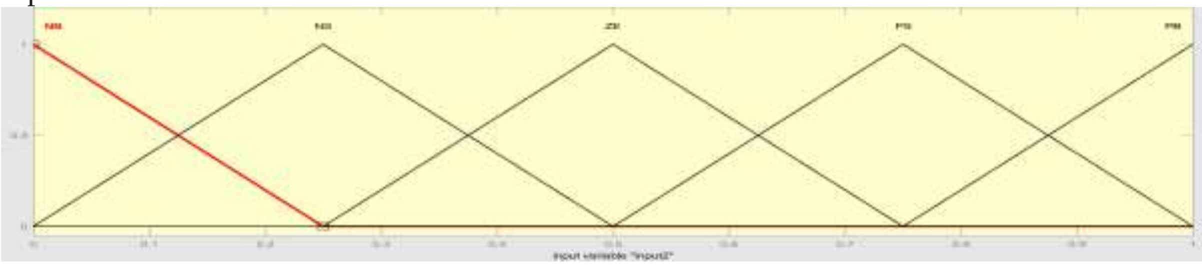

Fig 4: Input2 Membership Function

Rules Tables

e/ce	NB	NS	ZE	PS	PB
NB	ZE	NS	NB	NB	NB
NS	ZE	NS	NB	NS	NB
ZE	PB	PS	ZE	NS	NB
PS	PB	PS	PS	ZE	NS
PB	PB	PB	PB	PS	ZE

4.3: ANFIS basic structure

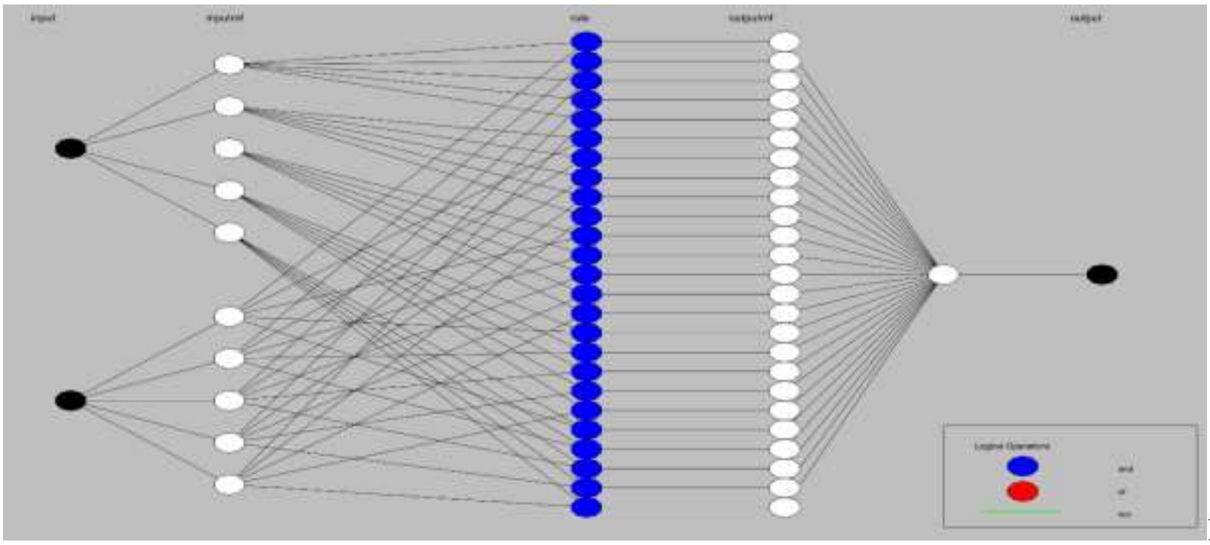

Fig 5: ANFIS Model Structure

Number of layers: 4
Number of nodes: 75
Number of linear parameters: 25
Number of nonlinear parameters: 30

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Total number of parameters: 55
Number of training data pairs: 9043
Number of fuzzy rules: 25

5.Simulation Model and Results

5.1: Simulation Model

The details of the parts of the hybrid micro-grid system model are as follows

s.no	Components	Specifications
1	Photovoltaic array	Rated capacity: 40 (KW) Number of parallel strings: 15 Series-Connected modules per string: 7 Cell per module: 72 Maximum power: 292.32 (W) Open Circuit Voltage: 44.95 (V) Voltage at maximum power point: 36 (V) Short-circuit current: 8.64 (A) Current at maximum power point: 8.12 (A)
2	Wind turbine system	Mechanical output power: 10 (KW) Base power of the generator: 10e3/0.9 (VA) Wind speed: 12 (m/s)
3	Battery	Rated capacity: 100 (Ah) Type: Lithium-ion Nominal Voltage: 278.7 (V) Initial State-of-Charge: 50 (%) Battery response time: 0.01 (s)
4	Load	Rated Capacity: 30 (KW) Phase voltage: 300 (V) Frequency: 50 (Hz)

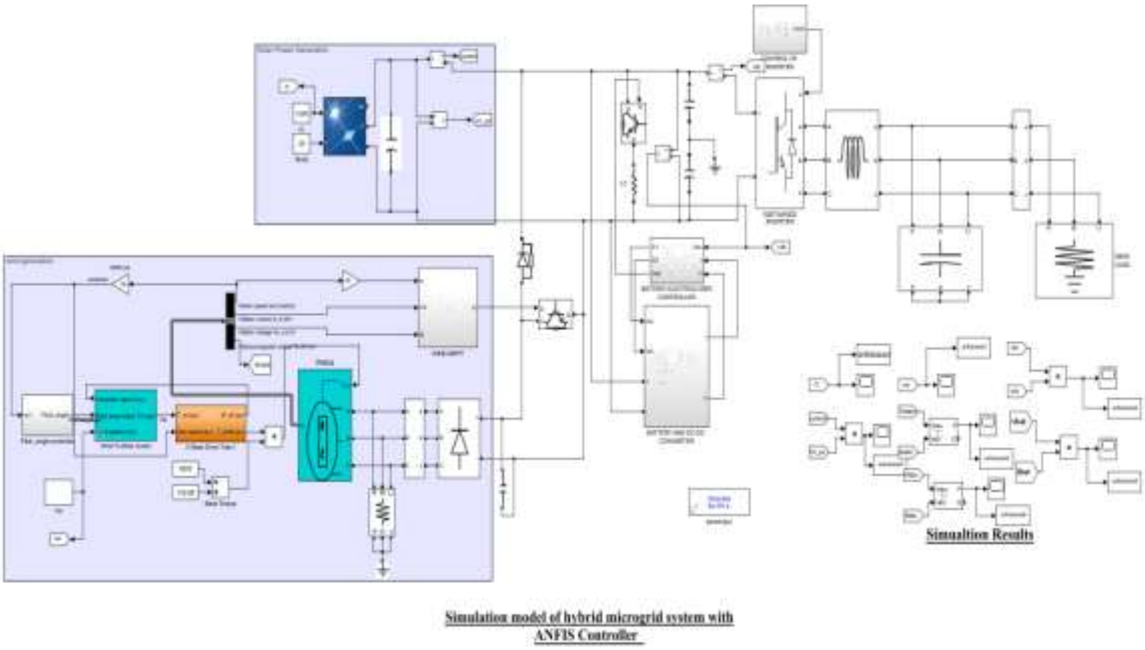

Fig 6: Schematic diagram of hybrid microgrid system with ANFIS controller

5.2: Simulation results:

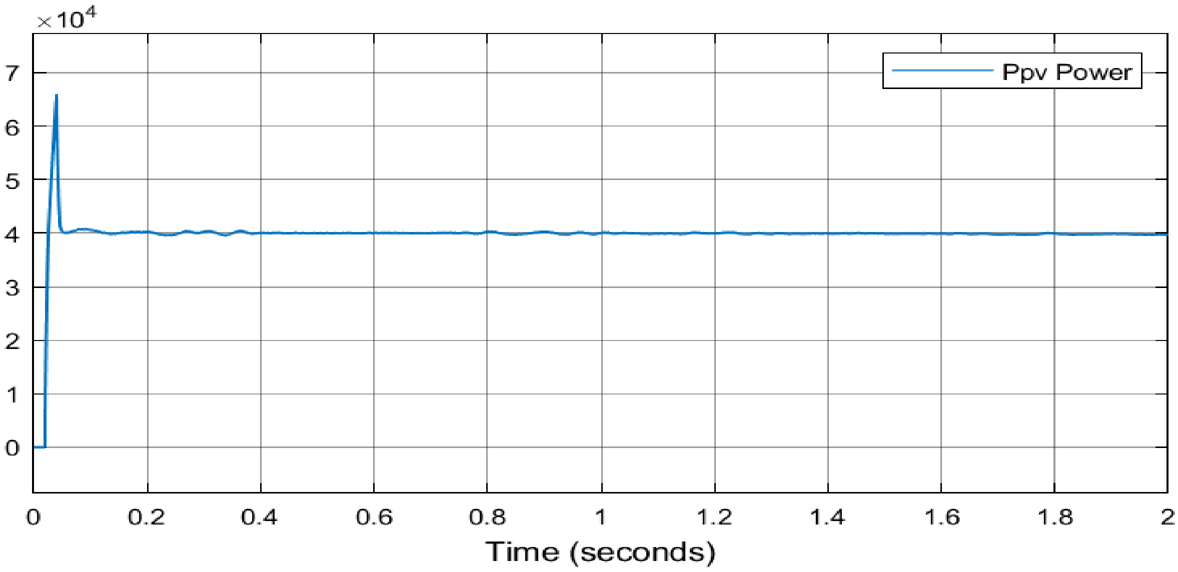

Fig 7: PVPowerVsTimeWaveform

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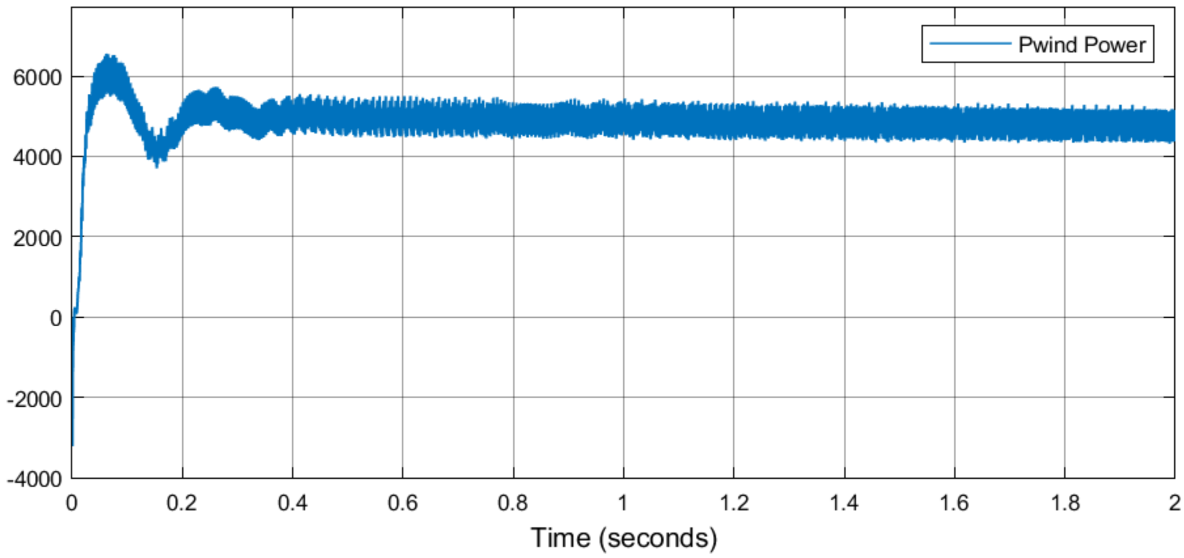

Fig 8: WindPowerVsTimeWaveform

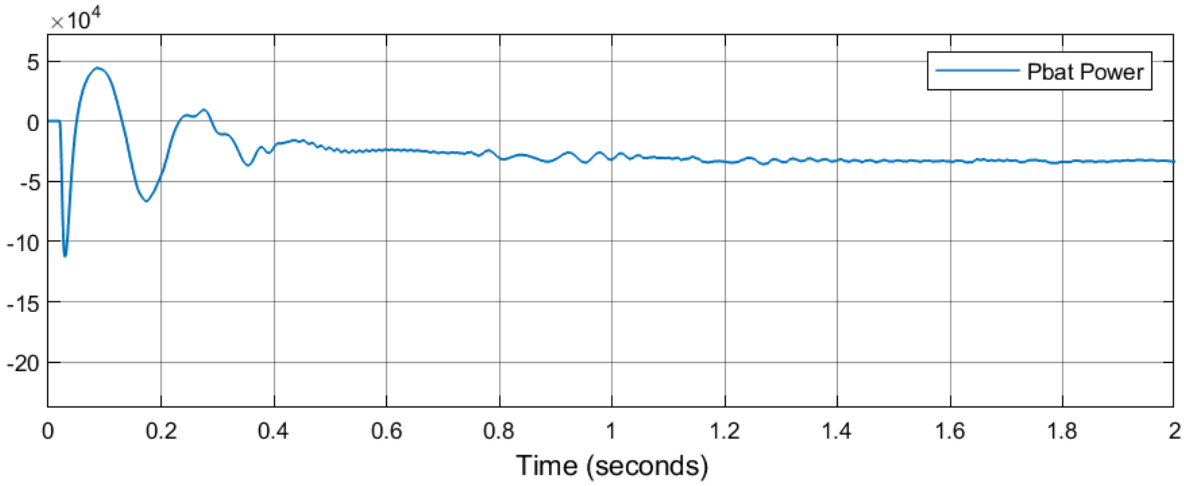

Fig 9: BatteryPowerVsTimeWaveform

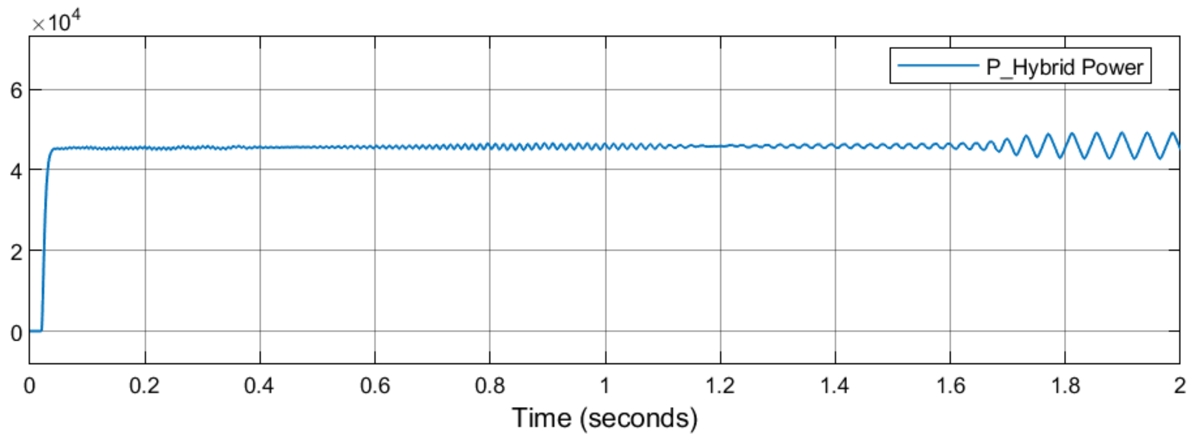

Fig 10: HybridSystemtotalpowerVsTimeWaveform

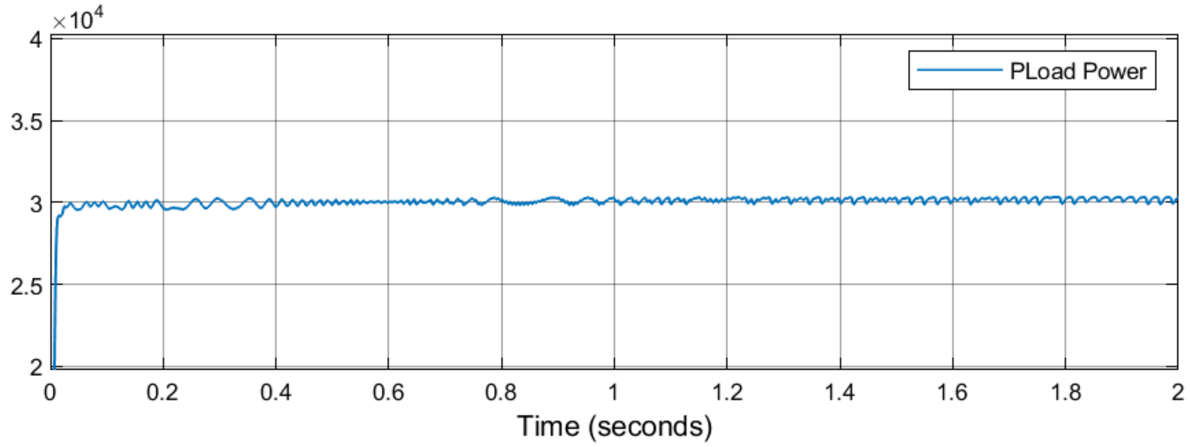

Fig 11: Load power Vs Time Waveform

5.3: Comparisons of PI and ANFIS Controller

In contrast to PI Controller, ANFIS Controller is implemented in the control circuit of the Wind system to ensure consistent output with fewer spikes. During grid disturbances, the ANFIS-PI controller allows online returning of their settings in accordance with the constantly changing power system. Output Load power waveform using PI controller oscillates in between 40(KW) and 20(KW) creates disturbances in the load side, whereas as in ANFIS controller output power waveform is maintained 30(KW).The ANFIS controller-based scheme performs better than the traditional PI controller-based scheme, according to simulation findings from MATLAB [12].

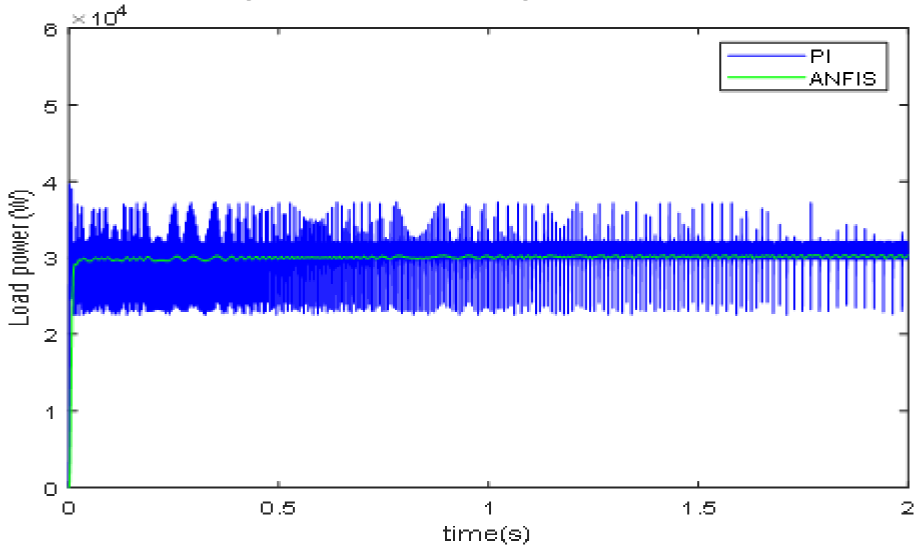

Fig 12: Load Power Vs Time Waveform

6.Conclusion

Developing a hybrid micro-grid system under ANFIS control is a potential strategy for improving sustainable energy in rural areas. In addition to improving operation smoothness and reducing the steepness of the spikes obtained in the power waveform, the installation of an ANFIS-based controller in a hybrid micro grid appears to be a cost-effective approach because it does not require the installation of any additional hardware. Output Load power waveform using PI controller oscillates in between 40(KW) and 20(KW) creates disturbances in the load side, whereas as in ANFIS controller output power waveform is maintained 30(KW). It has been determined through the examination of the simulation data that the ANFIS controller outperforms the traditional PI controller in terms of output. The system must be properly maintained and monitored to guarantee its long-term viability. The ANFIS-controlled hybrid micro-grid system presents a viable approach for sustainable energy optimization in remote places, not withstanding the difficulties.

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