Optimization of Hybrid Renewable Energy System for a Sustainable Poultry Farm

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Abstract
This paper presents the design and performance evaluation of an adaptive neuro-fuzzy inference system (ANFIS)-based maximum power point tracking (MPPT) algorithm integrated into a hybrid photovoltaic, wind, and battery system tailored for a sustainable poultry farm in Mgbumodu community, Rumuji in Rivers State, Nigeria. MATLAB/Simulink simulations compared ANFIS with Perturb-and-Observe (P&O) and incremental Conductance (Inc.Cond.) methods under varying solar irradiance and wind speeds. Results obtained shows that the proposed hybrid renewable energy system can meet the daily energy demand of 4497.035kWh for the poultry farm and 53964.42kWh yearly with a renewable fraction of 94.3%, reduced the transient response time to 0.13seconds, stabilized battery state of charge between 48-85%, and achieved the lowest levelized cost of energy (0.20$/kWh) for an optimized integrated hybrid renewable energy system in Mgbumodu community, Rumuji with 55.8% diesel savings.

Keywords: *Hybrid renewable energy system, ANFIS Control, MPPT, Photovoltaic System, Wind Energy, Poultry Farm, MATLAB Simulation, Sustainable poultry Farm, BESS, Optimization*

I. INTRODUCTION

In recent years, we have seen a growing trend towards integrating renewable energy systems as a promising way to tackle issues like energy security, climate change, and our reliance on fossil fuels. Poultry farming is an energy-intensive agricultural practice requiring stable electricity for lighting, automated feeders, water pumps, and ventilation. Unfortunately, the inconsistent power supply from the national grid, along with the high cost and environmental concerns associated with diesel generators, create significant challenges for poultry farms in rural areas. Notably, advancements in solar photovoltaic (PV) and wind turbine technologies hold great promise for providing sustainable, decentralized, and cost-effective energy solutions for poultry farms. In Rivers State, Nigeria, where grid reliability is poor, diesel generator is common but costly and environmentally damaging. Hybrid renewable energy systems integrating solar photovoltaics (PV), wind turbines, and battery storage have emerged as a viable alternative. However, these systems face challenges: solar and wind resources are intermittent, storage is expensive, and traditional MPPT methods such as P&O, Inc. Cond, struggle with rapid environmental changes. ANFIS integrates neural networks learning with Fuzzy Logic reasoning to dynamically model nonlinear relationships and improve MPPT performance which generate adequately the energy used for a sustainable poultry farm. Adaptive Neuro-Fuzzy Interference System (ANFIS)-based MPPT is used because it combines artificial Neural network (ANN) with Fuzzy logic, which enhances the decision-making, boost the performance of hybrid solar PV and wind energy systems by adapting to changing environmental condition of solar irradiance and wind speed. This research proposes an energy management strategy (EMS) for renewable energy sources, controlled and monitored by an ANFIS-based controller that optimizes the utilization of renewable energy sources, ensure optimal battery charging and discharging processes, and offers a practical solution to the region's power supply challenges.

II. REVIEW OF RELATED RESEARCH WORK

Several studies have explored optimization techniques on a hybrid renewable energy system aimed at enhancing the stability and electrical energy integrated with solar photovoltaic (PV), wind turbines and battery storage system. According to Twidell & Weir (**2021**): Explored that renewable energy systems present a viable and sustainable alternative to fossil fuels, which are known to contribute to greenhouse gas emissions and environmental harm. From the study, their analysis highlights the pressing need for cleaner energy sources in light of the detrimental effects associated with traditional energy production.

III. STUDY AREA

The study was conducted in Mgbumodu community, located within Rumuji, in Emohua Local Government Area of Rivers State, Nigeria. Geographically, the Mgbumodu community in Rumuji is situated at latitude 4.98°N and longitude of 7.03°E within the Emohua local government area of Rivers State, Nigeria. This community was selected based on its agricultural potential, increasing poultry activities that demands continuous power, and persistent power supply challenges necessitating energy alternatives, availability of renewable resources like solar and moderate wind potential, and willingness of local stakeholders to cooperate and adapt alternative solutions. Mgbumodu is strategically located along the East-West Road, linking Port Harcourt to the inland agricultural belts. Its location offers good exposure to solar radiation and moderate wind flow, making it suitable for hybrid renewable energy generation systems.

Fig 1.0 Map of Mgbumodu, Rumuji, Rivers State, Nigeria

IV. SYSTEM METHODOLOGY

In this research, an Adaptive Neuro-Fuzzy Inference System based on the MPPT algorithm (ANFIS) was used. The ANFIS-based MPPT is a hybrid intelligent system that combines the leaning capabilities of Artificial Neural Network (ANNs) with the Fuzzy Logic qualitative approach used in fuzzy inference systems. This approach aims to reduce reliance on the grid network by implementing an energy management strategy (EMS) that detects changes in wind speed and automatically turns off the grid energy source when the power generated from the hybrid renewable energy system falls short of meeting the load demand.

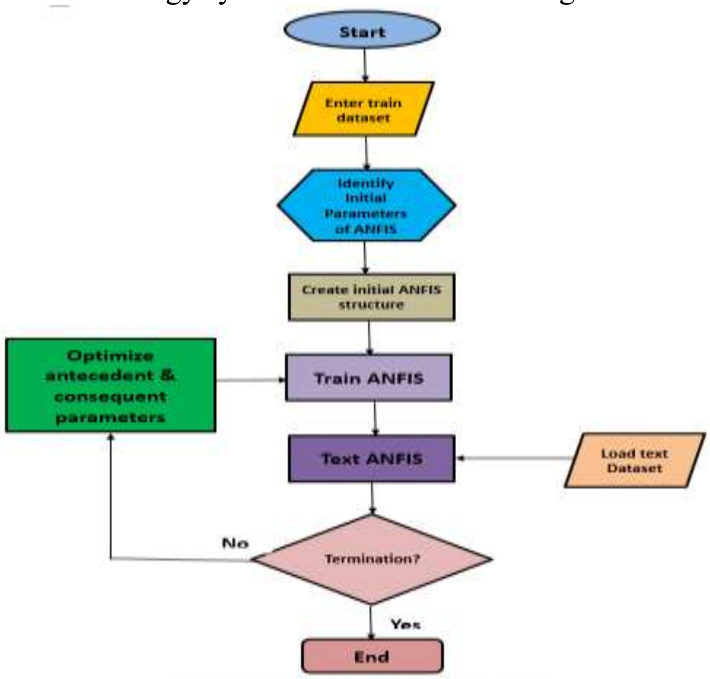

Figure 2: Operational Flowchart of ANFIS MPPT

V. ANFIS Training Procedures

I. First, we gather a set of training data that corresponds the power differences between the total generated power, the load demand, and the battery's state of charge, which is then fed into the Adaptive Neuro-Fuzzy Inference System (ANFIS)

II. The ANFIS is generated using a technique called grid partitioning; this method helps in organizing data into clusters based on their similarities. After that, we train the ANFIS using least squares estimations (LSE)

III. Various data sets are introduced to the ANFIS, and from the input-output relationships, we construct membership functions for the fuzzy logic controller (FLC). For more details, check appendices J, and K, which cover the construction of ANFIS membership functions.

IV. The rule base for the fuzzy logic controller (FLC) is developed based on how the ANFIS operates. This happens because the ANFIS automatically generates its own rules depending on the training data provided. For further information see appendix S for the construction of ANFIS rule.

Configuration and Description of Proposed System

The study focuses on a poultry farm located in the Mgbumodu community in Emohua, LGA, Rivers State. This area is positioned at approximately 4º56'N and 6º49'E, that is characterized by tropical wet climate, high humidity levels and significant solar exposure. Figure 3.1 presents a block diagram of the proposed setup, which includes 850kW solar photovoltaic (PV) farm, 650kW wind farm, a DC-DC boost converter, and a 1500kWh energy storage system. The load demand is met by the PV arrays, wind generator, and grid system. ANFIS controller monitors the changing weather conditions for both solar and wind energy, taking into account the irradiance and wind speed, compares the power generated from these renewable sources with the load demand and will promptly disconnect the grid power if the hybrid system can sufficiently meet the load on its own.

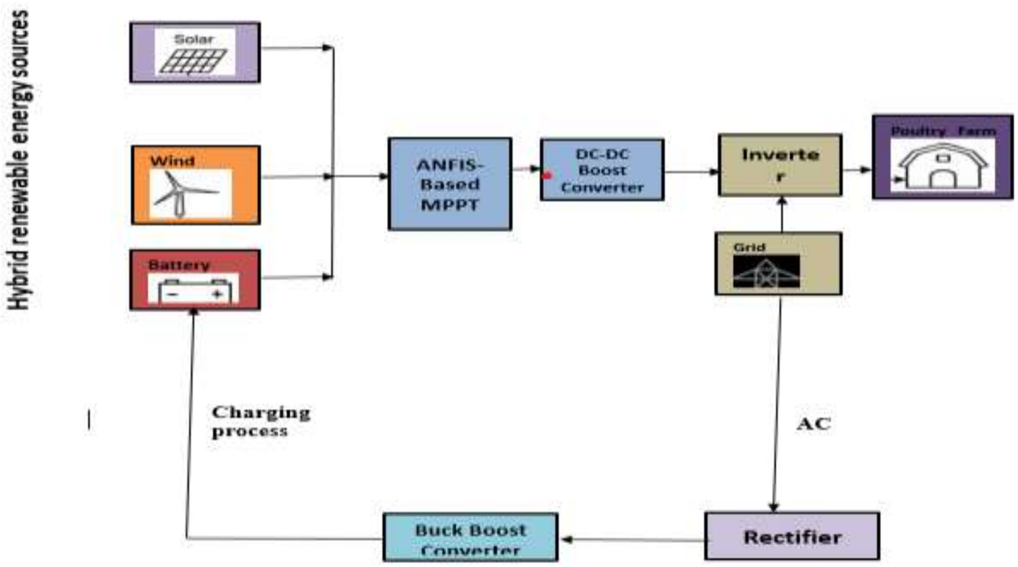

Fig 1: Block diagram of a hybrid renewable energy system.

VI. LOAD DEMAND ESTIMATION FOR MGBUMODU POULTRY FARM

This proposed system is designed for the poultry farm in Mgbumodu, community, Rumuji, Emohua Local Government Area, Rivers State, Nigeria. The electrical appliances and their wattages considered for Mgbumodu poultry farm cover a range of essentials such as lighting, water supply, ventilation, feeding systems, security, and other equipment. For this study, the estimated daily electrical load demand for poultry farm in Mgbumodu, Rumuji is 4497.035kWh/day, with a yearly demand approximately 53964.42kWh/year. Furthermore, the devices need the grid standard voltage of 220V AC, with a frequency of 50Hz for its operation.

Table 1.0 Shows Electrical Specifications for Mgbumodu Poultry Farm

Load Category	Equipment	Power Rating (W)	Quantity	Daily Usage (hrs)	Energy Consumption (kWh/day)
Lighting	LED bulbs	15	150	17	38250
Feeding system	Automation Feeders	1200	55	10	660000
Water pumps	Submersible Pump	1350	32	12	518400

Ventilation Fans	Exhaust Fans	125	50	13	81250
Heating Lamps	Brooder Lamps	152	40	15	91200
Incubation system	Egg incubators	1530	25	19	726750
Security systems	CCTV, Alarm Systems	110	125	24	330000
Office &ICT	Computers, Printer, Lighting, router	157	45	23	162495
Cold storage	Refrigerators, Freezers	1250	15	23	431250
Heating appliances	Heater, sterilizer	110	40	12	52800
Mixers	Food Mixers	1120	25	10	280000

Ventilation	Ceiling Fans	395	120	18	853200
Controller	Automated controllers	120	55	22	145200
Lighting	Infrared heating lamps	82	60	23	113160
Lighting	Outdoor security lights	55	120	18	118800
Miscellaneous Loads	Radios, chargers, sockets, Misc	50	---	24	1200
TOTAL		**7821kW**			**4497.035kWh/day**

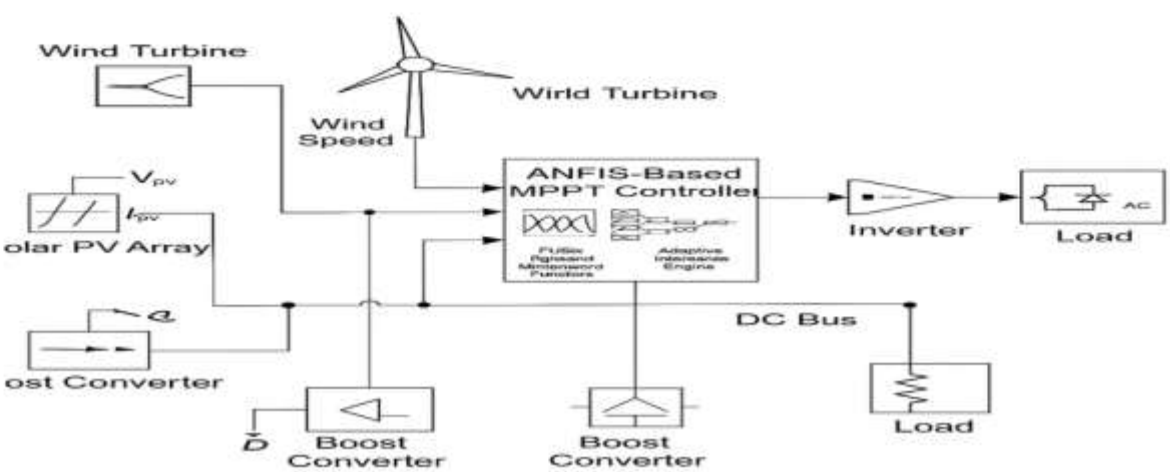

Figure 3 Simulink Model for HRES

The HRES Simulink model has four main subsystems connected by a common DC bus, where all the generated power from the PV and wind and stored power i.e the battery charging and discharging meet before being converted into AC for the load.

Solar PV Subsystem

PV array Block generates DC power depending on the irradiance and temperature input, the DC-DC Boost converter raises the PV voltage to match with the DC bus, and the MPPT Controller extracts the maximum power by adjusting the duty cycle of the converter with the aid of the ANFIS -based MPPT. A double–diode model type of a photovoltaic (PV) cell is used as it offers a more precise depiction of how PV systems behave in the real world compared to the simpler single-diode model. The model uses two diodes to account for recombination losses that occur in both depletion region and the quasi-neural areas of the PV cell. The double diode model consists a light-generated current source known as photocurrent, two diodes, D1 and D2, a series resistance and a shunt resistance.

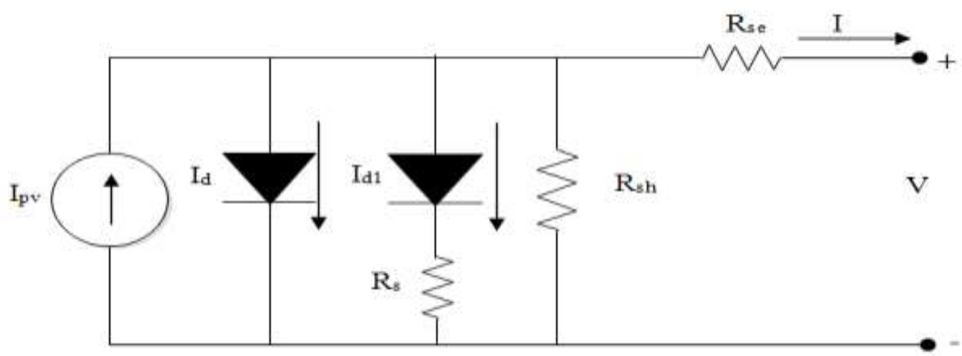

Figure 4 Schematic diagram of double-diode PV model

Photon Voltaic Current (I)

$I = I_{ph} - I_d\,(\exp^{\frac{V+IR_S}{nVt}} - 1) - I_{d1}(\, e^{\frac{V+IR_S}{nVt}} - 1) - \frac{V+IR_S}{R_{sh}}$ 1

Wind turbine system

The wind turbine model, converts wind speed into mechanical power

The Kinetic Energy of Wind in Air

$E = \frac{1}{2} m\, V^2_{max}$ 2

The shaft Power of the Wind Turbine

$Pt = \frac{1}{2} \rho A V^3 m Cp$ 3

Power coefficient of a wind turbine system (Cp)

$C_p = \frac{Pt}{Pw}$

Tip Speed Ratio

$\lambda = \frac{R.\omega}{V}$

Pitch Angle Control

$\beta = K_p.e(t) + k_i \int e(t)dt + Kd.\frac{de(t)}{dt}$ 4

VII. BATTERY ENERGY STORAGE SUBSYSTEM (BESS)

The battery energy storage system is modeled to manage and control the power mismatch between generation and the load and the state of charge (SOC). The BESS, stores the excess energy during low demand or high generation periods and supply during the peak demand, manages the daily load profile of the poultry farm fluctuations through load leveling, provide energy between solar and wind output is insufficient, and finally stabilizes the voltage and frequency variations in weak grids. It is mathematically expressed as:

$$SOC\ (t+1) = SOC\ (t) + \frac{ŋch.Pch(t)}{Emax} - \frac{Pch(t).\Delta t}{ŋdis\ .Emax} \quad 5$$

Battery Operation Strategy

The control strategy determines when and how the battery charges or discharges. For the charging mode condition, if the photovoltaic and the wind is less than the load, there will exist surplus charges battery but if the load is greater than the photovoltaic and the wind, there will be deficit met by the battery, and the idle mode is when the supply and the demand are equal, thus the SOC bounds is reached.

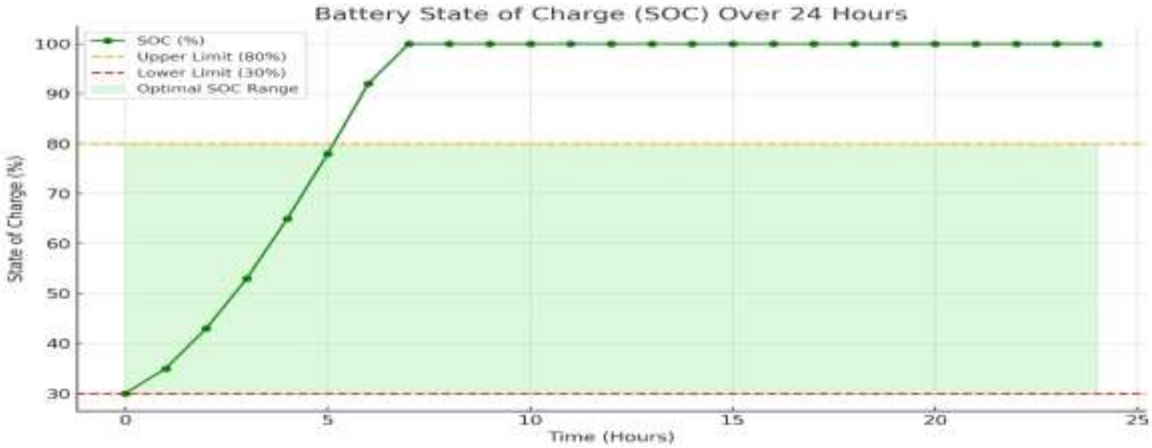

Figure 5 Battery State of Charge (SOC) of the system

VIII. LEVELIZED COST OF ENERGY (LCOE)

The levelized cost of energy (LCOE) is the average cost per unit of electricity generated by operation of power system over its life time. It is metric used in determining the present value of the total cost of building and operating assets over its lifetime, divided by the total electricity output. It is an indicator for a sustainable poultry farm used to evaluate the performance and viability of hybrid renewable energy system. The LCOE is mathematically expressed as

$$LCOE: \frac{\sum_{t=1}^{n} \frac{It + Ot + Ft}{(1+r)t}}{\sum_{t=1}^{n} \frac{Et}{(1+r)t}} \quad 6$$

Where,

I_t: Investment cost at year t

O_t : Operation and maintenance cost at year t

F_t: Fuel cost (if applicable)

E_t: energy generated at year t

r: Discount rate

n: Project life time

IX. SIMULATION RESULTS

Table 2.0 Shows the total power produced by the hybrid PV array and the wind turbine system

Time (hr)	Irradiance (W/m2)	Wind speed (m/s)	PV (KW)	WT (kW)	Pnet (kW)
0	0	4.6	1.3	79.4	80.7
1	0	4.9	0.29	108.5	108.79
2	0	5.3	1.26	182.2	183.46
3	0	7.6	1.39	378.5	379.89
4	0	8.1	188.23	385.6	573.83
5	125	9.3	295.78	393.8	689.58
6	380	10.5	376.25	458.1	834.35
7	590	12.1	338.27	559.8	898.07
8	755	12.8	392.56	755.4	1147.96
9	883	13.3	482.58	721.8	1204.38
10	830	13.5	505.73	561.7	1067.43
11	957	13.1	483.42	552.6	1036.02
12	1000	13.2	543.87	537.5	1081.37
13	1000	12.6	878.95	313.8	1192.75
14	985	9.8	453.74	650.4	1104.14
15	920	11.9	389.70	815.8	1214.5
16	853	10.1	795.96	798.9	1594.86
17	787	11.5	302.64	645.8	948.44
18	589	9.5	299.45	490.3	789.75
19	372	9.3	169.65	398.4	568.05
20	150	7.9	55.82	365.7	421.52
21	0	7.7	1.04	325.6	326.64
22	0	7.4	1.84	315.8	317.64
23	0	7.3	2.05	289.8	291.85

Table2.0: Illustrates the total power produced by the hybrid PV array and the wind turbine system, taking into account different levels of irradiance and wind speed while using conventional MPPT controller. The performance of the PV array is heavily influenced by environmental factors like the operating temperature, the configuration of the PV array. On the other hand, the wind turbine's efficiency is affected by wind speed, wind turbine height, the size, site of location, and the surrounding where the turbine is situated. The maximum power point tracking (MPPT) is a technique designed to maximize the power output from both photovoltaic (PV) array and the wind turbine. It does it by continuously adjusting the operating conditions to ensure they operate at their maximum power point (MPP), even as irradiance and wind conditions change.

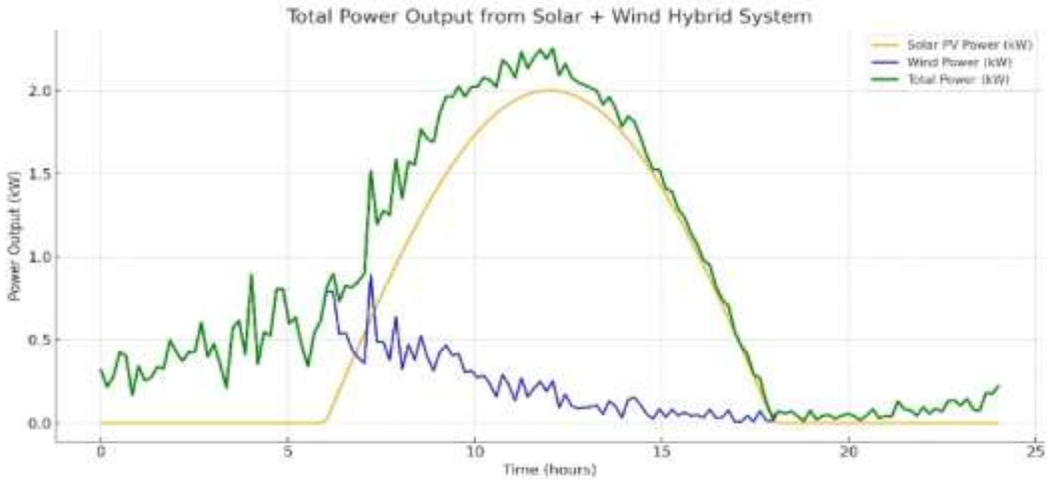

Figure 6: Shows Total Power Output from Solar & Wind Hybrid System

Grid Supervisory of ANFIS-based Energy Management Strategy

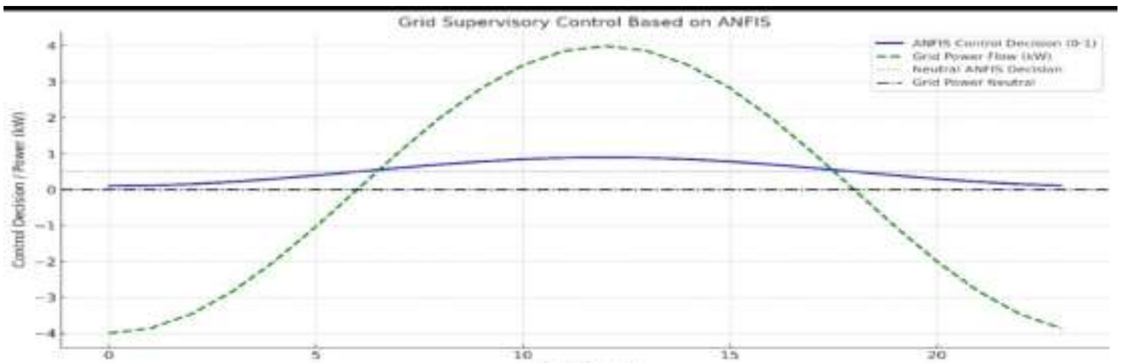

Figure 7: Shows the plot of Grid Supervisory Control Based on ANFIS

X. OPTIMAL PRODUCTION AND CONSUMPTION OF ELECTRICAL ENERGY

From the analysis, table 4.3 illustrates the total renewable generation, along with the grid inlet and grid outlet managed by the ANFIS EMS. From 0hr to 9hrs and again from 17hrs to 23hrs, the total generation from the hybrid renewable energy sources falls short of meeting the load demand. In response, the ANFIS EMS controller activates the circuit breaker to switch ON the grid source, ensuring to fine-tune the electric energy production so that the energy supply aligns perfectly with the energy demand of the poultry farm located in Mgbumodu, while keeping the dependence on grid power to a bare minimum. Taking a look at the result on table 4.3 which depicts that the generated electricity inlet from 0hr to 9hrs are enumerated as 795.35 kW, 783.56kW, 752.53kW, 653.12kW, 543.12kW, 487.23kW, 315.84kW, 256.81kW, 98.56kW and from 17hrs to 23 hours grid inlet are 183.22kW, 395.37kW, 511.98kW, 559.35kW, 598.65kW, 652.53kW respectively. If the grid is not available at the moment, the battery energy storage system, which is designed to kick in when the grid is down, will be activated by the ANFIS ems controller for period of 9hrs to 16hrs. This is when the sunlight and the wind conditions are just right to maximize the power output from the photovoltaic (PV) array and the wind turbine. Also, if the total power generated meets the load demand, the ANFIS EMS controller will trigger the circuit breaker to disconnect from the grid, and any extra electricity produced after satisfying the load will either charge the batter energy storage system, but if the state of the battery energy storage system is very low or be sent back to the grid, when the battery is already fully charged. A quick look at table 4.3 depicts that the electricity produced from 10hrs to 16hrs are 191.75 kW, 184.15 kW, 173.82 kW, 158.22 kW, 198.32 kW, 215.74 kW, 119.56kW respectively. However, if at this period the grid is not readily available, the battery energy storage system that is adequately designed to be operational when the grid system is not available will be turned ON by the ANFIS EMS controller. From 10hrs to 16hrs, the irradiation and wind speed is adequately high to generate maximum power from the photovoltaic PV array and the wind turbine energy system respectively. Similarly, if the net power produced can satisfy or meet the desired load demand, the ANFIS EMS controller, practically actuate the circuit breaker to turn OFF the grid energy source. The excess electricity produced after satisfying the desired load demand is the applied to charge the battery storage system, if the state of charge is very low or also deliver to the grid system, if the state of charge of the battery system is high. From table 4.3, shows that the excess electricity produced from 10hrs through 16hrs are 191.75kW, 184.15kW, 173.82kW, 158.22kW, 198.32kW, 215,74kW, 119.56kW. Figure 8 and figure 9 show the plot of both grid inlet and outlet controlled by ANFIS energy management system.

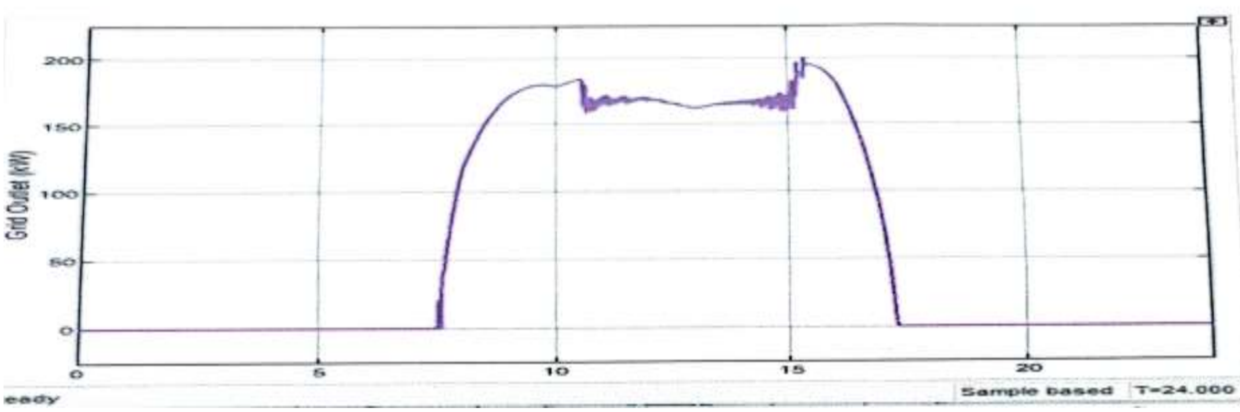

Figure 8: Grid outlet controlled by ANFIS Energy Management System
Grid Voltage and Current

Figure 8, illustrates the grid voltage and current managed by the ANFIS energy management system. The current in each phase, which carries an alternating waveform, is offset by one-third of a cycle, or 120 degrees, from each other. This arrangement helps ensures that the connected loads operate smoothly. A quick glance at figure 8 reveals that between 0hour to 7hours and from17hours to 23 hours, the ANFIS EMS controller activates the circuit breaker to turn ON the grid source that is connected to the system. This is done to balance the energy demand with the supply, especially since the total generation from the hybrid energy sources is not sufficient to meet the load demand during those times. However, from 8hours to 16 hours, the ANFIS EMS controller switches OFF the grid source because the net power generated by the renewable energy sources is adequate to meet the load demand, allowing for excess electricity to be sold back to the grid system. As shown in figure 9 the amplitude of the grid voltage and current waveform indicates a pure sinusoidal, which is ideal for grid-tied renewable energy integration at a frequency of 50Hz for its operation.

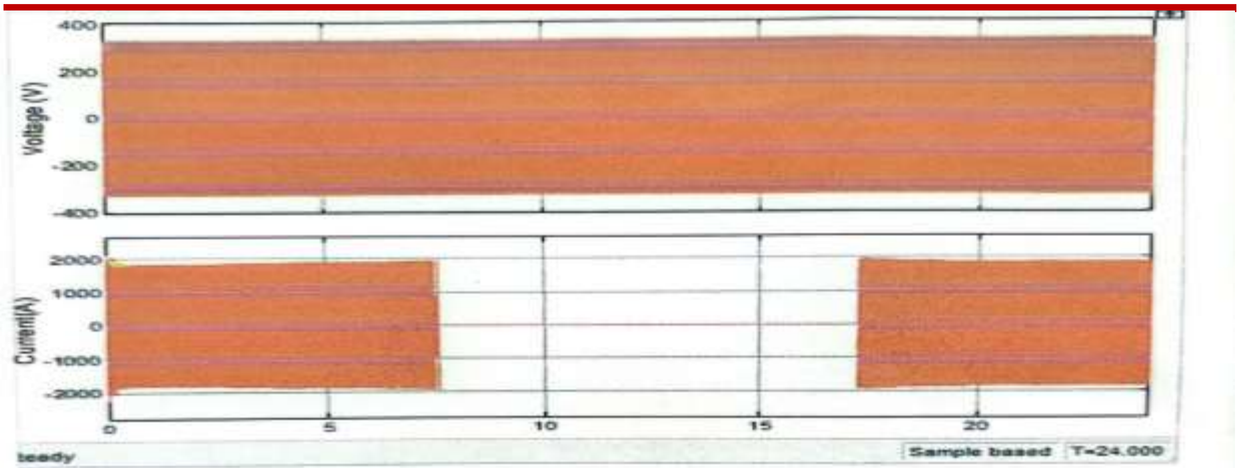

Figure 9: Grid outlet controlled by ANFIS energy management system

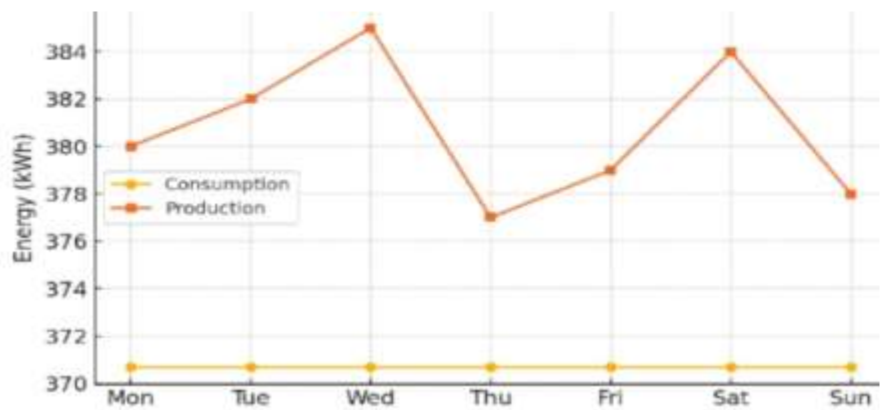

Figure 10: Daily Productions and Consumption Energy Generated

Figure 10 provides a plot that shows the comparison between daily renewable energy production and the poultry farm daily energy consumption. The hybrid system that combines solar and wind energy sources, consistently generates and average production between 377kW and 385kW each day. The table outlines the monthly energy output from the solar PV system, the adjusted wind energy output after elevating the height to 50 meters and the overall output from the hybrid system. The solar energy generation, remains consistent, and the energy peaks in April with 158.1kWh and drops 124.5kWh in August, reflecting to the seasonal changes in solar irradiance of Rumuji. Increasing the turbine height from 10m to 50m enhances. From the result January's wind output increased from 62.4kWh to 122.67 kWh and from July's output went from 80.6kWh to 158.45kWh since the wind power output is related to the cube of wind speed, and this adjustment results to a notable boost in wind energy production. The total hybrid energy output of solar PV and wind increased across all month. From the analysis, the lowest total output is January (261.67kWh), which is still far from the poultry farm daily load requirement of 20kWh/day. This demonstrates that the system is suitable for grid connected operations with battery backup.

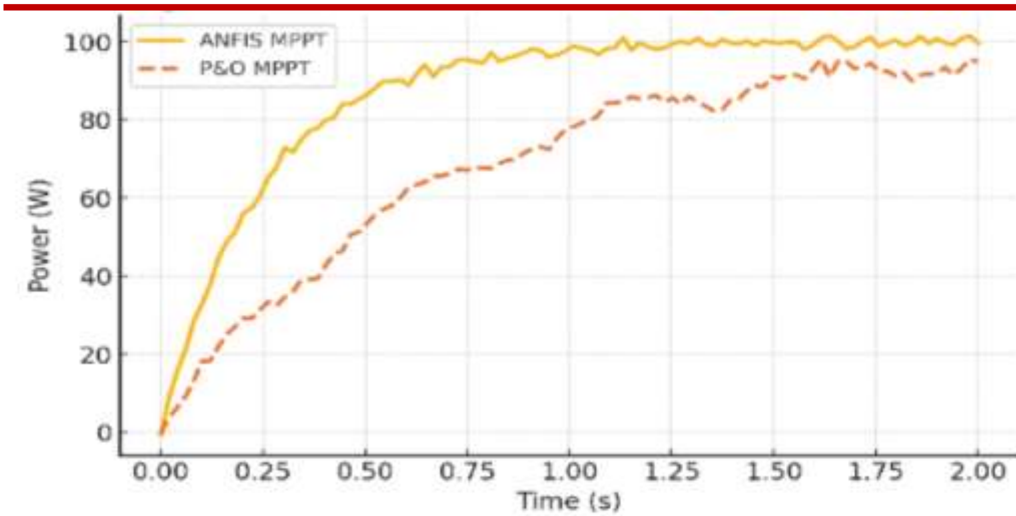

Figure 11: Plot of ANFIS vs P &O PPT

Figure 11 depicts the plot of ANFIS vs P&O PPT which assesses the dynamic response of two control strategies for maximum tracking. The Adaptive Neuro-Fuzzy Inference (ANFIS) and the traditional Perturb and Observe (P&O). The ANFIS shows a quicker convergence, improved tracking accuracy and less oscillation around the maximum power point. On the other hand, the P&O method has a slower response and greater fluctuations, which can lead to energy loss. From the analysis, the ANFIS is more effective at managing the real time changes in irradiance and temperature, ultimately maximizing the power extraction from solar module and wind energy system. The average annual wind speed at 50m is 5.6m/s and the peak wind month is between December–March for and effective and best for wind turbines and the low wind month is from July-August when the wind energy is minimal. Mgbumodu community, experiences moderate wind speeds of 5.6m/s at 50m that is suitable for small to medium wind turbines. The hybrid wind and solar integration ensures continuous power supply. With wind potential in December-March complements lower solar output in rainy reason.

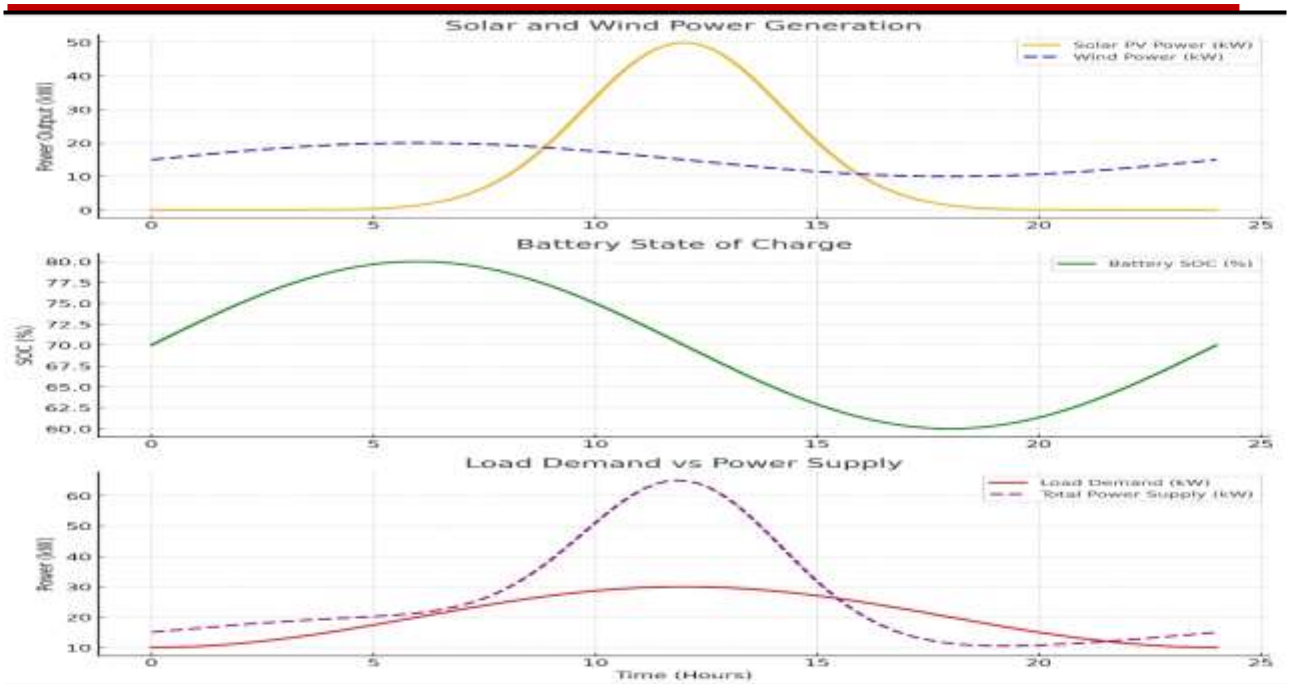

Figure 12: shows plot of solar and wind power output

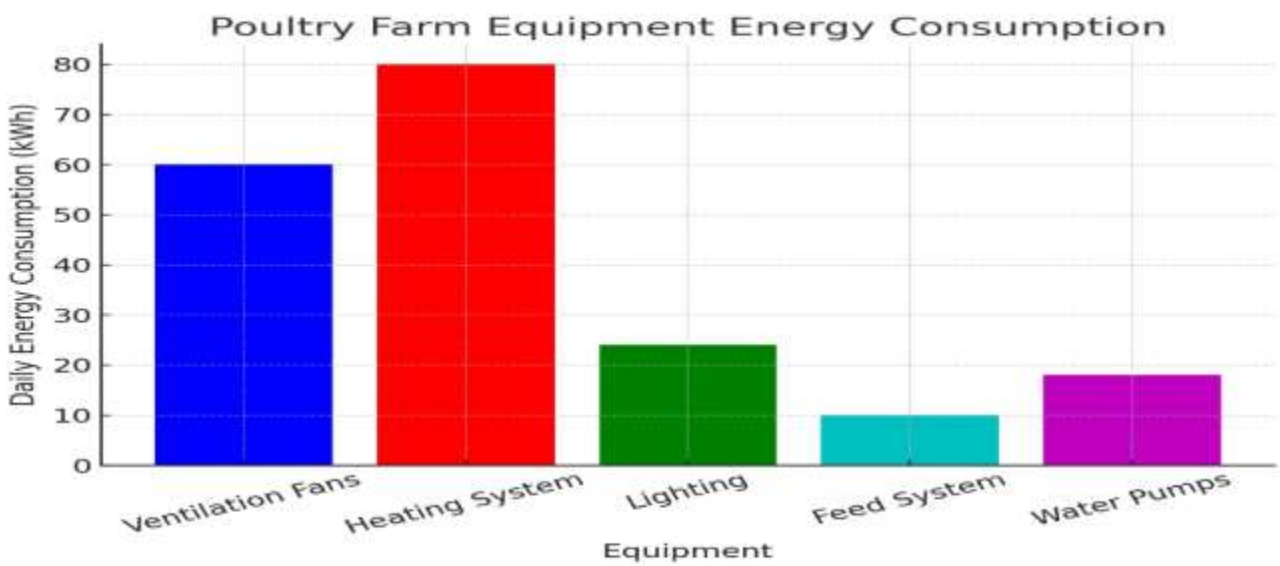

Figure 13: Bar Chart of Poultry Farm Equipment Energy Consumption Analysis

XI. DISCUSSION OF FINDINGS

The load profile analysis of the poultry farm typically uses about 4497.035kWh of energy each day, which add up to about 53964.42kWh over the course of a year. This energy is allocated for various needs, including lighting, ventilation, water pumping, and automated feeding system. from the plot of the daily curve, the energy demands peak in the early morning and late evenings, which aligns perfectly with the feeding and lighting routines of the Mgbumodu poultry farm.

XII. CONCLUSION

The study delves into optimizing and managing energy from grid-tied hybrid renewable energy sources using an ANFIS-based technique. In this research, the ANFIS Energy Management System (EMS) controller is utilized to monitor the changing weather conditions for solar and wind energy, taking into account factors like solar irradiance and wind speed. It then compares the power generated from resources falls short of meeting the load demand, the ANFIS controller automatically switches OFF the grid sources. Additionally, the ANFIS-based EMS controller manages the battery energy storage system by activating it when the grid is unavailable and renewable generation is sufficient, while also charging the battery during periods of excess electricity production.

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