Energy Management System in Microgrid with ANFIS Control Scheme using Heuristic Algorithm.

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Abstract - *Renewable energy sources (RES) are inherently variable resources. Especially in solar and wind turbines, wherein an abrupt range of solar and wind speeds causes power variations. This disrupts the power system's stability and greater operation with electricity. Energy storage devices such as battery storage systems (BSS) are being introduced to the grid to overcome these issues. The battery system is also utilized to reduce power fluctuations and to effectively balance the produced as well as demand energy. BSS is also used to assist balance load requirements by providing additional power. The proposed EMS interfaces with the ANFIS controller to govern the performance of both the battery as well as solar and wind systems based on demand. Mostly The battery management system (BMS) is an example of this, adaptive controllers assist in monitoring the battery's State of charge limitations to ensure that the necessary charging and discharging times are achieved. A brief overview of EMS procedures is presented in this study., which are simulated in MATLAB/Simulink, which is being used to validate the suggested controller. The simulation results demonstrate the suggested controller functions as an EMS and BMS, as well as being employed for power balancing between production and load, with efficiently mitigating power fluctuations during varying loads.*

Key Words: Energy Management System (EMS), Energy Storage System (ESS), Adaptive neuro-fuzzy inference system (ANFIS), Microgrid (MG), and State of Charge (SOC).

1. INTRODUCTION

Nowadays one of the most challenging tasks is integrating renewable energy sources into the utility system because electricity is unreliable and always fluctuates [1]. The grid's sustainability is affected by the net energy flow there; thus, the balance must be maintained. As more RES are incorporated into the system, power fluctuations become even more of a problem. Several studies have worked on this problem, and a few of the solutions proposed to result in additional usage of battery banks or other forms of energy storage i.e., ESS. [2] RES is considered as the prime alternative to conventional energy resources, as its vast accessibility throughout maximal energy demand and effectual amount of power supplied for robust grid support. However, the power generated from the solar and wind is unsteadily caused by climatic disparity; hence, solar and wind power are inadequate to maintain the grid. The RES's capacity to fulfill demand and maintain flexibility is Significant. Therefore, ESS used in conjunction with wind and solar power to provide output power stability is presented [3]. For optimal insertion of RES, MGs are configured in the system. These systems are characterized as power management approaches that integrate DERs with groups of loads by regulating MG power flow. MGs may operate in either grid-connected or grid-isolated mode [4]. Large-scale renewable DERs are becoming incredibly popular in conventional power systems. They have been mostly off-grid interconnection previously. Furthermore, a substantial number of renewable DERs are now being integrated into low/medium voltage distribution systems, creating serious hurdles to the system's operation and protection [5]. The EMS plays a critical role in the efficient use of renewable energy sources to meet load requirements. EMS is a combination of computer-assisted tools used

1. Premise i.e., base or reference
2. Consequence i.e., result by power systems managers to evaluate, regulate, and optimize the productivity of generation resources [6]. Due to the installation of RESs, EMS currently plays a crucial part in MGs. The power flow of MG is regulated by a succession of converters. The energy management algorithm that governs the envisaged grid controls how well these converters react to grid fluctuations [7]. Traditional controllers, such as PID controllers, have been used in the power industry for decades to constrain point of common coupling (PCC) voltage, and they are very responsive to dynamical systems, which could also result in an unsteady, oscillatory, or stagnant response while working circumstances change [8].

This research presents an energy management approach that relies on ANFIS, composed of RES, ESS, and an ANFIS-based control scheme, which is a much more advanced AI technology while contrasted to the fuzzy system. The core contribution of this work is the implementation of ANFIS as a supervisory control system for grid interconnected RES for the estimation of energy that should be supplied by/stored in the ESS. ANN, FIS, as well as neuro-fuzzy systems are advanced control strategies that do not require a precise prototype system to work and are undisturbed by system dynamics. Therefore, intelligent controllers can execute under a variety of circumstances [9]. Traditional rule-based techniques require a detailed mathematical description of the system and are extremely sensitive to parameter changes. [10]. There are more effective and adaptable ANN, FL neurofuzzy than conventional ones because they don't necessitate an accurate scheme's representation as well as improve the system's dynamic behavior. While compared with another neuro-fuzzy scheme, the ANFIS has a quicker computational efficiency. ANFIS is a smart platform that incorporates ANN's learning and concurrent processing capabilities with the fuzzy inference program's inference characteristics. The ANFIS is the combination of hybrid soft computing techniques, Using superior level reasoning skills and inferior level computational command, in addition to the neural network and fuzzy. ANFIS is a sophisticated adaptive network that may be used to describe complicated and nonlinear systems with fewer input and output target parameters. In the structure of ANFIS, there are two different parameter groups:

Training ANFIS means a determination of these parameters using an optimization algorithm. The selection of optimization methods utilized in training is very important to get effective results with ANFIS.

There are the following types of algorithms used in ANFIS training.

1. Derivate based (GD, LSE, etc.) and
2. non-derivative based (heuristic algorithms such as GA, PSO, ABC, etc.).

It has been observed that heuristic-based ANFIS training algorithms are best.

2. PROPOSED SCHEME

The proposed EMS is simple and operates using an intelligent logic for the switching algorithm. According to variable solar and wind speeds and load circumstances, the proposed algorithm generates dynamic standards for each subsystem. In addition, utilizes all renewable energy sources and battery storage technologies effectively. The suggested system offers a rather more optimal power flow with higher power quality and dependability. It comprises the following Contents:

Table -1: Nominal Power of DG Units and Load

Rated P›wer (kW)		Load(kW)	
PV	500	L1	L2
WIND	500	200	350
BESS	400		

2.1. Wind generator

The WT is illustrated by a scheme that includes the turbine and generating system components. As stated by the actuator disk theory, the turbine model represents the mechanical power collected by the wind concerning wind speed as well as blade TSR. Moreover, WT generating system includes a damping resistor at dc bus that dissipates power surplus with relatively high winds maintaining WT-rated power. Power surplus with relatively high winds maintaining WT-rated power. The wind turbine I used to convert mechanical energy from wind energy. Eq. 1 expresses the mechanical power of a wind turbine.

$$\boldsymbol{P_m} = \frac{1}{2}\boldsymbol{\rho A C_p(\lambda,\beta) V^3 \omega} \ldots\ldots\ldots\ldots\ldots 1$$

Where,
Pm - Mech. output power.
P – Density of air.
A – Blade area.
Vω -Speed of wind.
B - pitch angle degree.
Cp (λ, β) - power coefficient.
The power coefficient is calculated by Eq. (1).

$$C_P = 0.73\left(\frac{151}{\lambda_i} - 0.58\beta - 0.002\beta^{2.14} - 13.2\right)e^{\frac{-18.4}{\lambda_i}} \quad \ldots\ldots\ldots 2$$

$$\text{With } \lambda_i = \left(\frac{1}{\lambda - 0.002\beta} - \frac{0.003}{\beta^3+1}\right)^{-1} \quad \ldots\ldots\ldots 3$$

Where, C_P non-linear function of both the
λ - Tip Speed Ratio (TSR)
β - The pitch angles.

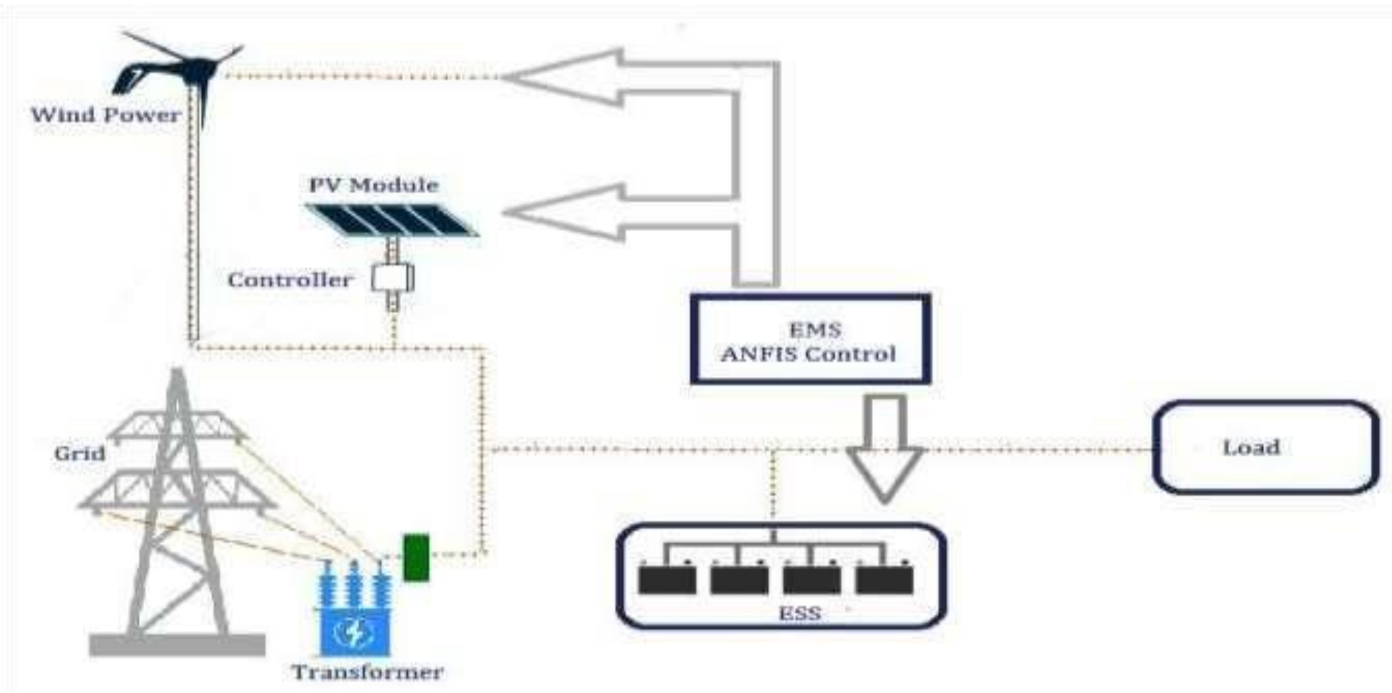


Fig1. Block dia. of the proposed model

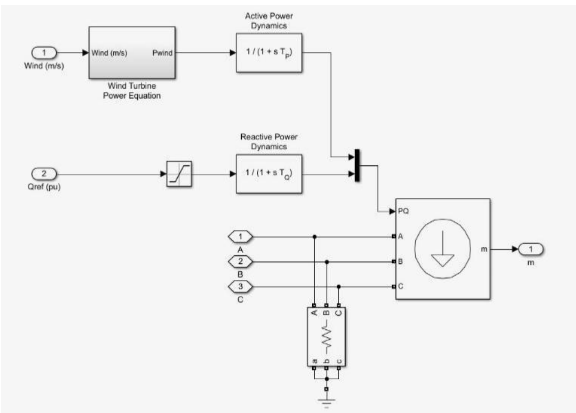


Fig 2. MATLAB/Simulink model of a wind turbine.

2.2. Solar PV

The Photovoltaic system uses a single-diode model to represent each PV panel, which is made up of optimal PV cells. This system offers high precision and the variables are easily obtainable in industrial datasheets [11], making it ideal for PV device computations using converters. PV output voltage that is converted to dc bus voltage using a dc-dc converter governed with the MPPT technique. The equivalent circuit diagram is shown in Fig 2.

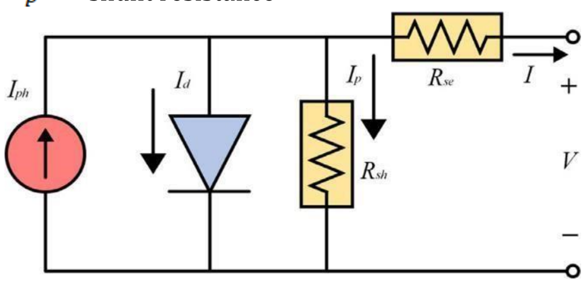
$$I = I_{ph} - I_0\left[exp\left(\frac{q\,(V + IR_s)}{nkT}\right) - 1\right]\frac{(V + IR_s)}{R_s}$$

…….4

Where,

I - Output current.
I_{ph} - Photocurrent due to irradiance.
I_0 - Diode saturation
current. V - Cell voltage. q -
Charge. n - Unideal constant of
the diode. k - Boltzmann's

R_s
R_p - shunt resistance.



c o n s t a n t . T -
Cell temperature.
- Series resistance.

Fig 3. Equivalent Dia. For PV Cell

The equation representing the output current of a PV cell is as follows:

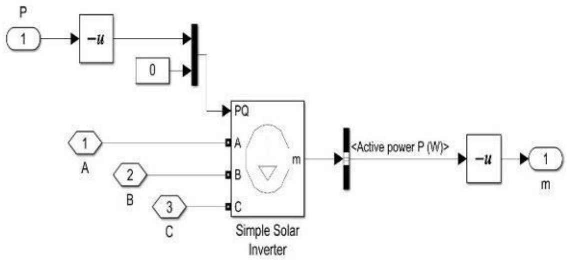


Fig 4. MATLAB/Simulink solar model

2.3. Energy storage system (ESS)

Bad weather causes considerable variation in solar as well as wind speed, resulting in instability in the solar and wind energy production process that offers power reduction to the power grid owing to inadequate power supply from the energy production. In this instance, sustaining the DC connection voltage includes the deployment of an energy storage technology including batteries to counteract grid disruptions. For any overabundance of solar and wind energy, the battery would recharge. Whenever wind speed falls owing to inclement weather, wind energy decreases, causing the battery to deplete. In ESS, a lead-acid battery is used for the hybrid system. This battery technology is typically the inexpensive reserve battery for any operation, while yet giving adequate performance and durability [13].

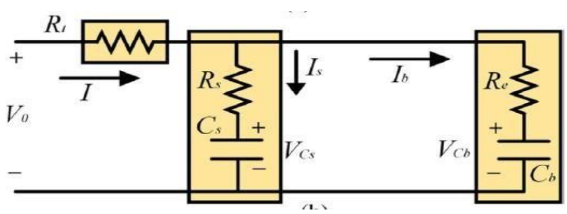


Fig 5. Equivalent Dia. For Battery Energy Storage System (BESS)

The following express the variation of the battery SoC:

$$SoC_t = SoC_o + \frac{1}{Q}\int_{t_0}^{i_f} Idt \ldots$$

Where' $\int idt$ - battery's instantaneous capacity Ah.
Q- Battery's maximal capacity in Ah. 5

It is vital to control the battery's SoC to prevent overcharging or undercharging to extend the battery's life. The associated constraint can be written as follows:

$$SoC_{min} \leq SoC_t \leq SoC_{max} \quad \ldots\ldots\ldots 6$$

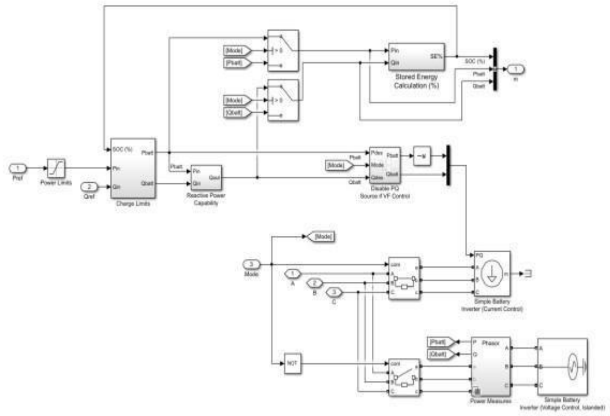


Fig 6. MATLAB/Simulink Model of Energy Storage System

3. ENERGY MANAGEMENT STRATEGY

After the ANFIS has been trained, the following steps should be taken. For the proper sending of troops, a plan has been used. Battery energy to smooth out the system's output power the total power generated is one of the two inputs to the ANFIS. At the current moment by the system, the other is the command smoothing power output's previous value. The ANFIS provides a result from these two inputs, the battery's power is controlled and the entire power is then deducted from this power available at batteries. Depending on the sign of the power, this power dictates whether the battery must charge or discharge. The battery must discharge if the indication is positive; else, yielding charged battery. This power is also susceptible to maximal and minimal restrictions, which contribute to either a lack of smoothing power or a surplus of power that will be discharged. It has two modes:

i. Excess power mode (EPM) ii.
Deficit power mode ((DPM)

The two modes of operation are determined by the availability of renewable power generation and the system's load demand. Based on the state of SOCb and SOCsc, four different operating circumstances are discovered in the DPM and EPM modes, as indicated in

Table 2. The suggested EMS achieves the following goals:

1. Maintain the SOCb and SOCsc within their safe operating ranges, which are the prescribed higher (H) and lower (L) SOC limitations.
2. Minimize battery stress and extend battery energy lifespan.
3. Less intensive in terms of computing.

Table 2: Modes of System Operating Conditions

Modes	circumstances of operation
Mode1	Because the load demand is lower than the electricity generated by RESs, a power limitation is imposed.
Mode 2	The power gap between RESs and load demand is smaller than the battery capacity. As a result, the storage system must meet the load demand.
Mode 3	Because the combined output of the RES and the batteries is less than the load requirement, the CESs participate in energy management to achieve power balance at the lowest possible cost.
Mode 4	Because the load demand exceeds each RES and CES supply limit, the load switches to a restricted mode, in which all power sources are used to meet the critical load's power requirement. This ensures system stability.

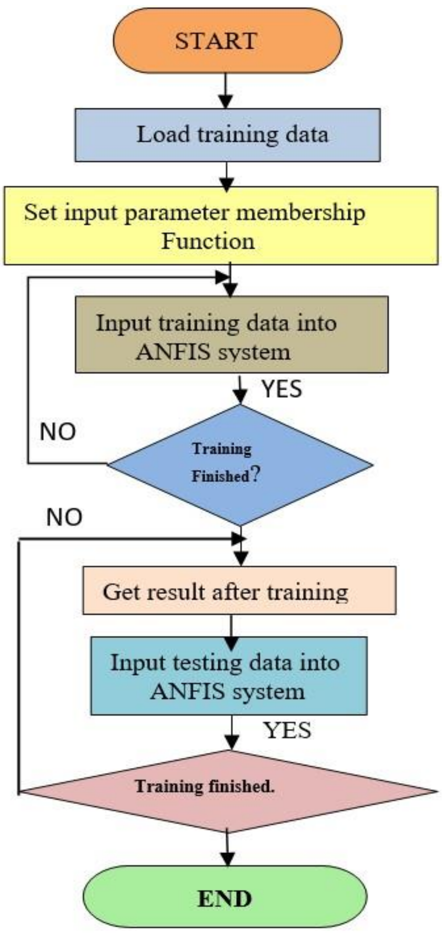


Fig 7. Flow chart of ANFIS control scheme.

4. ANFIS CONTROL

ANFIS is a composite model that combines ANN plus fuzzy schemes to reap the benefits of these approaches. It integrates using Takagi-Surgeon adopted the fuzzy scheme, with ANN optimizing the final fuzzy inference system. A typical ANFIS system is seen in Fig.8, An adaptable node is represented by a square, while a fixed node is represented by a circle. A multi-layer feed forward network is depicted in this diagram. While processing the inputs to produce the outputs, each layer has its function. A collection of input as well as output element functions is connected with fuzzy ifthen rules to regulate the inputs and outputs. Unlike a traditional fuzzy scheme, I/O functions, as well as The ANFIS offers it an edge by employing ANN training to modify the rules and membership functions. Fuzzy if-then rules are reliant on human skill. The process of creating an ANFIS system begins with the user intuitively selecting initial input and association functions according to the system's knowledge. If prior information is not accessible, the user can still pick associated functions. In addition, ANN executing procedure will then create a set of if-then rules that are appropriate for data. Different learning algorithms are used to optimize the fuzzy rules in place to evade entrapment into local minima and to increase efficiency. The hybrid technique incorporates the least-squares and training algorithm methods [15].

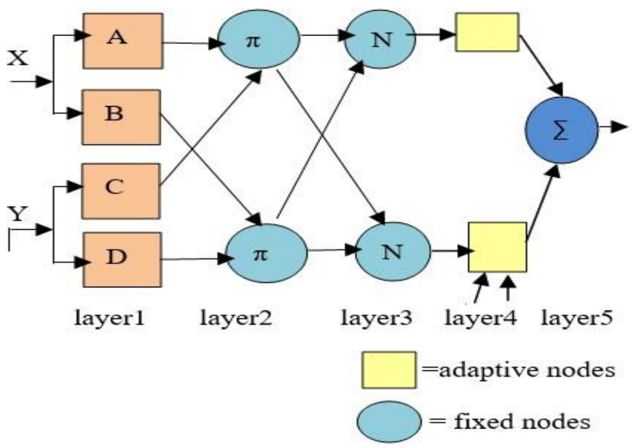


Fig. 8. Configuration dia. of ANFIS

Eqs. (7) and (8) describe a common rule set for the Takagi-Sugeno interference system with two fuzzy layers (8),

RULE 1:

If $P_G(t-1)$ is C_1 and $P_L(t)$ is D_1 then,

$$f_1 = m_1 P_G(t-1) + n_1 P_L(t) + k_1 \quad ....7$$

RULE 2:

If [illegible] is C_2 and $P_L(t)$ is D_2 then,

$$f_2 = m_2 P_G(t-1) + n_2 P_L(t) + k_2$$

…………..8

Where,
$m_1, m_2, n_1, n_2, k_1, and\ k_1$ Are the linear Parameters Are C_1, C_2, D_1, D_2 the non-linear parameters.

Figure 8 depicts the ANFIS layer framework in a beautiful way.

1.Fuzzification layer.
The fuzzy layer output is furnished in Eq. (9) And Eq. (10)

$$R_{L1,i} = \mu C_i(P_G(t-1)), \quad i = 1,2; \ \ldots \qquad 9$$
$$R_{L1,j} = \mu D_J(P_G(t)), \quad j = 1,2; \ \ldots \qquad 10$$

Where,
$R_{L1,i}$ and $R_{L1,j}$ - output of the fuzzy layer
$\mu C_i(P_G(t-1))$ And $\mu D_J(P_G(t))$ - Membership function of the fuzzy.

2. Product layer
This layer output can be described by Eq. (11) and Eq. (12)

$$W_1 = R_{L2,i} = \mu C_i(P_G(t-1)) * \mu D_J(P_G(t)), \quad i = 1,2; \ \ldots\ldots 11$$

$$W_2 = R_{L2,i} = \mu C_j(P_G(t-1)) * \mu D_J(P_G(t)), \quad j = 1,2; \ \ldots\ldots 12$$

Where,
W_1 And W_2 -The product layer outputs.

3. Normalization layer
The corresponding layer is expressed in Eq. (13) and Eq. (14).

$$W_1' = R_{L3,i} = \frac{W_i}{W_1+W_2}, \quad i = 1,2; \ \ldots\ldots 13$$
$$W_2' = R_{L3,j} = \frac{W_j}{W_1+W_2}, \quad j = 1,2; \ \ldots\ldots 14$$

Where,
W_1' And W_2' - The normalized layer outputs of.

4. Defuzzification layer
The defuzzification layer output is furnished employing Eq.
(15) and Eq. (16)

$$W_1' f_i = R_{L4,i} = \frac{W_i}{W_1+W_2}[m_1 P_G(t-1) + n_1 P_L(t) + k_1] \ \ldots\ldots 15$$

$$W_2' f_j = R_{L4,j} = \frac{W_j}{W_1+W_2}[m_2 P_G(t-1) + n_2 P_L(t) + k_2] \ \ldots\ldots 16$$

Where, $W_1' f_i$ and $W_2' f_j$ - de-fuzzy layer outputs.

5. Total output layer
It is possible to calculate the sum of the input signals, which is provided as $\sum W_1' f_i$.Eq. (17) provides the overall output of the layer.

$$f = R_{L5,i} = \sum W_1' f_i = \frac{\sum W_i f_i}{\sum W_i} \ \ldots\ldots 17$$

Where,
f – the total output.
When the ANFIS training is complete, the reference power $P_{ref}(t)$ to regulate the HRES' energy will be available.

Table 3: Reference calculation

Power source	**Power control**
PV	$V_{PV\,ref(t)} = \frac{P_{PV\,MPPT}}{I_{PV}}$ or $\frac{P_{PV\,Limit}}{I_{PV}}$
Wind	$V_{WT\,ref(t)} \frac{P_{WT\,MPPT}}{I_{WT}}$ or $\frac{P_{WT\,Limit}}{I_{WT}}$
Battery	$I_{BAT\,ref(t)} = \frac{P_{BAT\,ref}}{V_{BAT}}$

4.1. ANFIS PID-Control for PV inverter The grid-interfacing PV inverter includes four ANFISPID based control methods to manage active plus reactive power suitably to normalize voltage under customary circumstances and supply LVRT throughout the three phase's Symmetry grid failure state. Each ANFIS control scheme is made up of three intelligent ANFIS controllers that are in charge of different control parameters. Four ANFIS-PID-based control methods have been assigned, twelve intelligent ANFIS controllers. The ANFIS-PID based control system has been designed and studied to regulate grid interfacing PV inverters is shown in Fig.9. The training data set produced from simulations has been used to structure each of the twelve intelligent ANFIS regulators. For appropriately tuning for fuzzy parameters of ANFIS, a collection of data has been compiled for each from simulations that completely depict the weak distribution system's dynamic behavior when combined with large-scale PVs [16].

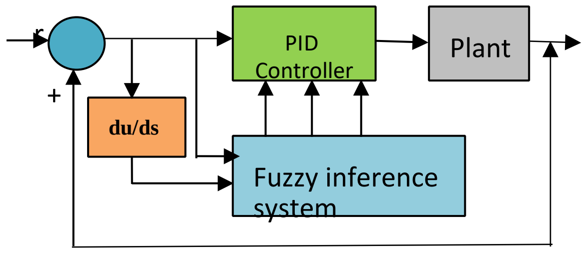


Fig. 9. Configuration of ANFIS

4.2. ANFIS Supervisory EMS for ESS

PV power generation progressively climbs, peaks around midday, and then begins to decline. The quantity of available energy leftover later than fulfilling the consumers is determined by the nonlinear performance of dynamic loading that varies throughout the day as well as year. By collaborating with the PV inverter control scheme, an ANFIS supervisory EMS smartly manages to balance power generation and abrupt load demand, the ESS is charged and discharged, improving the system's voltage profile A Continuous charging/discharging rate strategy, which may result in underutilized storage capacity, is preferred to this control technique. The SOC should be kept within the proper allowed range to avoid the battery bank from overcharging/over-discharging [17]. The supervisory EMS based on ANFIS protects the ESS from being charged more than SOC_{max} and has been programmed to mimic the planned the supervisory EMS based on ANFIS protects the ESS From being charged more than SOCmax and discharge d less than SOCmin.

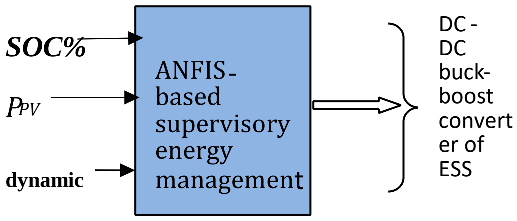


Fig. 10. Configuration of ANFIS supervisory EMS for ESS

Supervisory ANFIS has been programmed to mimic the planned supervisory management system using a collection of data.

5. SIMULATION RESULT AND DISCUSSION

The experimental results of the suggested algorithm implemented in a system with an Intel(R) Core (TM) i5 CPU, 4GB RAM, and the MATLAB/Simulink (R2021a) platform are described in this part. The proposed energy management system is constructed for the HRES system in Figure 1 and its effectiveness is evaluated. Table 1 shows the planned model for the HRES arrangement. Depending on the load variation, the suggested technique predicts the reference power of the sources. The proposed approach requires the previous instant generated power from the energy sources, as well as the present time load demand, for this purpose. Depending on the load variation, the suggested technique predicts the reference power of the sources. The proposed approach requires the previous instant generated power from the energy sources, as well as the present time load demand, for this purpose. When the generated power is greater than the load requirement, the excess power is used to charge the storage devices. However, if the generated power is less than the load requirement, the necessary power is drawn from the storage devices.

Table 4: Simulation parameters of HPS

Parameters	Values
PV rated power	3.78 kW
Open circuit voltage of PV	64.2 V
Short circuit current of PV	5.96 A
Rated power of WT	1 kW
Battery nominal voltage	26.4 V
Battery rated capacity	6.6 Ah

The efficiency of the suggested method is demonstrated using two different test cases: input power generation variation and output load variation. The suggested method is initially validated by varying the input power generation, but the load value remains constant at 3.5 kW nonlinear load (diode rectifier with R load). Fig.13 depicts the required reference load demand. The irradiation of the PV system is depicted in Fig.14 for the first test case. The output power generated by the PV is depicted in Fig.15 based on the irradiation level. The PV generator's output power ranges from 1.6 to 3.6 kilowatts. The PV's highest power is harvested between 0.25 and 0.85 seconds and 2 to 3 seconds. The minimum power generation occurs between 1.25 and 1.5 seconds. Currently, the required load demand is met by employing PV and WT output. power, and storage devices output power. The standard P&O technique is used to achieve the MPPT of the PV generation system.

Fig.16 depicts the generated power from the WT. The standard P&O MPPT technique is used to achieve the MPPT of the WT.

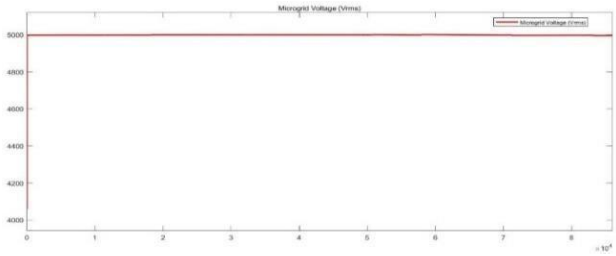


Fig. 12. Load demand of the first test case

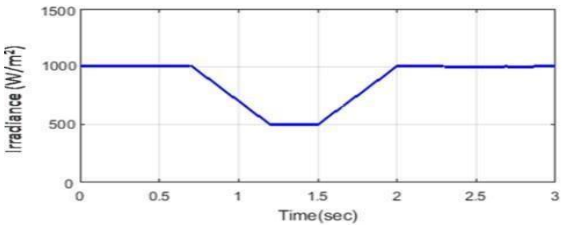


Fig. 13. Irradiation of PV generator

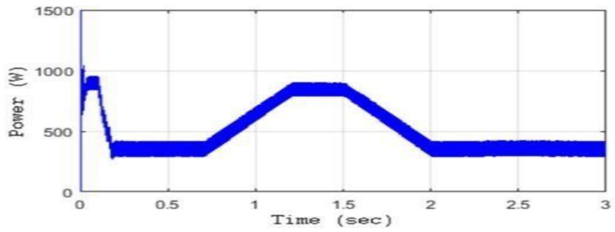


Fig.15. Output power of WT

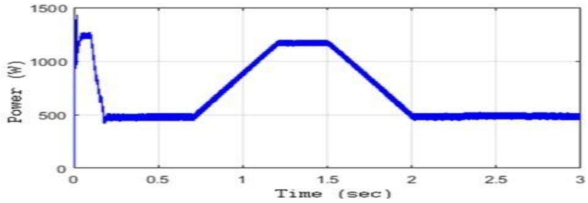


Fig. 16. Battery output power

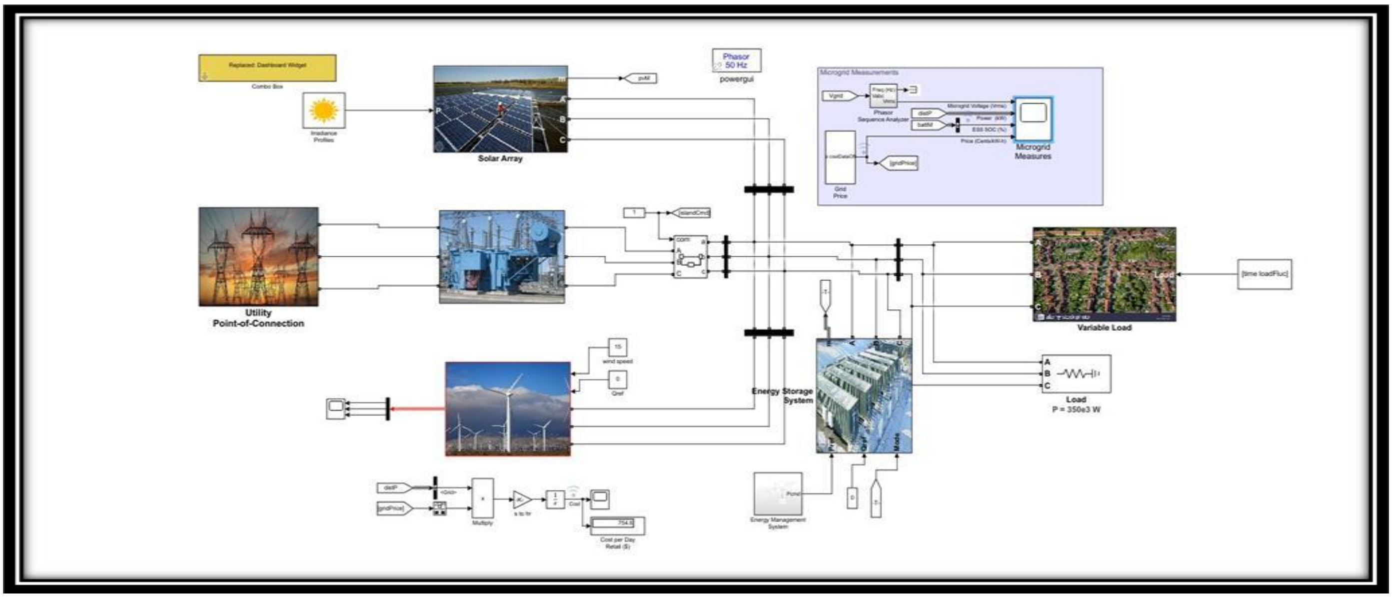


Fig.11. Block Illustration of Proposed Design

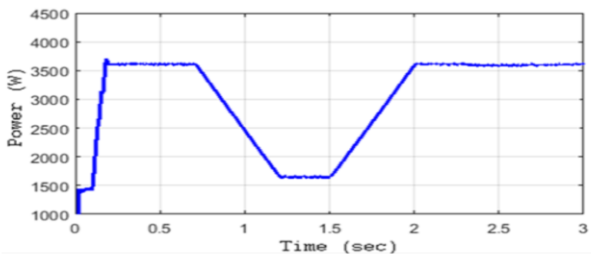


Fig.14. Output power generator by PV

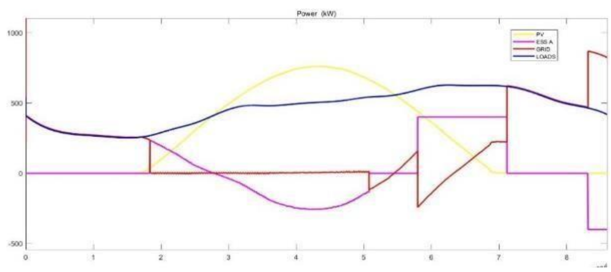


Fig. 17. Total power generation with reference to the load

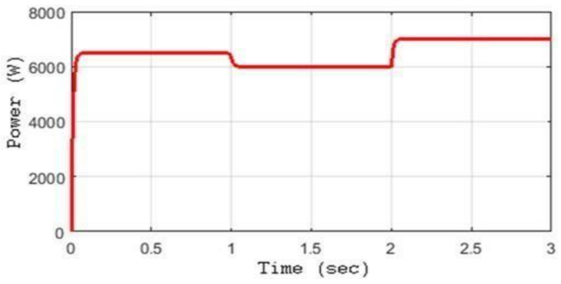


Fig. 18. Second test case load demand

The second test case was carried out with the following loads: I a 5-kW resistive load connected via a diode rectifier from 0 to 3 s ii) a 500 W active power RL load is connected during 0 to 1 s, and iii) a 0.5 kW active power RL load is connected during 2 to 3 s, as illustrated in Fig.19. The constant irradiance and wind power are taken into account in this scenario. Fig.20 and 21 show the irradiation and PV power in the second test instance, respectively. During 0.25 to 1 s, the PV's maximum power is extracted. Because the load value is reduced from 6.5 kW to 6 kW, the full power extraction is not required during the time period 1 to 2 s. The PV output is kept at 3.5 kW at this point, and the maximum power of the PV is extracted for another 2 to 3 seconds (3.78 kW). Figure 22 depicts the WECS's power output. The WECS output power is kept between 900 and 910 watts. Figure 23 depicts the battery output power with the proposed energy management. The amount of battery output power used is determined by the load variation. Fig.19 depicts the overall power generation when the energy management strategy is combined load demand.

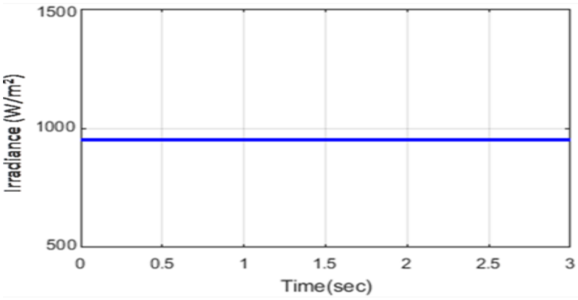


Fig. 19. Irradiation of PV generator

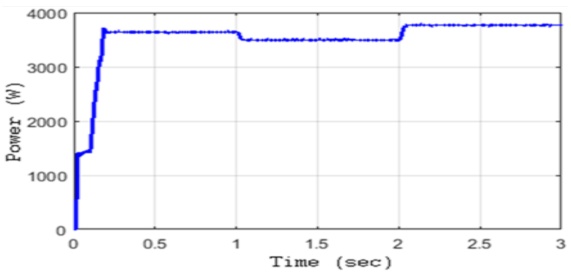


Fig. 20. Output power of PV

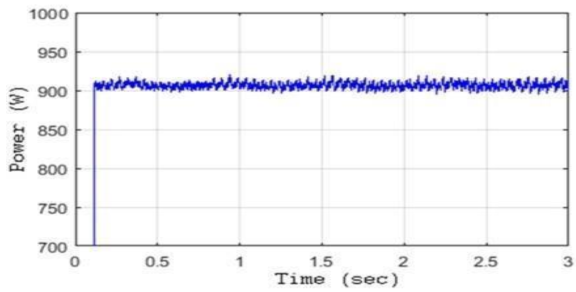


Fig. 21. Output power of WT

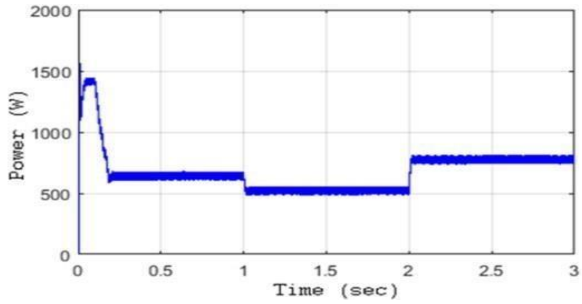


Fig. 22. Output power of battery

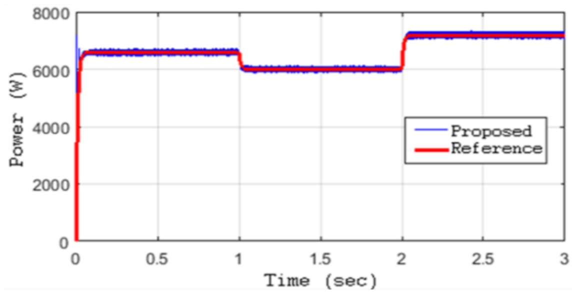


Fig. 23. Total power generation with load power reference

CONCLUSION

The focus of this work is on an energy management system (EMS) utilized in a grid-connected microgrid with a PV system, a wind farm, a battery storage system, and variable loads. An ANFIS technique has been developed to determine the ideal configuration of energy sources while taking renewable resource projections into account in order to minimize operating costs and grid dependence and optimize the usage of renewable energy and power exchange with the grid. This research has made an ANFIS-based EMS of a grid-connected hybrid system accessible and tested for a smart grid made up of renewable energy sources (WT and PV panels). It also suggests and evaluates the performance of an intelligent ANFIS-based voltage control scheme for grid-tied renewable energy systems at the PCC, Furthermore, it removes the need for costly conventional trial-error methods for tweaking traditional PID attributes on regular basis by providing a "plug-and-play" function for automated tuning once installed. ANFIS is utilized to control electricity between the grids, and the source, along with batteries. The outcome revealed that ANFIS provides higher performance with minimized fluctuations significantly. The proposed EMS is capable of fulfilling varying power requirements even while enabling energy management algorithms and efficient ESS deployment.

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