

# Intelligent control strategies for grid-connected photovoltaic wind hybrid energy systems using ANFIS

Thiruveedula Madhu Babu<sup>1</sup>, Kalagotla Chenchireddy<sup>2</sup>, Kotha Kalyan Kumar<sup>1</sup>, Vasukul Nehal<sup>1</sup>,  
Sappidi Srihitha<sup>1</sup>, Marikal Ram Vikas<sup>1</sup>

<sup>1</sup>Department of Electrical and Electronics Engineering, Teegala Krishna Reddy Engineering College, Hyderabad, India

<sup>2</sup>Department of Electrical and Electronics Engineering, Geethanjali College of Engineering and Technology, Hyderabad, India

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## ABSTRACT

This study proposes intelligent control strategies for optimizing the grid integration of photovoltaic (PV) and wind energy in hybrid systems using an adaptive neuro-fuzzy inference system (ANFIS). The ANFIS control aims to enhance grid stability, improve power management, and maximize renewable energy (RE) utilization. The hybrid system's performance is evaluated through simulations, considering various environmental conditions and load demands. Results demonstrate the effectiveness of the proposed ANFIS-based control in dynamically adjusting the power output from PV and wind sources, ensuring efficient grid-connected operation. The findings underscore the potential of intelligent control strategies to contribute to the reliable and sustainable integration of RE into the grid.

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## Corresponding Author:

Kotha Kalyan Kumar

Department of Electrical and Electronics Engineering, Teegala Krishna Reddy Engineering College

Medbowli, Meerpet, Saroornagar, Hyderabad 500097, Telangana, India

Email: kalyankumarkotha5@gmail.com

## 1. INTRODUCTION

The discussion of the worldwide issue of finite supplies of fossil and nuclear fuels in the introduction emphasizes the urgent need for alternative energy sources. It emphasizes the importance of moving away from conventional fossil fuel-based generators to keep the supply and demand for energy in check grid interactive electricity generation from renewable energy systems (RES) was over 12.1% of the total installed energy capacity as of March 31, 2012. By 2022, the Indian Ministry of New and Renewable Energy (MNRE) hopes to generate 38,500 MW of wind energy and 20,000 MW of grid-interactive solar energy [1]–[5]. It is known that solar radiation is a limiting factor for the amount of electricity that can be produced by photovoltaic (PV) systems, and the integration of PV modules with wind turbine systems is suggested as a solution. The topic of voltage variations due to wind and sun penetration is explored in depth. Power electronics play a revolutionary role in the production of electricity from renewable sources, notably wind and solar energy. Hybrid energy systems may be constructed using a variety of renewable energy (RE) sources, with wind and PV electricity being the most widely reported ones [6]–[8]. Communication systems are essential for integrating RE sources into the grid because they provide two-way communications that promote effective power flow and support distributed energy generation. Different grid components require monitoring and control, which calls for crucial decision support systems and applications. The article addresses the ongoing development of wind energy production on a worldwide scale, highlighting its crucial position in contemporary power networks as a result of significant investments. The expansion of wind power capacity and its effects on the total supply of energy are described [9]–[13]. Due to the depletion of

fossil fuels and rising environmental consciousness, the introduction of the article emphasizes the growing emphasis on renewable alternative energy resources. Alternatives that are considered to be more ecologically benign include hydraulic, wind, and solar energy. Solar and wind energy technologies have experienced substantial growth in recent years. The study emphasizes China's significant capability and efforts in wind power and solar energy installations, as well as the worldwide expansion in wind power capacity. However, the unpredictable nature and reliance on climatic and weather variations are a common negative for both solar and wind energy sources. Their changeable nature might not always match the timing of load demand, impacting system performance and causing batteries to be discarded too soon. By using the advantages of one energy source to make up for the shortcomings of the other, integrating them might lessen these difficulties [14]–[18]. A crucial development path for the creation of sustainable energy is defined as RE, notably solar PV and wind power. However, several obstacles, including their intermittent nature, technological constraints, and regional differences in the availability of renewable resources, prevent the smooth integration of RE into the grid [19], [20]. The implementation of the hybrid adaptive neuro-fuzzy inference system (ANFIS)-particle swarm optimization (PSO) based maximum power point tracking (MPPT) algorithm for PV MPPT functionality and grid integration is the work's main contribution. Real-time power pricing plans and the incorporation of RE into smart networks are highlighted [21], [22]. The study presents a strategy for size optimization to do this while ensuring the lowest investment and optimal utilization of the PV system, wind system, and battery bank. Numerous optimization methods, including dynamic programming, Multi-objective approaches, graphical construction techniques, linear programming, probabilistic methods, and iterative methods, have been studied in the literature for scaling hybrid PV/wind systems [23]–[25].

## 2. HYBRID OF PV-WIND

Figure 1 shows a hybrid energy system that consists of a PV array coupled with a wind turbine. This would create more output from the wind turbine during the winter, whereas during the summer, the solar panels would produce their peak output. Solar PV wind turbine (WT) hybrid system is the best way to utilize not just one locally available RE resource but multiple renewables RE resources. According to many RE experts, a small "hybrid" electric system that combines home wind electric and home solar electric PV technologies offers several advantages over either single system.

Hybrid PV and wind energy systems have demonstrated significant power output in several cases. As an illustration, a well-known project in La Paz, Mexico, integrated solar PV arrays with wind turbines. With a 500-kW total power output, this hybrid system displayed excellent energy production, producing 1,500 to 2,000 kWh on average each day and making a major contribution to the local power grid.

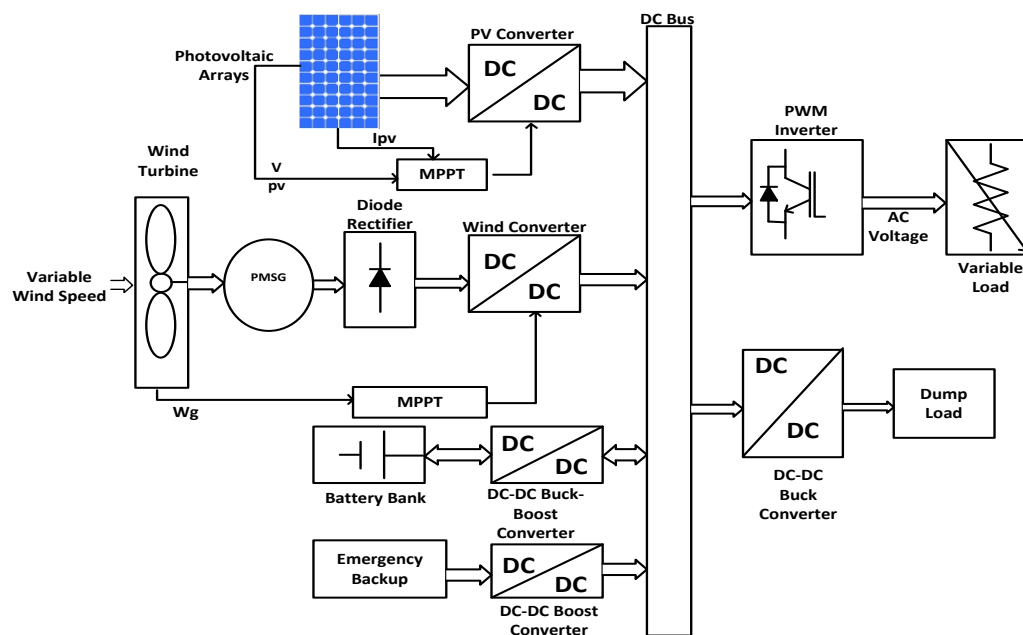


Figure 1. The hybrid of PV and wind

### 3. ADAPTIVE NEURO-FUZZY INFERENCE SYSTEM CONTROLLER

The ANFIS is a very promising control method for hybrid PV and wind energy systems. To represent complex interactions between input factors (such as solar irradiance, wind speed, and grid demand) and the resulting power output of the hybrid system, ANFIS combines the flexibility of neural networks and the interpretability of fuzzy logic. Figure 2 is a flowchart of ANFIS that builds a fuzzy inference system by training it on historical data and designing membership functions and fuzzy rules that capture the inherent uncertainties associated with RE sources. The ANFIS system develops an intelligent control framework that can adjust to changing climatic conditions, grid demand, and RE supply by combining the interpretability of fuzzy logic and the flexibility of neural networks. To achieve the ideal power balance between PV and wind source safety meticulously trains and learns its fuzzy rules and parameters, improving accuracy and responsiveness. The system's performance is optimized by this dynamic modification, guaranteeing reliable and effective operations. Using the hybrid modulation approach, the ANFIS controls the error signal and creates the necessary switching pattern. Figure 3 structure of ANFIS to an error ( $e$ ) and the rate of change in error ( $ce$  or  $d(e/dt)$ ) are inputs to the proposed ANFIS.

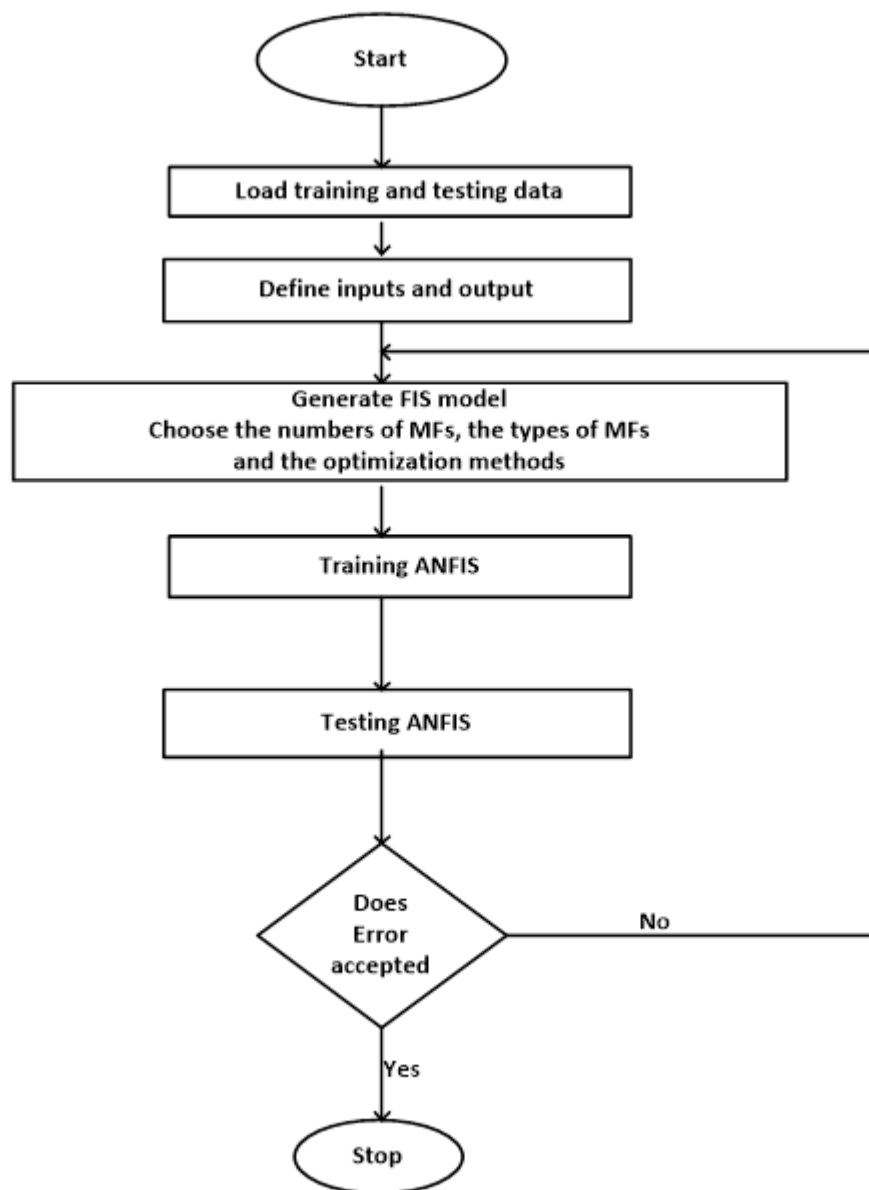


Figure 2. Flowchart of ANFIS

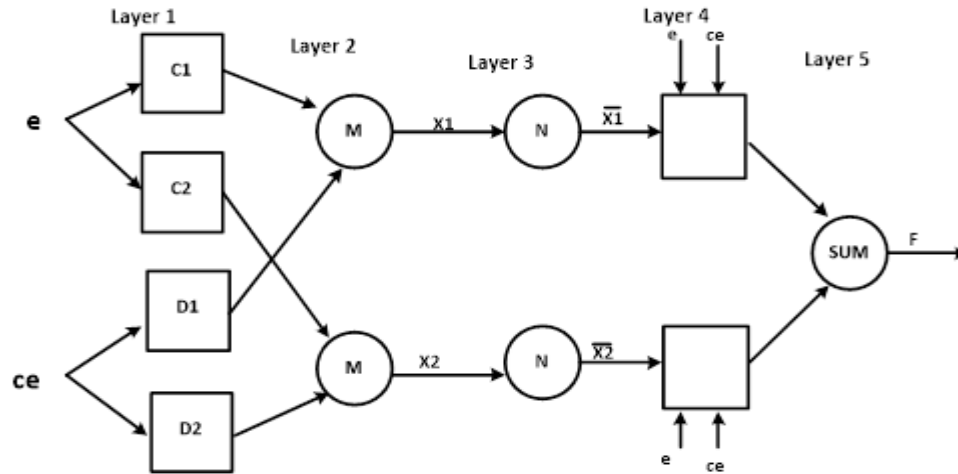


Figure 3. Structure of ANFIS

From Figure 3 we can derive layer outputs as (1).

$$\begin{aligned}
 &\text{Rule i: } C_{k1} \text{ and } ceV_k \text{ is } D_{k1} \\
 &\text{then } F_{k1} = A_1(e_k) + B_1(ce_k) + S_{k1} \\
 &\text{Rule i2: } eV_k \text{ is } X_{k2} \text{ and } ceV_k \text{ is } D_{k2} \\
 &\text{Then } F_{k2} = A_{k2}(e_k) + B_{k2}(ce_k) + S_{k2}
 \end{aligned} \tag{1}$$

Where  $M_1$ ;  $M_2$ ;  $N_1$ ;  $N_2$ ;  $S_1$  and  $S_2$  are used to represent the linear parameters,  $C_{k1}$ ;  $C_{k2}$ ;  $D_{k1}$  and  $D_{k2}$  are used to present the nonlinear parameters.

Fuzzy layer, at layer 1. Fuzzification is the process of transforming crisp data into fuzzy data using a fuzzy layer. Nodes and have, respectively, errors ( $e_k$ ) and rates of change in errors ( $ce_k$ ). Using fuzzy linguistic labels generated from fuzzy theory, membership functions are separated. The (2) illustrate the fuzzy layer's output.

$$\begin{aligned}
 F_{k1,i} &= \mu C_{ki}(a) \\
 F_{kL1,j} &= \mu D_{kj}(a)
 \end{aligned} \tag{2}$$

Where the output of the fuzzification layers is represented by the variables  $F_{k1,i}$  and  $F_{kL1,j}$ . Where the fuzzy layer membership functions are  $C_{ki}(a)$  and  $D_{kj}(a)$ .

Product layer, at layer 2. The logical "AND" operation is carried out on this layer, which is referred to as the product layer. It is denoted by the symbol "•", which stands for the product of the input membership function. The following node's input weight function, represented by  $W_1$  and  $W_2$ , is the output in this mode. The (3) can be used to represent the output of the product layer.

$$\begin{aligned}
 X_{k1} &= F_{k2,i} = \mu C_{ki}(a) \cdot \mu D_{ki}(a) \\
 X_{k2} &= F_{kL2,i} = \mu C_{kj}(a) \cdot \mu D_{kj}(a)
 \end{aligned} \tag{3}$$

Outputs of the product layer  $X_{k1}$ ,  $X_{k2}$ .

The normalized layer, at layer 3. The IF portion of the fuzzy rule is represented by each fixed node in this layer, which is the third layer overall. This layer is in charge of conducting the "AND" operation as well as normalizing the input weights. This layer is labeled as  $N$ , and the (4) serves as a representation of its output.

$$\begin{aligned}
 \overline{X}_{k1} &= F_{kL3,i} = \frac{X_{ki}}{X_{k1} + X_{k2}} \\
 \overline{X}_{k2} &= F_{kL3,j} = \frac{X_{kj}}{X_{k1} + X_{k2}}
 \end{aligned} \tag{4}$$

Outputs of normalized layer  $\overline{X}_{k1}$ ,  $\overline{X}_{k2}$ .

Defuzzification layer, at layer 4. Defuzzification is performed and carried out by this layer, also known as the defuzzification layer, employing membership values and pre-established fuzzy rules. The output of the defuzzification layer is seen in (5).

$$\begin{aligned}\bar{X}_{k1}f_{k1} &= F_{kLi,i} = \frac{X_{ki}}{X_{k1}+X_{k2}} (M_{K1}(e_K) + N_{K1}(ce_K) + S_{K1}) \\ \bar{X}_{k1}f_{kj} &= F_{kL3,j} = \frac{X_{kj}}{X_{k1}+X_{k2}} (M_2(e_K) + N_2(ce_K) + S_{K2})\end{aligned}\quad (5)$$

$\bar{X}_{k1}f_{k1}, \bar{X}_{k1}f_{kj}$  outputs of the defuzzification layer.

Total output layer, at layer 5. The fuzzy rules then portion is represented by the whole output layer. You may compute and identify the input signal total. Using the (6), the layer's overall output is determined. Figure 4 will be the first-order interface and total output of the layer.

$$f_k = F_{kL5,i} = \sum \bar{X}_{k1}f_i = \frac{\sum \bar{X}_{k1}f_k}{\sum X_{ki}} \quad (6)$$

Total layer output  $F_{kL5,i}$ .

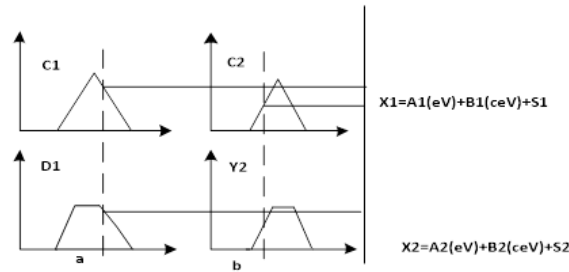


Figure 4. First-order Takagi-Surgeon interface system

#### 4. SIMULATION RESULTS AND DISCUSSION

The complete power system of PV and wind energy hybridization with an unregulated rectifier is modeled using MATLAB/Simulink. To simulate the control methods needed in the MATLAB/Simulink environment to produce the tracking signal, the sim power system block sets are employed. In this, we integrate the energy supply from wind and PV sources by managing the proportional-integral (PI) and ANFIS controllers. Figure 5 shows time in seconds on the X-axis and grid supply voltage (Figure 5(a)) and current (Figure 5(b)) at 25,000 V on the Y-axis. Peak to peak voltage is 25,000 V in Figure 5. Three phases should have a phase shift that is 120 degrees apart. Additionally, the grid supply has not altered as indicated by the supply current number in the PI and ANFIS controller as follows, the only hybrid energy of PV and wind by voltage source inverter (VSI) controller to change the controllers.

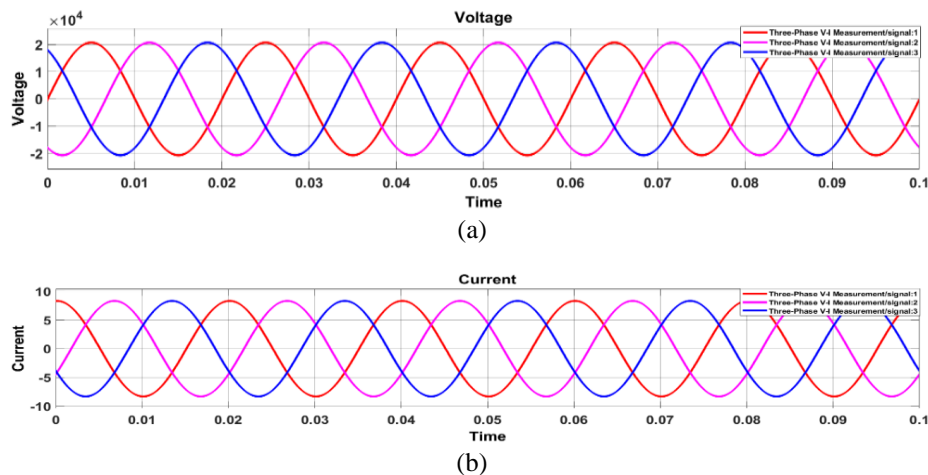


Figure 5. Supply in (a) voltage and (b) current by grid

Figures 6 and 7 show the voltage and current of buses 1 and 2 by the PI controller. The voltage and current of bus 1 are shown in Figures 6(a) and (b). Thus Figures 7(a) and (b) show the voltage and current of bus 2. The time interval between 0 and 0.1 is shown for the voltage fluctuations and approximate zero current in Figure 6. Figure 7 shows further voltage variations from 0 to 0.001. Voltage amplitude fluctuates in relation to time. In the same way, the current varies between 0 and 0.001. Because the PI controller does not address the variation in PV-wind integration, it will flow upward and remain constant until the end, peaking at the R and Y phases.

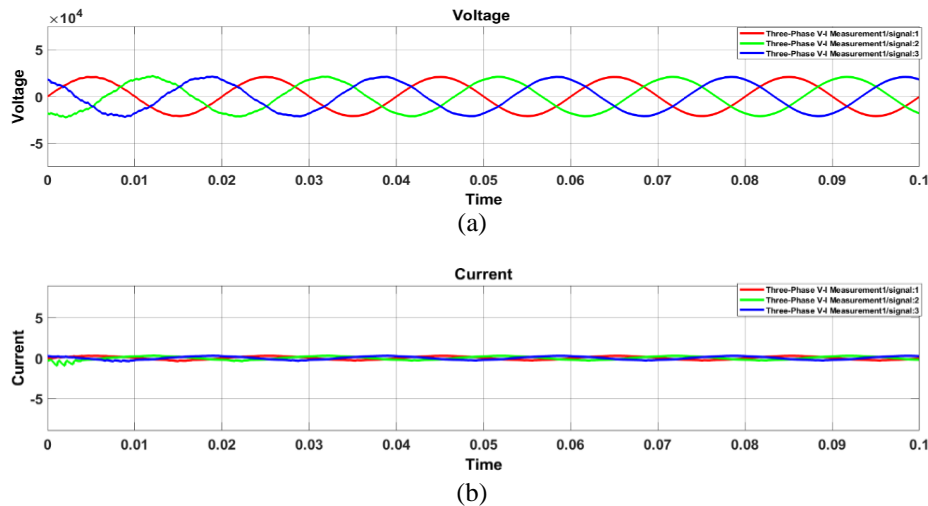


Figure 6. Bus 1 in (a) voltage and (b) current using PI controller

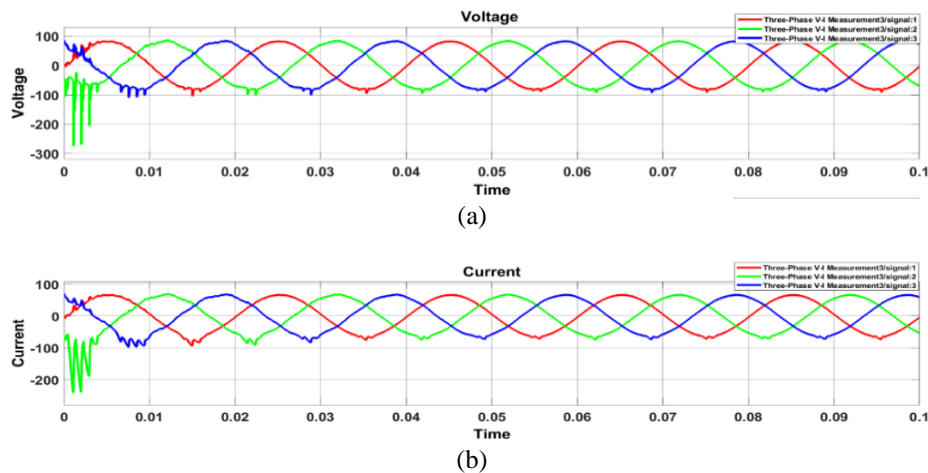


Figure 7. Bus 2 in (a) voltage and (b) current using PI controller

The X-axis of time and the Y-axis of voltages and currents are represented by the voltage and current wave patterns bus 1 and bus 2 in Figures 8 and 9. The voltage and current of bus 1 using the ANFIS controller are shown in Figure 8(a) and (b), and the voltage and current of bus 2 are shown in Figure 9(a) and (b). The ANFIS controller enhances the wave shapes. Then, there are no amplitude variations or fluctuations. It provides any kind of load with effective power. The fluctuating time has improved from 0 to 0.001. The ANFIS controller is effective in organizing inputs and outputs, producing refinements to change iterations and create the optimal result. The circuit breaker time will be the same for both controllers. Any non-linear demand is supported.

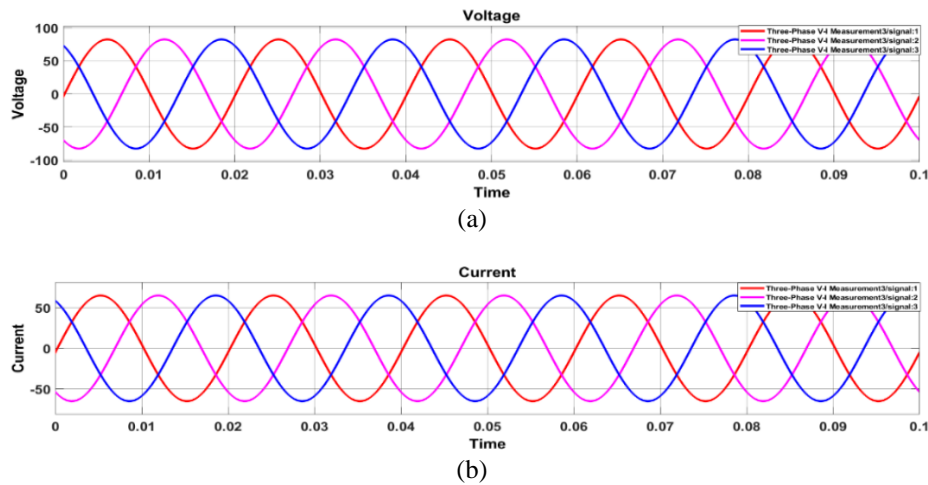


Figure 8. Bus 1 in (a) voltage and (b) current by ANFIS controller

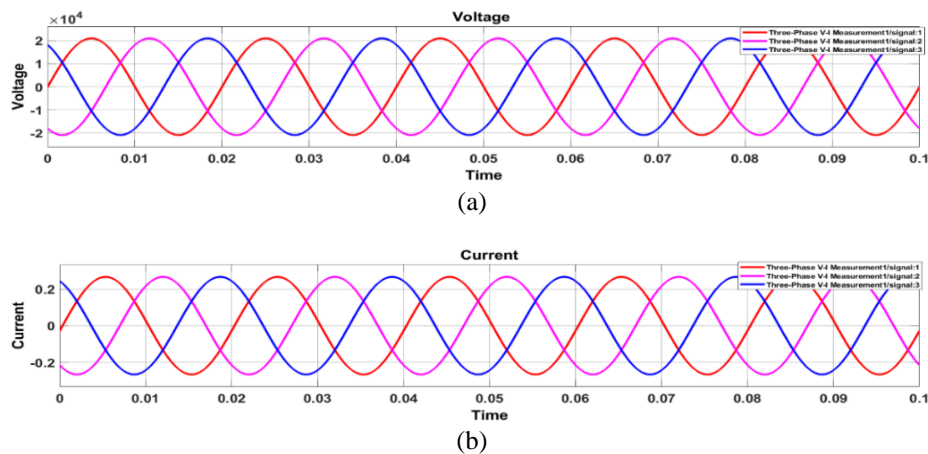


Figure 9. Bus 2 in (a) voltage and (b) current by ANFIS controller

The ANFIS controller will be set up through a series of iterations for interface, testing, and training to desired outputs, improve stability, and resolve power quality concerns. The direct current (DC) voltage of the PV and wind energy system combination is displayed in Figure 10. This combo can integrate and link the grid. It will be able to maintain supply while increasing grid voltage. The sophisticated controller is similar to ANFIS. Changes the outputs when used in a current regulating block.

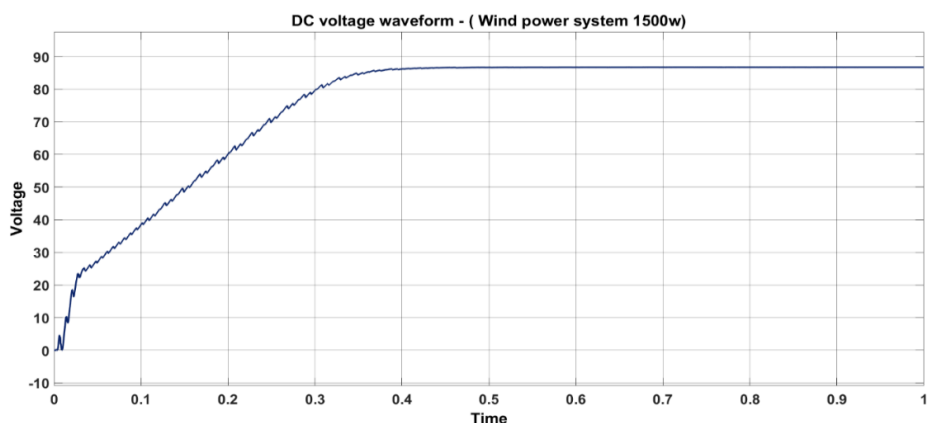


Figure 10. combined voltages of wind and PV (DC voltage)

## 5. CONCLUSION

In conclusion, A standard PI controller with the ANFIS. The goal was to maximize the integrated system's functionality and stability while supplying power to the grid. Our research strongly supports the integration of PV-wind hybrid energy systems using ANFIS-based control. Assuring dependable and sustainable grid integration while optimizing the use of RE sources, ANFIS is shown to be a more flexible, accurate, and efficient control technique. ANFIS control should be further explored and improved in future studies and real-world applications to improve the integration of RE sources into the current power grid. The conventional PI controller, in contrast, shows limits in its ability to adapt to shifting circumstances and sustain steady performance. The hybrid energy system's non-linearity and unpredictability were difficult for it to handle, which led to less-than-ideal regulation and possible grid instability.

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## BIOGRAPHIES OF AUTHORS






**Thiruveedula Madhu Babu**    is received B.Tech. from JNTU Hyderabad, Hyderabad, India, in 2010 and M.Tech. from NIT Calicut in 2012 respectively, and pursuing a Ph.D. in Annamalai University, India. He is working presently as an assistant professor and HOD in Teegala Krishna Reddy Engineering College, Hyderabad, India. He has presented technical papers in various national and international journals and conferences. He can be contacted at email: madhumk448@gmail.com.






**Kalagotla Chenchireddy**    is received a B.Tech. and M.Tech. from JNTU Hyderabad, Hyderabad, India, in 2011 and 2013 respectively, and pursuing Ph.D. in Karunya Institute of Technology and Sciences, Karunyanager, Coimbatore, TN, India. He is working presently as an assistant professor at Geetanjali College of Engineering and Technology, Hyderabad, India. He has presented technical papers at various national and international conferences. His areas of interest include power electronics, power quality, and multilevel inverters. He is a regular reviewer of ISA Transactions, Cybernetics, and Systems SCIE journals. IJPEDS and IJAE Scopus journals. He can be contacted at email: chenchireddy.kalagotla@gmail.com.






**Kotha Kalyan Kumar**    received the Diploma (Electrical and Electronics Engineering) from KITS Khammam Institute of Technology and Sciences, Khammam, India in 2021. He is presently a UG student in Electrical and Electronics Engineering at Teegala Krishna Reddy Engineering College, Hyderabad, India. He has presented technical papers at various national conferences. His area of interest is power systems and electrical machines. He also presented some technical presentations in various colleges. He also has some internships on hybrid electrical vehicles and 33/11 KV substations. He can be contacted at email: kalyankumarkotha5@gmail.com.






**Vasukul Nehal**    received the Diploma (Electrical and Electronics Engineering) from T.R.R College of Technology Hyderabad, India in 2021. He is presently a UG student in Electrical and Electronics Engineering at Teegala Krishna Reddy Engineering College, Hyderabad, India. He has presented technical papers in various national and international journals and conferences. His area of interest is power systems and electrical machines. He also presented some technical presentations in various colleges. He has an internship in electrical and electronics under the South-Central Railway. He can be contacted at email: vasukulnehal08@gmail.com.



**Sappidi Srihitha**    received the Diploma (Electrical and Electronics Engineering) from Annamacharya Institute of Technology and Sciences, Hyderabad India in 2021. She is presently a UG student in Electrical and Electronics Engineering at Teegala Krishna Reddy Engineering College, Hyderabad, India. She has presented technical papers at various national and international conferences. Her area of interest is power systems and electrical machines. She has an internship in electrical design and drafting at the National Skill Development Center. She can be contacted at email: sappidisrihithareddy0406@gmail.com.



**Marikal Ram Vikas**    received the Diploma (Electrical and Electronics Engineering) from KDR GOVT Polytechnic College, Wanaparthy, India in 2021. He is presently a UG student in Electrical and Electronics Engineering at Teegala Krishna Reddy Engineering College, Hyderabad, India. He has presented technical papers at various national and international conferences. His area of interest is power systems and electrical machines. He also presented some technical presentations in various colleges. He designs the hybrid vehicle in Teegala Krishna Reddy Engineering College. He can be contacted at email: vikasmarikal123@gmail.com.