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Fuzzy Logic Based Grid Integration of Photovoltaic/Wind Hybrid Power Generation

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Abstract: The study outlines a hybrid solar-wind system that uses three-phase power grid architecture to ensure sustainable and effective power generation. The hybrid solar-wind device uses the one of the technique of Maximum Power Point Tracking (MPPT) to optimize total effectiveness at the Common Coupling Point (PCC) by combining a photovoltaic station with a wind farm. This guarantees the best possible energy production with wind and solar power systems, regardless of the weather. The 3-phase neutral point clamped multilevel inverter's DC-link voltage is adjusted using a fuzzy logic controller that has been designed and proven to follow the vector control technique. This ensures that the inverter maintains the intended level. The hybrid system MATLAB/SIMULINK is used to execute the simulation, comparing the performance of the PI controller and the FLC controller overall. Step reaction of the MPPT and DC-link voltage technique performance are included in the assessment. The findings demonstrate that, in spite of fluctuating weather conditions, the FLC controller effectively maintains a grid voltage, achieves a power factor of one, and makes the most of the use of the solar-wind hybrid energy system injection by employing active power. In conclusion, the research presents a thorough method to maximize power production and improve overall performance of a hybrid solar-wind system. It makes use of the FLC controller and MPPT technique to manage the DC-link voltage in an efficient manner for the best performance in various weather conditions. The design of effective renewable energy integration of renewable energy sources and systems into the electrical grid are both greatly enhanced by the suggested approach.

Keywords: *Photovoltaic, wind, solar array, MPPT, PI controller, and FLC*

I.INTRODUCTION

Meeting the rising demand for energy is currently posing a serious challenge to the energy sector. The necessity to investigate alternate energy choices has arisen from the depletion and restricted supply of conventional power sources. Because of their capacity to produce power, renewable energy resources including wind and solar energy have attracted a lot of attention. However, wind and photovoltaic electricity have their limits. They are sporadic and highly dependent on the surrounding circumstances, such as wind direction and solar radiation. So as to overcome the challenging conditions related to those renewable energy sources, hybrid power structures that combine wind and photovoltaic power are being used in order to produce electricity. The enhancements of energy quality and electricity dependability are the main areas of focus for PV/wind hybrid power structure improvements. Numerous studies have been conducted in this area, looking into different aspects of system optimization. S.B. Kjaer [1] and E. Koutroulis[2] made a significant contribution by introducing novel modeling and control techniques that efficiently connect hybrid photovoltaic-wind farm systems with the electricity grid.

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With an integrated backup battery, they presented an amazing quinary asymmetric inverter design that was tailored to meet the unique requirements of Hybrid PV/wind power systems. Additionally, C.S. Brune[3] provided a specialist method of sliding mode control intended for isolated hybrid power systems combining wind and PV. These days, the preferred option for photovoltaic/wind hybrid power is the DFIG. Framework The decision to use DFIG is based only on its many benefits, as well as its capacity to maximize energy extraction from wind turbines, impartial control over active and reactive power, use of part-rated converters, and consistent generation [4-6].

This study investigated a hybrid power system [7, 8] that incorporated a 9MW wind farm with a 100KW photovoltaic plant through the principal AC-bus. The main aim of integration is to improve the device's overall performance by injecting the produced electricity. Both wind farms and photovoltaic stations use the MPPT strategy to maximize power extraction from the HPS under changing environmental conditions. The MPPT technology aims to maximize power extraction for the Power Generation system. The MPPT technique efficiency and the corresponding control technique were evaluated in a range of weather scenarios, taking into account variations in solar irradiation and wind speed.

Even in the existence of environmental variations, simulation results show that the MPPT approach effectively maximizes power extraction from the hybrid energy system. While operating at a unity power factor, hybrid power system will not inject any reactive power into the grid. Using climatic changes and HPS power injection has no effect on the control method's ability to maintain a steady grid voltage. This hybrid gadget offers several benefits and is a significant advancement in the fusion of renewable sources of energy thanks to the merging of solar and wind energies. Initially, it gets over the erratic nature of any renewable energy source. The PV device can still create energy when the wind isn't blowing, and the wind turbines can still provide power during periods of darkness. Second, the hybrid gadget has the capacity to generate additional power by combining solar and wind energy. The ability to deliver a more dependable and steady power supply is ultimately what makes it possible to fulfill the rising demand for electricity. The industry is facing a challenging issue in supplying the growing demand for power. Energy generation from renewable energy sources, such as wind energy and solar energy, has demonstrated exceptional capacity. However, there are obstacles for both wind and PV energy. When those renewable energy sources are combined, HPS can deliver an even more dependable and robust power supply, even in the face of the challenging conditions that each source presents. At some point in time, the hybrid energy system's power production may be maximized under various environmental conditions by utilizing the MPPT technique and control method that were assessed in this study.

II. HYBRID RENEWABLE POWER SYSTEM (PV/WIND)

The Hybrid Renewable Power System (PV/Wind) under study is a renewable energy system that produces electricity by combining wind and photovoltaic (PV) power sources. The system is set up with a 100 kW PV station and a 9 MW wind farm, both of which are situated in different locations [7]. A principal Common Coupling Point (PCC) bus connects the wind power plant and solar farm, enabling them to inject produced electricity and improve device performance. A 260 V/25 KV step-up transformer connects the PV station to the grid, while the wind farm may operate in a hybrid mode with a massively aggregated wind turbine that is outfitted with a Induction generator with dual feeding (DFIG). The device is equipped with a Rotor-side Converter (RSC) to maximise power extraction from the wind turbines and a Grid-side Converter (GSC) to regulate the DC-bus voltage [10]. In order to achieve the maximum power point under varying wind speeds, a newly modified MPPT approach is employed, primarily concentrating on mechanical power production. The device features a GSC to modify the DC-bus voltage and an RSC to maximize power extraction from the wind turbines. This PV/wind hybrid energy system, which is universal, integrates the wind farm and PV station by using specific power conversion parts for each. The hybrid electricity system aims to successfully generate energy and contribute to sustainable power manufacturing. The solar power station uses a boost converter and a inverter, while the wind farm incorporates DFIG with GSC and RSC. The device optimizes power extraction via MPPT techniques based on the respective power measurement.

The effective transmission of injected active electricity to the electrical grid is made possible by the hybrid power system's unity operation. In order to do this, a step-up transformer with a voltage ratio of 25 kV/120 kV and a 30 km transmission line are used to transfer the electricity. The hybrid PV/Wind power system creates a stronger and more durable power generating system by merging PV and wind power factor. By integrating multiple energy sources through the PCC bus, it is possible to reduce output variations in power generation and enhance the overall execution of the device. When PV and wind power resources are combined, they have a complimentary impact because the output from one source can offset the production from the other during periods of low solar radiation or low wind speed. A more stable and trustworthy energy technology system is ensured by the two renewable energy supplies working together synergistically [19] [20].

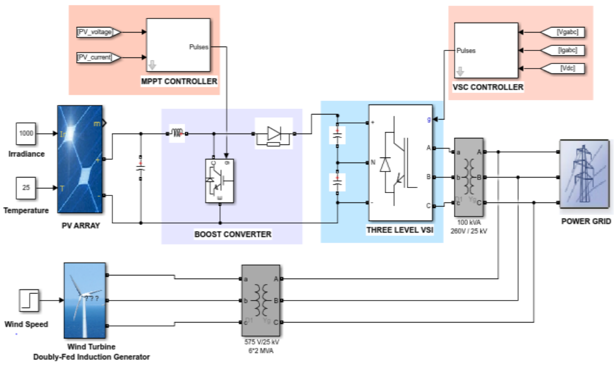

Fig. 1: hybrid Solar-wind power system configuration

III.PHOTOVOLTAIC (PV) SYSTEM

The PV conversion device described on this phase utilizes a combination of PV modules linked in to form strings and parallel-related strings to create a PV array [14]. This configuration permits the system to obtain the desired voltage level and energy capacity. A converter is used to maximize power extraction, and it is called as boost converter. It efficiently maximizes the PV array's energy output by adjusting to different solar irradiation ranges. The primary inverter receives the output from the Boost converter and regulates the amount of energy added to the grid while maintaining the appropriate reactive strength. This setup guarantees a steady dc-link voltage, which lowers losses, boosts efficiency, and is economical. The widely used Shockley diode model serves as the foundation for the electric modeling of the photovoltaic array, effectively simulating the behavior of solar cells. It determines the PV array's current-voltage (I-V), providing vital information about how it operates. The version may be described via the subsequent equation: This equation captures the vital characteristics of the PV array, allowing accurate analysis and knowledge of its performance.

$$I = I_{pv} - I_O \left[\exp\left(\frac{V + R_s I}{a V_t} \right) - 1 \right] - \frac{V + R_s I}{R_p}$$

Inside the specified PV conversion device, the overall performance of the PV array can be represented by utilising the Shockley diode model. The generate dc current (I) by the way of the PV array is influenced by means of elements such as photo-generated reverse saturation current (I_0), current (I_{pv}), output voltage (V), parallel resistance (R_p), series resistance (R_s), diode ideality factor (a) and thermal voltage (V_t). This model lets in for accurate simulation of the PV array's overall performance, thinking about environmental elements consisting of sun irradiation depth and temperature variations [12]. Figure 2 shows the P-V characteristics and I-V Characteristics of the PV array below distinctive solar irradiation conditions. The I-V curve shows the relationship correlation output current and voltage, while P-V curve represents the correlation among output power and voltage these curves are critical for optimizing the PV device to obtain maximum performance and energy output by way of understanding and utilizing those characteristics, the PV system can be efficiently designed and operated to optimizing the PV array of the maximum energy.

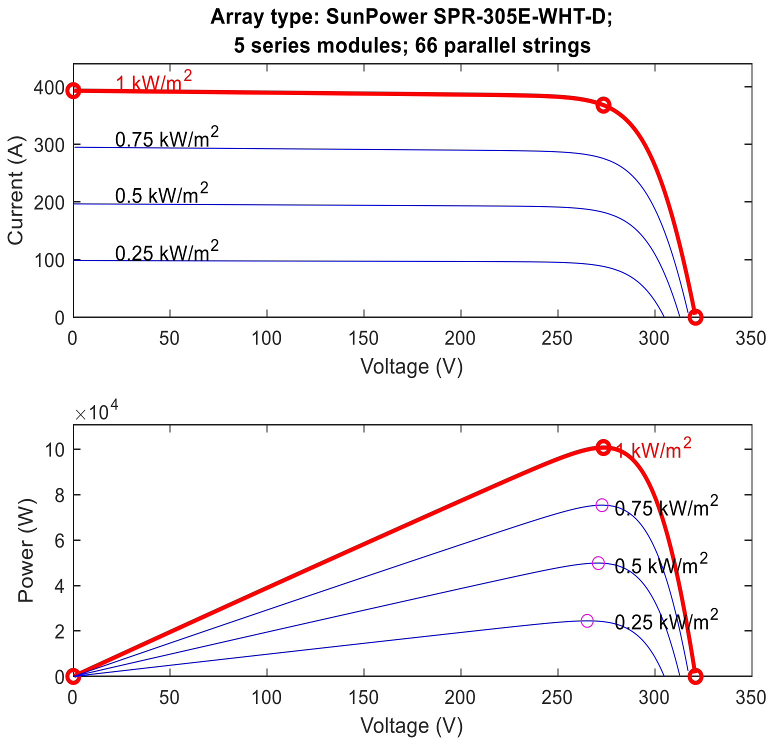

Figure 2: Performance Characteristics of PV Array in Response to Changing Solar Irradiance

The MPPT algorithm adjusts the boost converter to maintain the PV array at its MPPT even with changing solar irradiation. The DC/AC inverter controller manages power flow, optimizing performance and ensuring grid compliance. Both are essential components for efficient and reliable PV system operation.

i. Incremental Conductance MPPT Technique:

The extensively used incremental conductance MPPT set of rules is employed to maximize power extraction from PV arrays. The algorithm operates by means of measuring the Power and of the Photovoltaic Array and adjusts the array voltage to track the course of the MPP variant the set of rules uses the idea of incremental conductance, which calculates the change in energy with reference to variations in voltage and compares it to the conductance of the PV array [14]. If the variation in power is extra than the conductance, the set of rules adjusts the voltage in that path to track the maximum power. Conversely, if the variation in power is less than the conductance, the algorithm adjusts the voltage in the opposite direction. This iterative method maintains till the MPP is reached. The incremental conductance MPPT set of rules is mainly appropriate for systems with unexpectedly changing temperature and irradiance conditions able to speedy and appropriately monitoring the MPP below such dynamic conditions. Moreover, the algorithm is exceedingly trustworthy to enforce, making it a popular preference for many PV systems [15]. In conclusion, MPPT algorithms, which include the incremental conductance algorithm, play essential popular choice in PV systems. They enable the system to perform at its most efficiency by extracting the peak energy from the PV system. Via constantly monitoring and adjusting the voltage to keep the MPP, these algorithms optimize the performance and power possible capabilities of PV array [16].

ii. Fuzzy Logic MPPT

Fuzzy logic MPPT is an opportunity set of rules hired in photovoltaic (PV) systems to optimize era from sun panels. Much like the fuzzy logic MPPT, incremental conductance MPPT, constantly adjusts the current and voltage of the solar panels (3) to make certain they function at their MPP, even during variable weather conditions such as temperature and irradiance. The fuzzy logic MPPT algorithm utilizes a fuzzy Logic controller that takes input variables inclusive of solar irradiance and panel temperature. It makes use of predefined rules, derived from professional knowledge and experience in PV systems, to decide the output voltage of the PV device. With the aid of considering these inputs and making use of fuzzy logic, the controller dynamically adjusts the output voltage in real-time to method the MPP. One advantage of fuzzy logic MPPT over other algorithms is its capability to correctly track the MPP even in eventualities with partial shading or rapidly converting environmental situations. By using considering a couple of inputs and making selections based on them, the algorithm can attain greater correct and efficient power generation, resulting in extra power yields. In summary, fuzzy logic MPPT is a popular and powerful set of rules employed in PV system. It utilizes a fuzzy logic controller to dynamically song the MPP of solar panels in real-time. This technique allows advanced energy yields, especially in tough environmental conditions wherein and adaptive power generation is important.

IV. WIND TO ELECTRICAL ENERGY CONVERSION SYSTEM

The performance of wind turbines is reflected of their overall performance coefficient. This is impacted by the aerodynamic qualities of the blades [8]. The term C_p represents the ratio of mechanical power extracted (P_m) to wind power (P_w). In mathematical terms, C_p may be expressed in the following way: $P_m = P_w$. Using the following equation, we can determine how much power is available in a wind pw:

$$P_w = 0.5 \text{ x } \rho \text{ x } A \text{ x } V^3$$

Where ρ represents the air density, A indicates the rotor's swept area, and V denotes the wind speed.

To determine the wind turbine's extracted mechanical power (P_m) the following formula may be used:

$$Pm = 0.5 \text{ x } \rho \text{ x } A \text{ x } C_p \text{ x } V^3$$

In the above equation, ρ denotes the air density, A represents the rotor's swept area of the, C_p represents the wind turbine performance coefficient, and V is the wind speed. The correlation of mechanical power output with wind velocity is shown by the wind turbine characteristic curve and it is usually obtained through wind tunnel checking out or field measurements, is carried out to identify the effective performance of a wind turbine and to obtain the Peak power output from the wind [17].

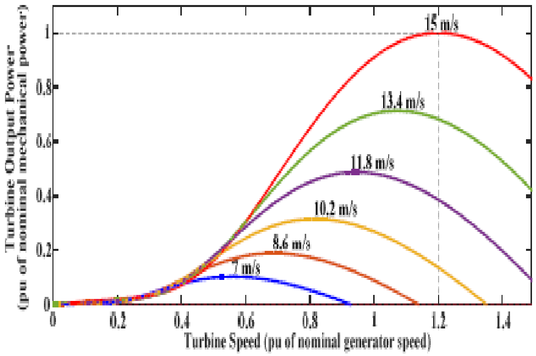

Fig.3. Wind turbine performance curve.

i. Modified MPPT Technique based on Mechanical Power

To Convert Wind Energy to Electrical Energy various components, including the wind turbine, MPPT technique, GSC controller, RSC controller, etc., are being used. On this segment, our recognition is on the MPPT approach, which plays an important position in extracting the most to be had power from the wind turbine [9]. The MPPT approach operates with the aid of optimizing the rotational velocity of the rotor of a wind turbine, at once influencing its power output. Traditionally, MPPT techniques have optimization on wind speed measurements and turbine traits to determine the top-quality rotational speed. However, inaccuracies in sensor readings and modeling mistakes can introduce uncertainties that have an effect on the precision of the MPPT method. To conquer this problem, a modified MPPT manage approach is proposed in this look at, utilizing the dimension of mechanical power to establish the best rotational velocity (ω_{ref}). The MPPT approach starts off evolved with an initial estimation of P_m-P_u and ω_{ref}, and in the end calculates the real mechanical power to decide the most suitable rotational speed. Whilst P_m-P_u exceeds 0.75 p.u., the most appropriate rotational pace is set at 1.2 p.u., representing the wind farm's most power output. Conversely, while Pm-pu falls below 0.75 p.u., the most excellent rotational speed is computed the usage of a specific formula measurement for such situations.

$$\omega_{ref} = \begin{cases} 1.2 & 1 \geq P_{m\_pu} \geq 0.75 \\ -0.67(P_{m-pu})^2 + 1.42(P_{m-pu}) + 0.51 & P_{m\_pu} < 0.75 \end{cases}$$

The suggested MPPT manage method offers a particular and efficient technique for maximizing the wind turbine energy output, removing the need for wind velocity measurements. This is of high-quality importance given that inaccuracies in wind speed measurement can bring about suboptimal electricity technology and decreased performance of the entire Wind to Electrical Energy Conversion System (WECS) [18].

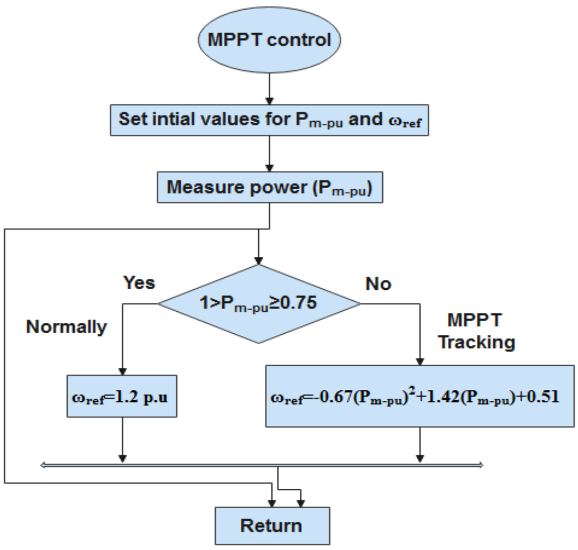

Figure.4. Flowchart Illustrating the Modified MPPT Method with Mechanical Power Measurement

V.SIMULATION RESULTS

Utilizing the recommended MPPT technique and manage techniques, the simulation results shows that the MPPT method proposed can extract the maximum power point of both PV and wind farms. Moreover, the control strategies are able to ensuring a stable voltage at the Common Coupling Point (PCC) of the electrical grid. Moreover, the proposed hybrid system can obtain a unity power factor and take away the injection of reactive electricity, even if environmental situations alternate and fluctuations arise in the generated active power. These findings emphasize the practicality and effective performance of the proposed MPPT method and control strategies for solar-wind hybrid systems.

1. PV Performance with PI Controller under Solar Irradiance Variation.

On this phase, the performance of an MPPT set of rules is examined below specific solar radiation conditions, spanning from 1000 W/m^2, to 250W/m^2, as depicted in determine 5(a). Figure 5(b) illustrates how versions in solar radiation impact the photovoltaic modern (I_{pv}), ensuing in a lower within the output current of the PV array. In addition, figure 5(c) demonstrates that the MPPT controller additionally reduces the photovoltaic voltage (V_{pv}) in response modifications in irradiance conditions.

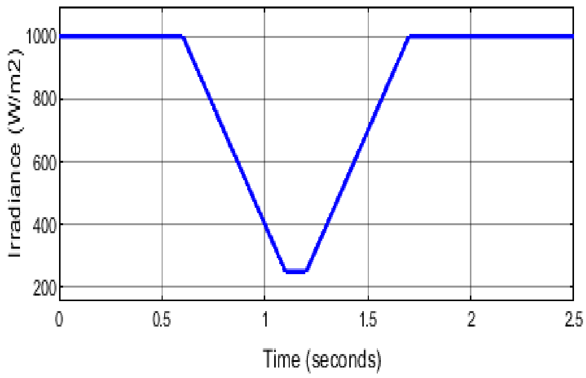

Figure 5(a) Solar irradiance Variation

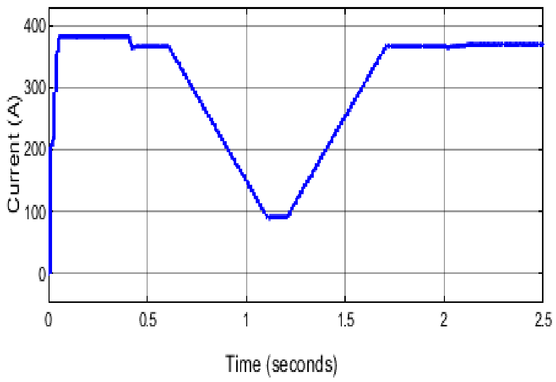

Figure. 5(b) PV array current Variation

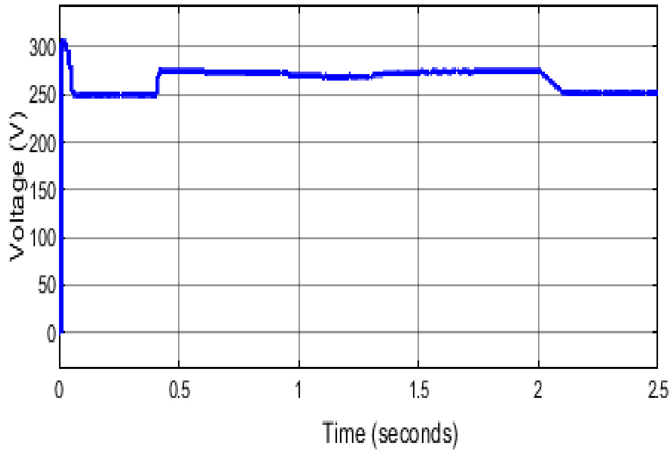

Figure. 5(c) PV array Voltage

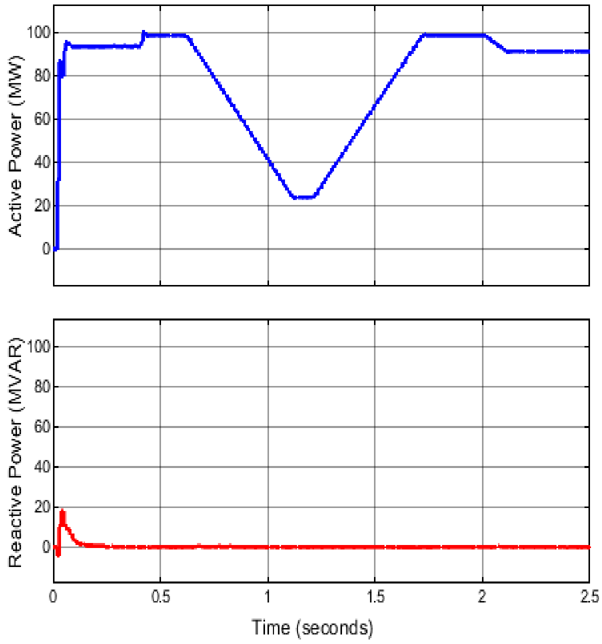

Figure 5(d): Grid-Injected Active Power and Reactive Power

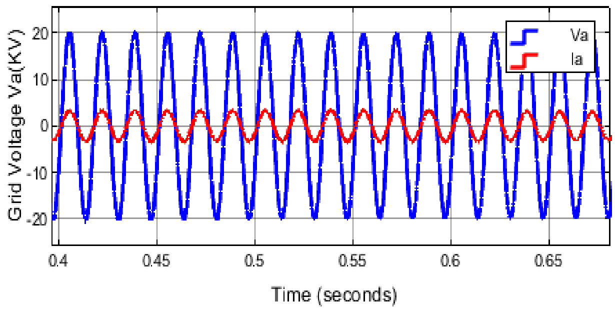

Figure 5(e): Three-Phase Voltage and Current Waveforms Controlled by PI Controller

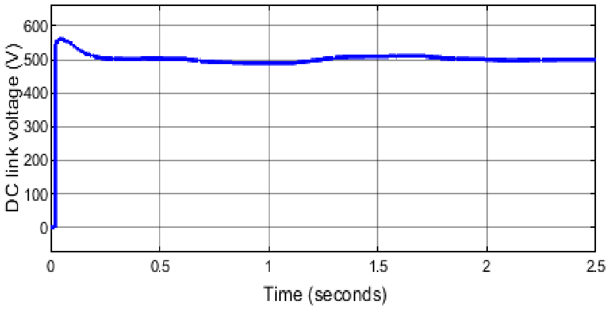

Figure 5(f). DC link voltage using PI controller

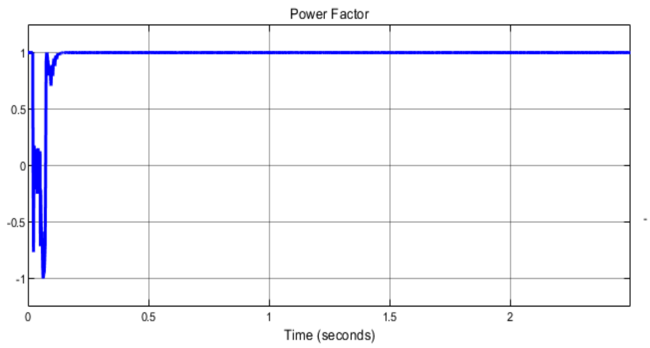

Figure 5(g) Inverter power factor using PI controller

Figure 5 presents the simulation results of the PV station below various solar irradiance situations. Figure 5(a) evaluates the overall performance of the MPPT algorithm through assessing exceptional levels of solar radiation, starting from 1000W/m^2, to 250W/m^2. Figure 5(b) illustrates how the photovoltaic current (I_{pv}) decreases with modifications in irradiance. In addition, figure 5(c) indicates that the MPPT controller lowers the photovoltaic voltage (V_{pv}) in reaction to various irradiance situations. Figure 5(d) demonstrates that the PV station's lively power modifications according with solar radiation, while the injected reactive power stays constant at zero determine 5(e) exhibits clean Sinusoidal current and waveforms of the grid voltage day for all 3 stages. the DC-bus voltage, managed via the PI controller, barely surpasses the FLC, as illustrated in Fig 5(f) the inverter power thing measured with the aid of the PI is obtainable in figure 5 (g).

2. Improving PV Performance in Varying Solar Irradiance Conditions using FLC Controller

Figure 6(a) illustrates the integration of grid voltage and power using FLC controller. The DC-bus voltage, with very less settling time by the FLC controller, is presented in Figure 6(b). The inverter's power factor during solar irradiance variations is depicted in Figures 6(c) and 6(d), showing the performance of the PV station controlled by the FLC controller.

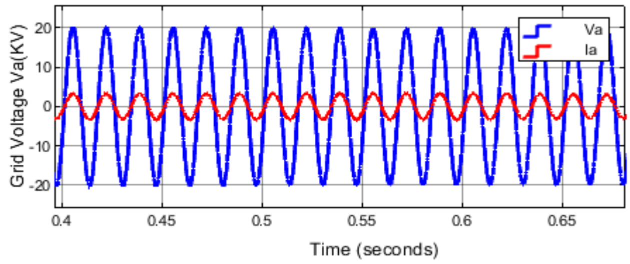

Figure. 6(a) Three phase voltage and current and waveforms using FLC

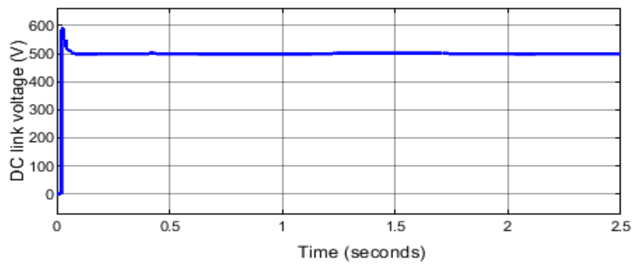

Figure. 6(b) DC link voltage using FLC

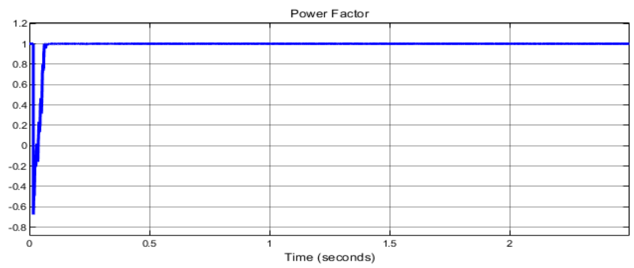

Figure. 6(c) Inverter power factor using FLC

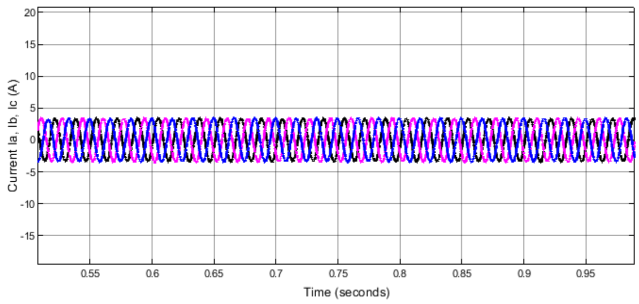

Figure 6(d) Injected current from PV system.

3.Wind Farm Performance under Varying Wind Speeds

Figure 7(a) showcases the dynamic performance of wind farm, capturing the modifications in wind speed and velocity fluctuations. Despite the different variants of wind speed, the DC link bus voltage was almost maintained constant by the GSC controllers, as shown in Figure 7(b).

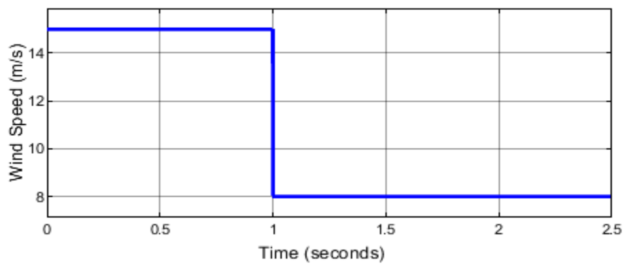

Figure.7 (a) profile of Wind speed

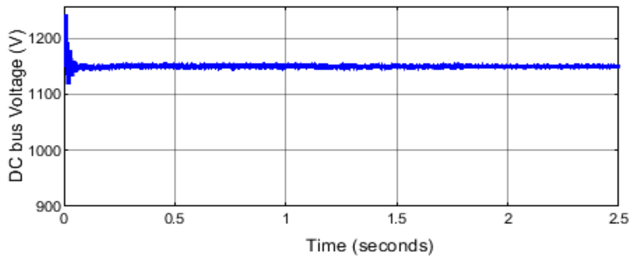

Figure.7 (b) DFIG DC-link voltage

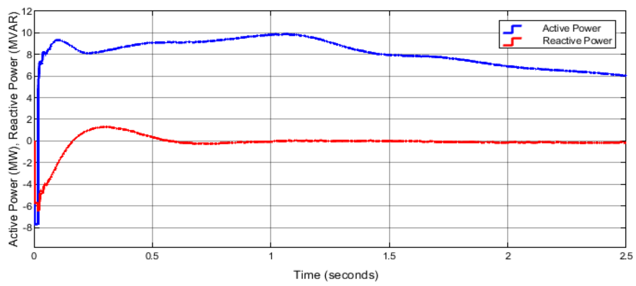

Figure 7(c) wind farm's injected active and reactive power

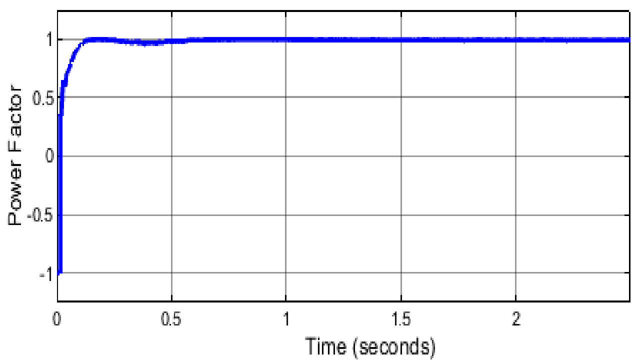

Figure 7(d) Power factor of the Inverter

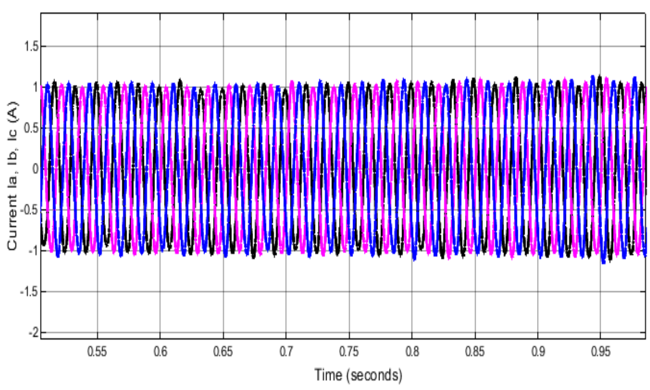

Figure 7 (e) current Injected by wind farm

ig 7 illustrates the wind farm's overall performance in response to variations in wind speed; Fig 7(a) showcases the time-mainly based modifications in wind speed. The grid side converter (GSC) controllers successfully alter a strong dc bus voltage, as depicted in Fig 7(b). Fig 7(c) showcases the reactive power and active power injected by means of the wind farm (3) for the duration of fluctuations in wind speed the Peak Power Point Tracking (MPPT) manipulate precisely tracks the reference speed (ω_{ref}) and achieves excessive active power generation even as maintaining zero injected reactive power, resulting in a unity power factor, as verified in fig 7(d). The modern-day injected waveforms are displayed in fig 7(e), with the RSC regulating the injection of active power.

VI.CONCLUSION

This research paper gives an efficient version of a grid integrated Hybrid PV-wind power tool carried out in MATLAB/SIMULINK the device includes FLC for MPPT in the PV system, further to a complicated MPPT manipulate method for the wind farm this integration permits to extract maximum power from each power resources the regulation of the dc-link voltage is exactly achieved using PI and FLC controllers. The simulation results screen that the FLC controller exhibits advanced overall performance in terms of step responsiveness the proposed Method maintain unity power factor for the hybrid power device without injecting reactive power, while moreover ensuring a steady PCC bus voltage those achievements are verified below numerous environmental situations and degrees of active power technology. Standard, the effects show that the proposed manipulate tool efficaciously affords Stability, reliability, and finest performance for the HPS.

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Conflicts of interest

The authors declare no conflicts of interest.