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WIND POWER FREQUENCY CONTROL IN DOUBLY FED INDUCTION GENERATOR USING CFMPC-FOPID CONTROLLER SCHEME

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ABSTRACT

Because the majority of wind turbines operate in maximum output power tracking mode, power system frequency cannot be supported. However, if the penetration rate of wind power increases, the system inertia related to frequency modulation may decrease. In addition, frequency stability will be severely affected in the event of significant disturbances to the system load. Due to the high penetration of wind power in isolated power systems, this study suggests a coordinated frequency management approach for emergency frequency regulation. In order to prevent the phenomenon of load frequency control in doubly fed induction generators (DFIGs), a unique efficient control scheme is developed. The Cascaded Fractional Model Predictive Controller coupled with Fractional-Order PID controller (CFMPC-FOPID) is developed to provide the DFIG system with an efficient reaction to changes in load and system parameters. The proposed controller must have a robust tendency to respond quickly in terms of minimum settling time, undershoot, and overshoot. Nonlinear feedback controllers are designed using frequency deviations and power imbalances to achieve the reserve power distribution between generators and DFIGs in a variety of wind speed conditions. It makes upgrading quick and easy. In Matlab/Simulink, a simulation model is built to test the viability of the suggested approach.

Keywords: *cascaded fractional model predictive controller, fractional-order PID controller, frequency deviation, wind power frequency control, wind speed.*

I. INTRODUCTION

ALTHOUGH wind turbines are quite high, this has little impact on land use for other things such as agriculture, irrigation, etc. In addition, compared to some other similar renewable resources, such as solar photovoltaics, the investment cost of wind power is considerably lower. The environmental quality of wind turbines is also excellent [1], [2]. The energy required for the extraction of materials, the construction, installation, and operation of wind turbines with life spans of roughly twenty years can be compensated by the electricity produced by wind power in about six months. Wind turbines have an impact on the scenery, which not everyone appreciates, although their effects on nature and wildlife are minimal, especially if they are strategically placed [3]. Additionally, the benefit of wind energy for the power system is that it has a large capacity in addition to being free and clean energy. A large amount of electrical power can be produced by grouping several wind turbines together as a wind farm or park [4]. A suitable grid connector, control system, and regulation must exist in order to connect wind energy to the utility grid and guarantee high power quality, dependability, and stability. However, one of the most significant issues with wind power is that since the quantity of electricity produced by it is influenced by the intermittent nature of wind flow, it is challenging to predict the outcome [5], [6].

It is not always guaranteed that the scheduled power from WECS will match with the power available from wind energy due to the fluctuation of wind flow. Therefore, the modeling of the aforementioned problem differs in a wind integrated system [7]. Consequently, the grid-integrated wind power units may significantly complicate current generation scheduling techniques and power system operation. The variability in wind power may need to be compensated by other forms of generation for satisfactory grid integration [8]. Alternately, additional costs may need to be included in the system's total cost of power generation in order to make up for the power imbalance caused by wind unpredictability [9].

Using NSGA-II, Tiong Teck Teo et al. [10] proposed optimized fuzzy energy management system for grid connected microgrid. The authors suggested a grid-connected microgrid comprising RES and ESS equipped with a fuzzy logic-based energy management system (FEMS). By using the ESS as an arbitrage device, the FEMS aims to lower average peak load and operational costs. These goals are accomplished by managing the ESS charge and discharge rate based on the ESS state of charge, the power difference between the load and the RES, and the price of energy on the market. The membership functions (MFs) are a key component in how successful fuzzy logic is. Non-dominated Sorting Genetic method (NSGA-II), a Pareto-based multiobjective evolutionary method, is used to offline optimize the fuzzy MFs of the FEMS.

For small scale energy management system, P. Satish Kumar et al. [11] proposed the hybrid wind solar battery based microgrid. It is suggested that a small-scale hybrid wind-solar-battery-based microgrid utilize an effective energy management system. To verify the functionality of the hybrid microgrid, systems for converting wind and solar energy as well as battery storage have been built together with power electronic converters, control algorithms, and controllers. An energy management system controls the power balance to account for variations in load demand and renewable energy power generation. This microgrid functions independently and offers a testing ground for various control algorithms, energy management systems, and testing scenarios.

For a grid-connected wind turbine with PMSG, Youcef Belkhier et al. [12] presented an adaptive linear feedback energy-based backstepping and PID control strategy. Due to the nonlinear operation circumstances and outside disturbances of PMSGs, wind conversion system-based PMSG controller design is still a difficult task. In order to allow the PMSG to run at an optimum speed and robustness of the system dynamics, this work presents a passivity-based control connected with a backstepping technique that ensures asymptotic convergence to the maximum power extraction and stability of the closed-loop system. A wind turbine, a PMSG, and a buck-to-buck converter with a DC-link voltage connected to the grid make up the conversion system under study. While a proportional-integral (PI) controller is utilized on the grid side to transfer just the active power to the distribution network, the proposed approach is employed to regulate the generator-side converter.

Mahmoud A. Mossa et al. [13] proposed a renewable energy system to enhance the performance for stand-alone operation and grid connection with battery storage. Predictive control theory serves as the foundation for the created control scheme, which avoids the drawbacks of earlier predictive controllers. Additionally, maximum power point tracking and blade pitch angle controls were implemented to enable the best possible utilization of the wind energy and limit the power in the event of surpassing the nominal wind speed. The characteristics of each controller were clearly described by a thorough performance comparison, demonstrating the superiority of the suggested control method over existing predictive controllers.

Control-based maximum power point tracking was introduced by Mouna Ben Smida et al. [14] for a grid-connected hybrid renewable energy system. Renewable energy sources have many benefits, but they also have some serious drawbacks, such as the discontinuity of their generation because of their strong reliance on the weather and climate change, which impacts how well they convert renewable energy. In the literature, a number of novel approaches to optimization have been explored. Here, a shaded photovoltaic generator and a wind generator are used to operate a hybrid renewable energy system using an intelligent technique based on particle swarm optimization.

Ganthia and Subrat Kumar Barik [15] proposed a grid-connected wind energy conversion system based on fuzzy-logic-controlled DFIG and fault analysis of PI. It depends on the DFIG-based design of a modified Type-III wind turbine system. The Type-III wind turbine system's control method is a modified Type-I fuzzy logic controller. Type-III DFIG-based wind turbine system with a mechanically changed drive trains under various fault situations, such as voltage dip conditions and swell conditions with respect to wind speed variation. In the study, four distinct types of fuzzy structures are implemented with various modelled modes of operation, and comparisons between all the structures with PI control structure were conducted for both steady state and dynamic state. With regard to the transients caused by a sudden shift in wind speed, the steady state operation and transient characteristics of the entire wind energy conversion system are thoroughly studied and discussed.

Sedaghati and Mahmoud [16] suggested a hybrid PV/FC/SC/battery renewable power system-based grid-connected microgrid with an innovative control method. A PV, a BSS, a supercapacitor, and a solid oxide fuel cell make up the HRES system. The primary energy source is the PV, whereas the SC and the BSS are thought to offer a steady and transient load demand, respectively, due to their different power densities. The SOFC source is chosen to maintain the BSS at full charge in order to increase system reliability. The DC voltage is then converted to AC using a three-phase voltage source inverter (VSI). An adaptive fractional fuzzy sliding mode control approach for VSI-based HRES system is provided to maintain the power balance and proper load-sharing. Additionally, fractional adaptive rules-based fuzzy sets are used to precisely predict the microgrid's unknown parameters.

Youcef Belkhier et al. [17] proposed a fuzzy passivity-based voltage controller method of grid-connected wind renewable energy system based on PMSG. For improving dynamic performance, a passivity-based control (PBC) and fuzzy logic controller combination was suggested. A wind turbine-based PMSG coupled to the power grid via a PWM converter makes up the investigated renewable system. When a traditional PI control is applied to the grid-side, the PBC is applied to the generator-side.

Prince et al. [18] presented a grid-connected wind energy conversion system based on PMSG for modelling, parameter measurement, and control. A dynamic model and accurate wind generator characteristics are necessary for the design of dependable WECS controllers. Therefore, a dynamic model for a direct-drive variable-speed WECS with a PMSG is described, together with parameter measurement and control. By regulating the d- and q-axis currents in the synchronous reference frame, an MPC is made for the grid-side voltage source converter (VSC) to regulate the active and reactive power flows to the electrical grid. The modelling and experimental findings demonstrate dynamic and steady-state performance under varied wind speeds and prove the effectiveness of the developed controllers utilizing the measured parameters.

Shabnam et al. [19] proposed grid connected wind turbine energy system based on PID controller for power quality improvement. When there is no wind control available, it is suggested that the controller improve the power quality by using a DC-connect capacitor with the power converter attached to the lattice. The major difference between the suggested technique and others is that the suggested control structure relies on deteriorations in the Conservative Power Theory. The results validated our ability to control quality improvement, and they allowed us to forbid unattached channels, contributing to a steadily reduced, flexible, and reliable electronic execution of a sharp framework-based control.

Numerous control strategies are examined to combat the frequency oscillations in the power system following a thorough assessment of the literature. Regarding frequency and consistency of the power flow, the power system faces numerous obstacles [20], [21]. Maintaining the frequency at its nominal operating value is essential for ensuring the stability of the power system. However, when RES (PV and wind) are heavily integrated into the power system, these difficulties become more severe. Different control strategies are studied from the aforementioned literature study, although the complexity (incorporation of RES) is only moderate [22] [23]. A variety of control strategies have been used to handle the LFC difficulty. A variety of control strategies have been used to handle the LFC difficulty. However, the literature is less focused on cascaded based MPC formations/structures, and most studies ignore how renewable energy affects the AGC of a deregulated power system [24]. The key contribution of the work is as follows:

- An emergency frequency regulation plan is proposed for isolated power systems with significant wind power penetration.
- For an effective response of the DFIG system under load disruption and system parameter fluctuations, cascaded fractional model predictive controller linked with fractional-order PID controller (CFMPC-FOPID) is created.
- The suggested controller must have a robust tendency to respond quickly in terms of minimum settling time, undershoot, and overshoot.

II. RESEARCH METHOD

A battery storage system and its converters connected to the DC bus enable the renewable energy source of wind energy. A wind turbine based on a permanent magnet synchronous generator (PMSG) makes up the wind energy conversion system. The turbine, which the windmill's shaft is attached to, transforms the kinetic energy of the wind into mechanical energy. Since, velocity of air is dependent on

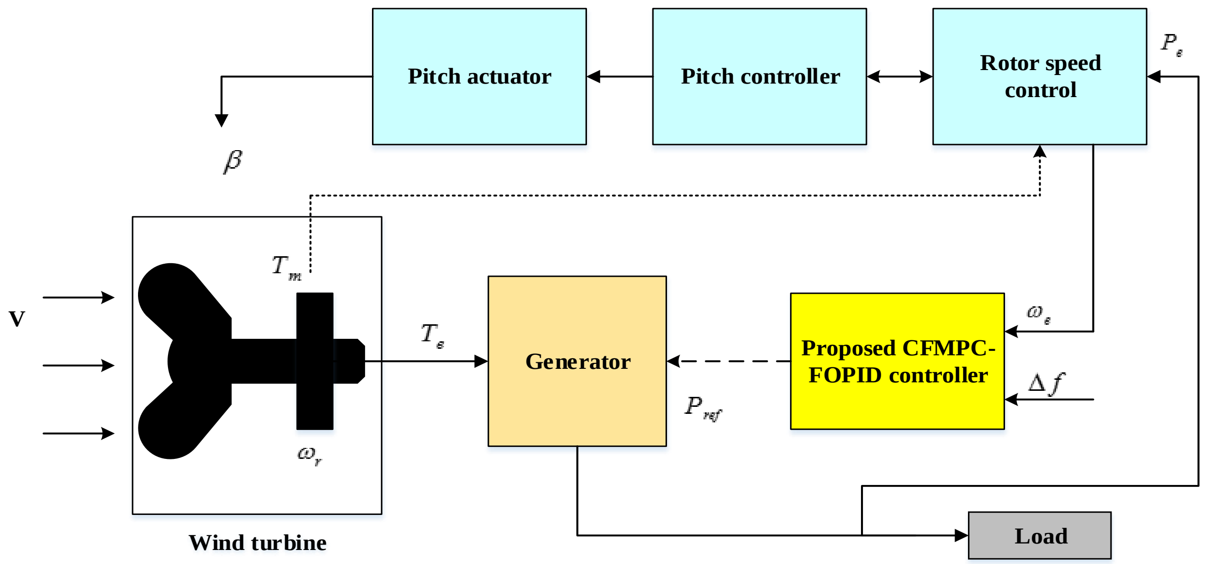

Figure 1. Block diagram of proposed Method

the weather, cannot be controlled, and exhibits nonlinear behavior depending on the location of the power plant, wind power plants, like solar power plants, are an intermittent source of energy. The modelling of the wind farm system includes representations of the induction generator, pitch actuator, and pitch control. The suggested cascaded fractional model predictive controller linked with fractional-order PID (CFMPC-FOPID) controller regulates the DFIG's load frequency. The block diagram of proposed method is shown in Figure 1.

A. Wind Power Generation in WECS

The kinetic energy of the wind resource is converted to mechanical energy according to the WECS theory. Wind turbines convert the kinetic energy of wind energy into mechanical form by capturing its aerodynamic power. The generators erected and powered by wind turbines and convert energy from mechanical to electrical form. Mechanical energy gathered from the wind turbine's rotating shaft is driven and transformed into electrical energy by the generator's spinning shaft, which is connected to it by gears. It is not always essential to use a gear box to connect the generator's high speed shaft to the low speed shaft of the wind turbine rotor blades. Because they are pricy, large, and heavy, gearboxes are occasionally not necessary. Hence, as an alternative to a gearless system, a multi-pole generator is used.

The power wire of a wind turbine generator sends electricity to a transformer. The generator typically produces a voltage of a few hundred volts or less. Generator transformers step up the generated low voltage to the distribution or sub-transmission level. The generated power that is proportional to the kinetic energy (E) of the wind, can be expressed in terms of the flowing air mass$m$, and its velocity v as (1). Further, the instantaneous power derived from the wind flowing through an area A_w with air mass density $\mu_a$can be expressed as (2). Because, the air mass per second can be expressed as (3).

$$E_w = \frac{1}{2} m v^2 \tag{1}$$

$$P_W = \frac{1}{2} \mu_a A_w v^3 \tag{2}$$

$$m_a = \mu_a A_w \tag{3}$$

The rotor blades of a wind turbine with variable speed freely rotate in response to the strength and direction of the wind. The ability of the rotor to catch aerodynamic power determines how much power is drawn from the wind. This is due to the inability of the wind flow speed to reach zero after passing through the rotor blades, which results in an efficiency of less than 1. According to the Betz limit, the rotor power efficiency of the wind turbine determines how much mechanical power it can capture. This efficiency is expressed as (4).

$$P_t = \frac{1}{2} C_p(\alpha, \beta) \mu_a A_w v \tag{4}$$

The rotor power efficiency of the turbine C_P is the function of the blade tip speed ratio α and blade pitch angle β. In order to avoid any wake effect, the two wind turbines are mounted at a distance that is equal to at least three times that of their rotor radius from one another. If the tip speed ratio is less than 3, the wake effect reduces the maximum rotor power efficiency. The tip speed ratio can be calculated as (5) where ω the rotor speed in radian/sec. R_r is rotor radius from axis to tip in meter.

$$\lambda = \frac{\omega R_r}{v} \tag{5}$$

B. Battery Storage System

The most developed type of commercially available storage solution on the market is electrochemical storage in the form of batteries. They can be used for many different applications, ranging from electric vehicles to backup reserves, as they are available in a wide range of features. The positive and negative electrodes in a battery's structure interact with the electrolyte to create a circulating current. The amount of energy absorbed by or discharged from the battery determines the frequency and kind of these chemical reactions. Individual battery cells are connected to create arrays to form larger battery systems. To increase the desired voltage, battery cells are connected in series, and the Ampere-hour (Ah) capacity can be raised by connecting those cells in parallel. Every battery has an energy rating that indicates the amount of energy it can store based on the mass and volume of the electrolyte. However, the contact area and reaction surface area between the electrolyte and electrodes will determine the battery's power rating.

A lead acid battery and a potential DC-DC switching capacitor converter make up the BSS. Through a suggested TID controller, this converter is in charge of maintaining the DC bus voltage as we can see in (6).

$$SOC = 100\left(1 + \frac{\int I_b \, dt}{Q_b}\right) \tag{6}$$

Where Q_b, is the battery capacity and I_b is the battery current. The battery has two operating modes: charging and discharging, which are dependent on the amount of wind energy present. Based on the energy limitations set by the SOC limits, the battery also functions in these two modes as we can see in (7).

$$SOC_{min} \leq SOC \leq SOC_{max} \tag{7}$$

C. Frequency control in DFIG

A three-phase winding rotor and stator make up the DFIG (Double-Fed Induction Generator), a type of electric generator used in wind turbines. While the rotor is connected to the grid via a power converter that enables control of the rotor current and voltage, the stator is connected to the grid directly. Maintaining the frequency of the generator output at a constant value that matches the grid frequency is one of the main control goals in DFIG-based wind turbines. This is crucial to ensure that the grid is synchronized with the power produced by the wind turbine and that it can be distributed to the end consumers without jeopardizing stability.

Frequency regulation is crucial in a Doubly Fed Induction Generator (DFIG) for preserving the reliability and effectiveness of the power system. The converter attached to the rotor controls the rotational speed of the rotor, which determines the frequency of the electricity generated. By altering the rotor voltage and current, the converter can modify the rotor's frequency. The converter can control the electromagnetic torque generated by the rotor, which in turn controls the rotor's rotational speed, by modifying the voltage and current of the rotor. The converter modifies the rotor voltage and current to match the grid frequency in order to maintain a consistent frequency. Typically, a control algorithm is used to accomplish this, measuring the frequency and adjusting the rotor voltage and current correspondingly. The converter can do additional control tasks including reactive power control and voltage control in addition to keeping a constant frequency. These activities support keeping the power system stable and effective.

The speed of the rotor in relation to the stator, which is managed by the power electronics linked to the rotor circuit, determines the frequency of the output voltage and current in a DFIG. Both managing the generator's output power and preserving a steady grid frequency in a wind power system depend on the frequency control in a DFIG. In a DFIG, the rotor current is often controlled using a technique called vector control, also referred to as field-oriented control, to regulate the frequency. In order to do this, the stator current and voltage must be measured, and the rotor current needed to maintain the target output power and frequency must then be calculated using these measurements. The voltage and frequency of the power electronics connected to the rotor circuit are then changed to control the rotor current.

The DFIG must be able to react promptly to variations in wind speed and load demand in order to maintain grid frequency. This is accomplished by using a control system that can modify the rotor speed in response to variations in the grid frequency. To guarantee a steady and dependable power supply, the control system must also be able to balance the power output of the generator with the power consumption of the wind turbines and other loads on the grid. There are several ways to implement frequency control in DFIG, including rotor-side control, grid-side control, and pitch control.

1) Rotor-Side Control

In order to modify the generator torque and subsequently the rotor speed, rotor-side control involves adjusting the rotor current and voltage. The output frequency of the generator can be altered to match the grid frequency by adjusting the rotor speed. Rotor-side control in a DFIG refers to managing the rotor-side converter, which in turn manages the rotor current and, consequently, the active and reactive power output of the generator. The generator's rotor windings are connected to the rotor-side converter, which enables regulation of the rotor current.

In a DFIG, rotor-side control enables variable speed operation of the generator and supplies the grid with the required reactive power supply. The active power output of the generator can be altered to fit the load demand by adjusting rotor current. Additionally, the reactive power output of the generator can be regulated to support the grid's voltage by modifying the phase angle of the rotor current. A proportional-integral (PI) controller is commonly used to manage the rotor-side converter. This controller modulates the rotor current depending on the discrepancy between the desired and actual values of the active and reactive power output. To prevent overloading of the generator, the control system may additionally have extra features like a maximum torque restriction. Overall, rotor-side control is essential to a DFIG's functioning because it makes it possible for the generator to run effectively and steadily and for it to be integrated into the power grid.

2) Grid-Side Control

In order to vary the generator speed and subsequently the output frequency, grid-side control involves managing the active and reactive power transferred between the generator and the grid. By controlling the converter which links the generator to the grid this can be achieved. The control system that manages the electrical power flow between the DFIG and the grid is referred to as grid-side control in DFIG.

In DFIG, the rotor windings are connected to the grid via a power electronic converter that may regulate the rotor current and, in turn, the flow of electrical power between the rotor and the grid. In contrast, the stator windings are connected to the grid directly. Grid-side control in DFIG controls the power electronic converter to maintain the grid's voltage and frequency as well as the power balance between the wind turbine and grid. The primary control and the secondary control are the two stages that normally make up the control mechanism.

The main control entails adjusting the rotor current to the wind speed in order to maximize the turbine's output of power. This is accomplished by employing a vector control approach to regulate the angle and amplitude of the rotor current. In order to maintain power balance and control the grid's voltage and frequency, the secondary control entails managing the power flow between the DFIG and the grid. This is accomplished by employing a voltage control or a frequency control technique to regulate the active and reactive power exchange between the DFIG and the grid. Overall, grid-side control in DFIG is essential for guaranteeing the steady and dependable operation of wind energy systems, and it calls for sophisticated control strategies and algorithms to work at its best.

3) Pitch Control

In order to maintain optimal power output, pitch control, a crucial component of DFIG functioning, helps in regulating the speed of the turbine blades. Pitch control is the process of changing the angle at which the turbine blades catch wind energy and transform it into electrical power. In a DFIG system, the stator is connected to the wind turbine blades and the generator's rotor is connected to the grid via a power electronics converter. The DFIG system employs a pitch control mechanism to regulate the pitch of the turbine blades. This mechanism alters the pitch angle of each blade dependent on variables including wind speed, generator speed, and power production. Each individual blade's angle is often adjusted by a set of hydraulic or electric actuators that make up the pitch control mechanism. The DFIG technology can maintain a steady generator speed and maximize power output even under fluctuating wind conditions by regulating the blade pitch. This maximizes energy production and ensures the wind turbine's efficient operation.

To manage the quantity of wind energy captured by the blades, this entails altering the pitch angle of the wind turbine blades. The output frequency can be changed to match the grid frequency by modifying the pitch angle, which will also change the rotor speed. Pitch-regulated rotors lower the local angle of attack of the rotor parts, which in turn lowers the aerodynamic torque. The section lift coefficients and, thus, the aerodynamic torque on the rotor, are decreased by the lower angles of attack. When the wind speed is adequate to produce the turbine's rated power output, the pitch control starts working. Up until the cut-out wind speed, it keeps reducing the pitch in an effort to maintain an optimum λ while still keeping the rated power constant. The blade pitch angle at zero degrees that captures the most power is called $\beta*$. Pitching to feather is generally understood to correspond to rising, or positive, pitch angles. In order to keep the generator speed at its rated level, the blade pitch control system normally applies proportional integral (PI) control to the generator speed error signal. Overall, for DFIG-based wind turbines to ensure dependable and consistent grid operation, frequency regulation is a crucial component.

D. Fractional Order Proportional Integral Derivative Control

Over the past few decades, various control strategies have been proposed. One of the most popular and practical among them is the proportional integral-derivative (PID) control method, which is also one of the simplest. Based on Figure 2, the fractional-order PID (FOPID) controller is a generalization of a normal PID controller. This controller is based on fractional-order calculus, a powerful modelling technique for many engineering phenomena. Due to additional degrees of freedom produced by an integrator of fractional order and a differentiator of fractional order, the FOPID controller offers greater control performance than the traditional PID controller. Some benefits of this controller include its straightforward construction, increased design freedom, wide stability zone, improved set point tracking, excellent disturbance rejection, and high capability of handling model uncertainties in nonlinear and real-time applications. Significant thought has been given to the FOPID controller as a novel strategy in electrical power engineering.

The FOPID controller is interpreted into transfer function as given by (8). K_p, K_i, andK_d are denoting the gains of the FOPID controller. α and π define as integrator and differentiator fractional parameters.

$$G(s) = K_p + \frac{K_i}{S^{\alpha}} K_{d}s^{\pi} \qquad (8)$$

Where α and π are limited between 0 and 1 which enhances the ability over conventional PID controller by purifying the tuning. The FOPID controller is an expansion of the PID controller from a point in the α-δ plane to a square in the same plane.

E. Model Predictive Control

A constrained dynamical system's cost function is minimized using model predictive control (MPC), an optimum control technique, across a finite, receding horizon.

An MPC controller receives or estimates the current status of the plant at each time step based on Figure 3. The next step is to determine the sequence of control actions that minimizes the cost across the horizon by resolving a restricted optimization problem that depends on the present system state and

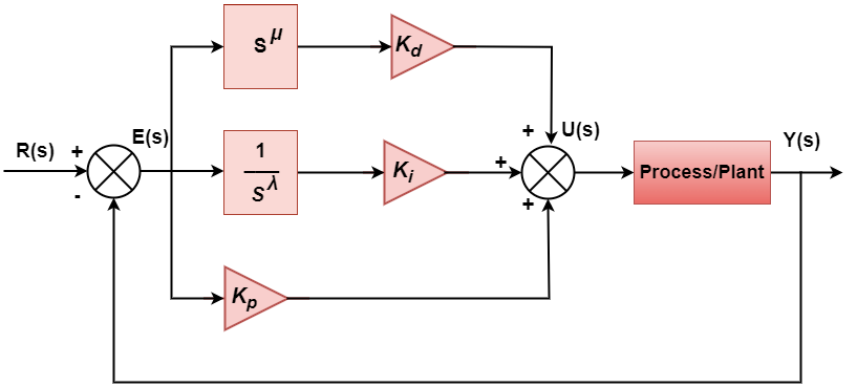

Figure 2. Structure of FOPID

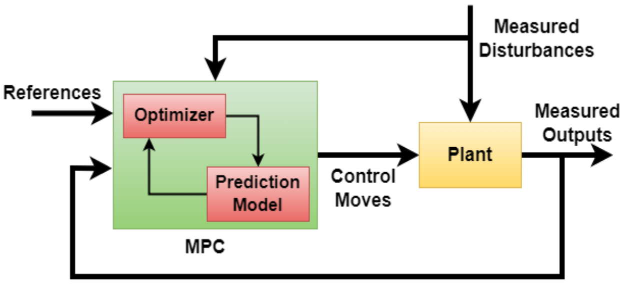

Figure 3. Structure of MPC

uses an internal plant model. The controller then only applies the first computed control action to the plant, ignoring the subsequent ones. The procedure is repeated in the subsequent time step.

The MPC consists of a controller and a prediction unit. The prediction unit projects the system's potential into the future using its output. In order to reduce the controlled fitness equation, the control module decreases the anticipated output. When there are system limits, the fitness equality can be made simpler by using the output estimation unit and the control element.

F. *Proposed Cfmpc-Fopid Controller*

The proposed controller in CFMPC-FOPID controller is created by combining the FOPID and MPC controllers. It works well to boost the isolated power system's ability to quickly regulate frequency and return the frequency to a normal value. The suggested frequency controller is resistant to variations in wind speed. Numerous control strategies are examined to combat the frequency oscillations in the power system following a thorough assessment of the literature. Regarding frequency and continuity of the power flow, the power system encounters numerous difficulties. Maintaining the frequency at its nominal working value is essential for ensuring the stability of the DFIG. The challenges of Frequency control in DFIG have been addressed using a variety of control approaches. MPC formations/structures built on cascades, however, are less concentrated. The complexity of incorporating renewable energy sources (RES) from various control approaches is limited. To suppress the frequency deviation and power variation of the Doubly Fed Induction Generator (DFIG), the absolute error times the integral time (I_{TAE}) is calculated using the formula:

$$I_{TAE} = \int_{0}^{\infty} \left(t(\Delta f)\right) dt \tag{9}$$

Meanwhile, there is a dual FOPID controller called FOPID-1, which aims to smooth the received signal of the output frequency. The summation of the responses from the two controllers, namely Model Predictive Control (MPC) and FOPID-1 (Figure 4), is transferred to FOPID2 as part of the cascaded structure of the proposed CFMPC-FOPID controller.

III. RESULT AND DISCUSSION

This section discusses the simulation results of the proposed network connected DC-DC converter based WECS system. The proposed system is designed using the MATLAB/Simulink platform on an

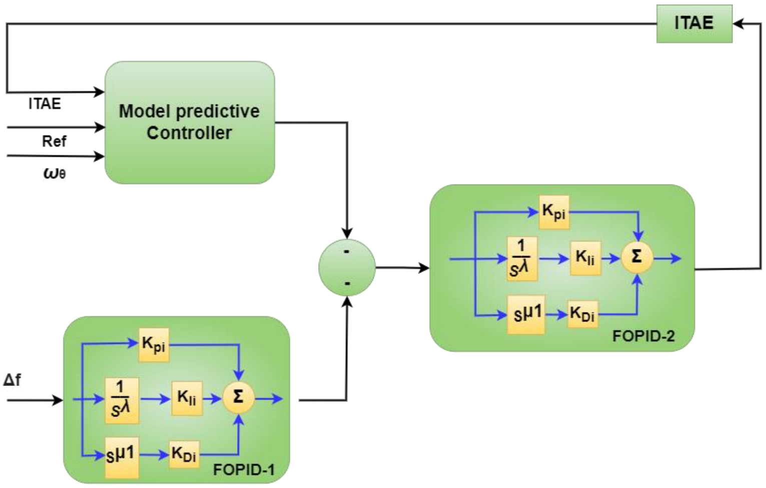

Figure 4. Structure of proposed CFMPC-FOPID controller

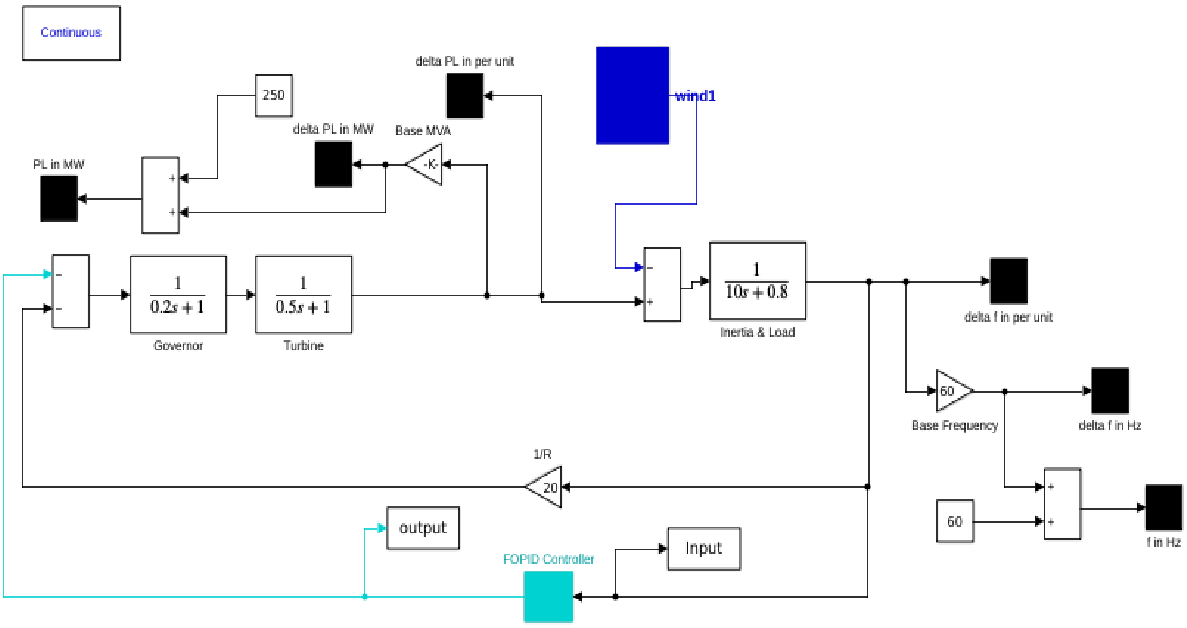

Figure 5. Simulink model of proposed system

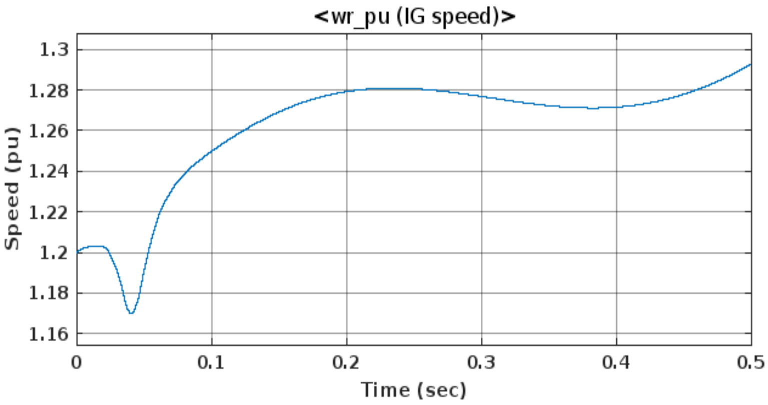

Figure 6. Turbine Speed

Intel Core i5 processor-based system with 4 GB RAM version 2022a. Furthermore, the implementation of the Simulink model is presented in Figure 5.

Figure 6 displays the turbine speed waveform. In this case, the load is kept constant, although this condition does not always reflect the practical situation. Keeping the load fixed allows better observation of the performance of the renewable energy conversion system and battery storage system against

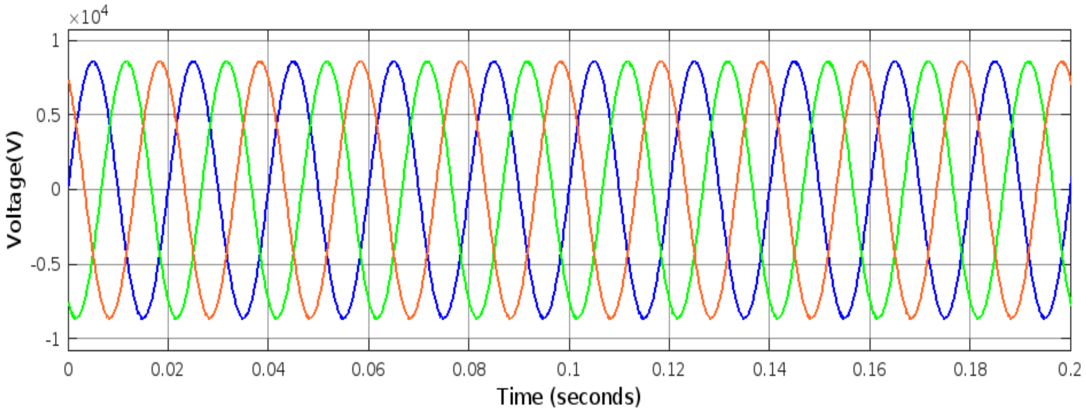

Figure 7. Wind voltage waveform

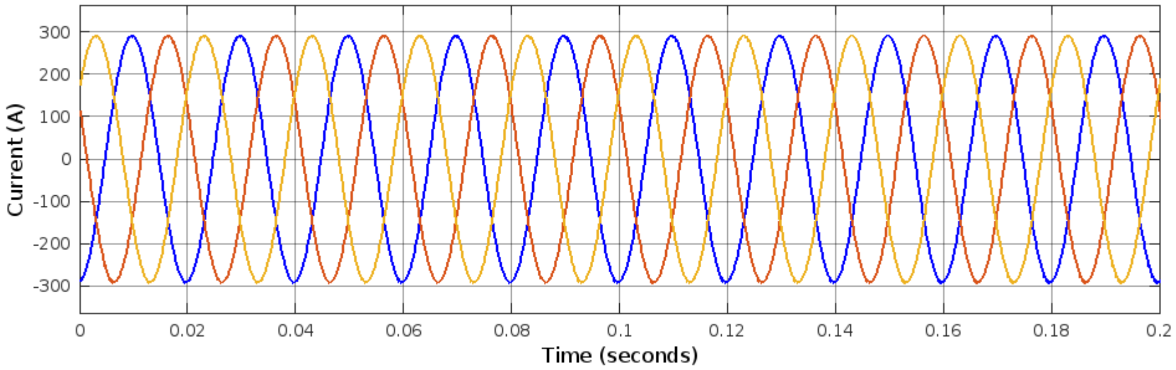

Figure 8: Wind Current waveform

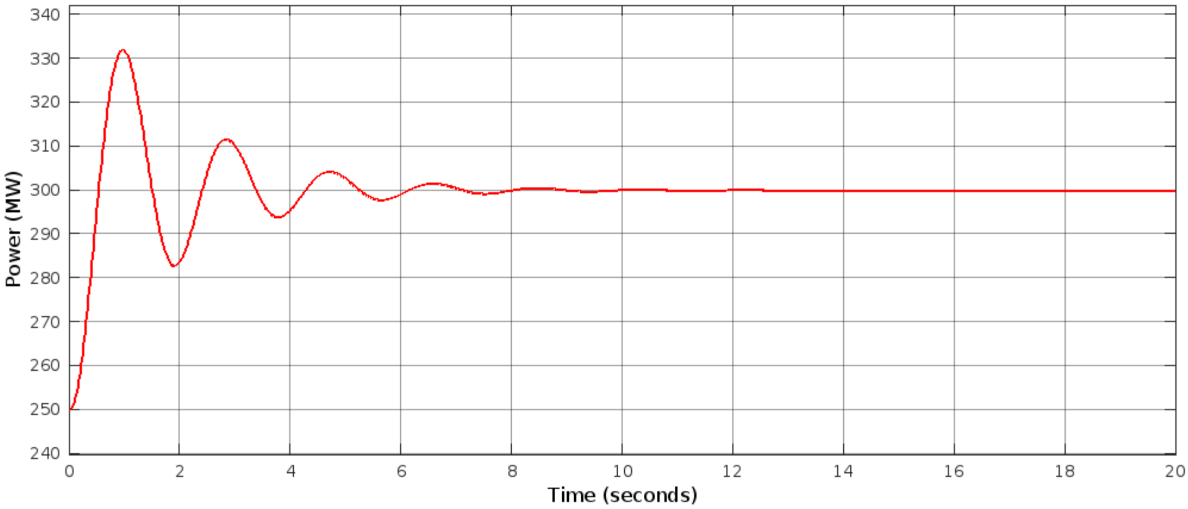

Figure 9: Wind Power waveform

variations in the power generated from renewable energy sources. This becomes difficult to observe if the load is constantly changing. Power balance is achieved through energy storage devices that keep the DC bus voltage fixed at 50V.

Figure 6 shows the turbine speed, which fluctuates within the range of 1.16 m/s to 1.3 m/s. To design a viable frequency controller for the power system, an initial step involves designing a coordinated frequency controller for a simple power system comprising a single generator and a single Doubly Fed Induction Generator (DFIG). Subsequently, by considering the straightforward configuration and one-way power flow characteristic of the isolated power system, frequency controllers for multiple generators and DFIGs can be deduced.

Figure 7 and 8 displays the wind voltage and current waveforms. Based on the suggested controller, the harmonics reduced voltage and current value is obtained. From the observation, 3 phase voltage and current is gained which implies the power characteristics. The wind power is given in Figure 9.

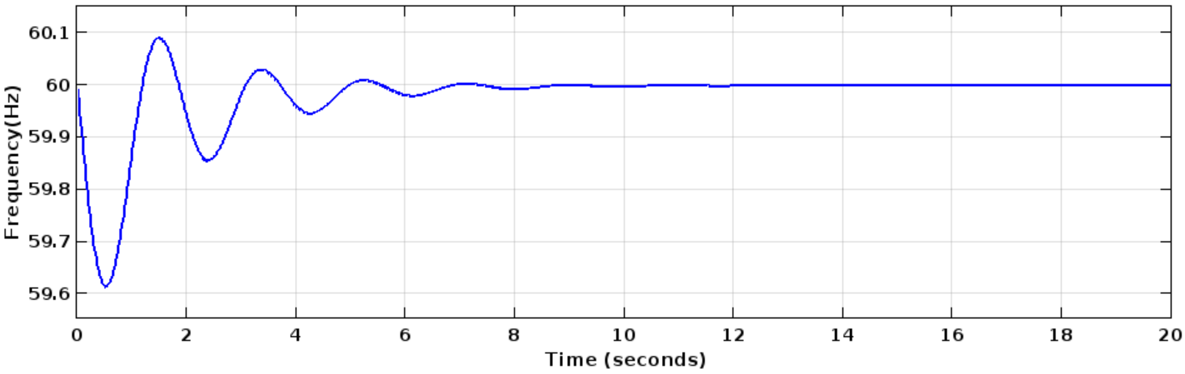

Figure 10: Frequency waveform

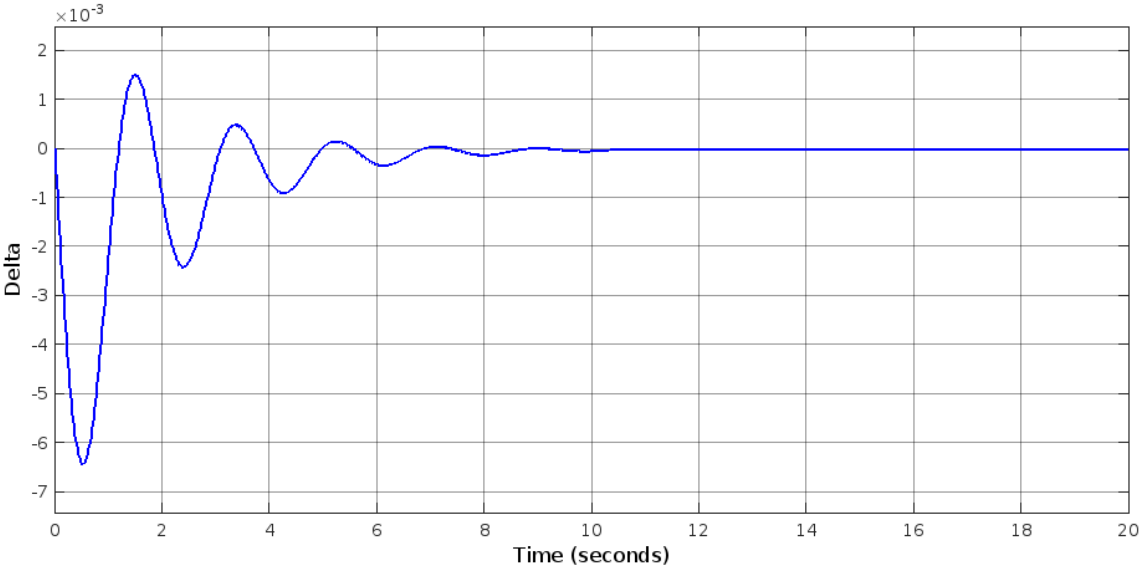

Figure 11: Load Frequency waveform

By the proposed controller, DFIG frequency is controlled and the frequency waveform is displayed in Figure 10. From the analysis, the proposed method achieves 60Hz frequency after some oscillation at the time range of 0 to 6 seconds.

Figure 11 shows the load frequency waveform. After the load applied case, the frequency is varied in the range of -0.006 to 0.015 in the time period of zero seconds to 6 seconds. From the observation, the DFIG frequency is controlled by the proposed CFMPC-FOPID controller.

IV. CONCLUSION

This paper proposed a coordinated frequency control scheme for emergency frequency regulation of isolated power systems with high penetration of wind power. To regulate the frequency, CFMPC-FOPID controller is designed for an efficient response of the DFIG system under load disruption and system parameter variations. The proposed controller should have the robust tendency to achieve the rapid response in terms of minimum settling time, undershoot, and overshoot. The proposed method experiment is conducted on Simulink/Matlab tool. The proposed frequency controllers exhibit more satisfactory dynamic performance even when wind speed fluctuations exist. The major formulation of MPC is to minimize the ITAE, while FOPID-1 is refining the signal, entering from output frequency of DFIG and their collective sum, i.e., MPC and FOPID-1 are fed to FOPID-2. The outcomes encapsulate that the proposed controller has robust ability to restrain the frequency in range between 2 sec and 6 sec in DFIG system.

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