A novel approach of Active Voltage Control for DFIG-based Wind Farm power system by Coordinating Active & Reactive Powers under Wind Speed Variations

Shubham Gayakwad[1]
Student , BIT Ballarpur, Maharashtra India

Prof Shiwani Rasekar[2]
Assistant Professor, BIT Ballarpur, Maharashtra India

ABSTRACT

Long-distance transmissions are commonly used to connect large-scale wind farms, however power networks cannot handle the access point voltage of these wind farms. Under wind speed fluctuations, the access point voltage has a difficulty with stability. The reactive power compensation device, on the other hand, is unable to meet both the response speed and the compensation capacity criteria. The reactive power capabilities of doubly fed induction generators are limited by active power output, notwithstanding their quick power decoupling control. Coordinating the reactive power capability and active power output of the wind farm is the important solution for satisfying the reactive power demand of the system under wind speed variations, and it is based on this that a novel active control notion is given. The wind farm's reactive power capability and the system's reactive power demand are both investigated, as well as the controllable circumstances of access point voltage. Active voltage control solutions are proposed, including active reactive power reference modification, active speed control, and active pitch angle intervention based on wind speed ranges. The method is verified in the simulation to appropriately account for reactive power demand and excavate the wind farm reactive power capability. The approach also efficiently reduces the change in grid voltage caused by variations in wind speed.

Keyword: -. Wind speed variations, DFIG-based wind farm, reactive power control, voltage stability. SVG.

I. INTRODUCTION

The global energy situation has worsened, and wind power development has accelerated [1]. Wind energy in resource-rich areas often uses a large-scale centralised development model with long-distance high-voltage transmission [2]. The access point voltage (APV) of large-scale wind farms is insufficiently supported by the electricity grid. The active power output of a wind farm is affected by wind speed variations, although the reactive power is normally unaffected, and this discrepancy causes APV to fluctuate, thereby jeopardising the voltage stability of power networks [3]. Grid voltage is currently stabilised by reactive power adjustment devices. In [4], the capacitor and reactor banks are used to maintain the voltage and power factor according to the commands of an integrated control system. The on-load tap changer relies on an appropriate algorithm and reliable communication network [5]. But they could not meet the requirements of response speed. The static var compensator (SVC) can regulate reactive power in real time and thus is widely used for reactive power compensation in wind farms [6]. However, SVC is very expensive, and SVC exhibits obvious delayed response, voltage overshoot and cascaded trip-off of wind turbines occur occasionally, so the installation capacity of SVCs is limited. Utilizing SVC solely is hard to satisfy the reactive power compensation demand of large-scale wind farms under adverse environments [7-8]. As a supplementary control in emergencies, it is necessary to excavate and utilize the available capacity of wind turbines to support gird voltage.

The DFIG wind turbine and control system are depicted in Figure 1. The DFIG is made up of a grid-side converter (GSC) and a rotor-side converter that are connected back to back (RSC). The stator windings are connected to the power grid, while RSC and GSC connect the rotor windings to the power grid. The benefit of detaching the rotor from the power grid is that the converters' power capacity is 30 percent that of the wind turbine [3]. As a result, converter and harmonic filter costs are greatly lowered. Furthermore, the smaller converter size not only reduces power loss but also improves efficiency. The controllability of the active and reactive power outputs is a distinguishing feature of a DFIG wind turbine (PDFIG, QDFIG, respectively). The control system in Fig. 1 can regulate both PDFIG and QDFIG independently using the vector control technique [8].

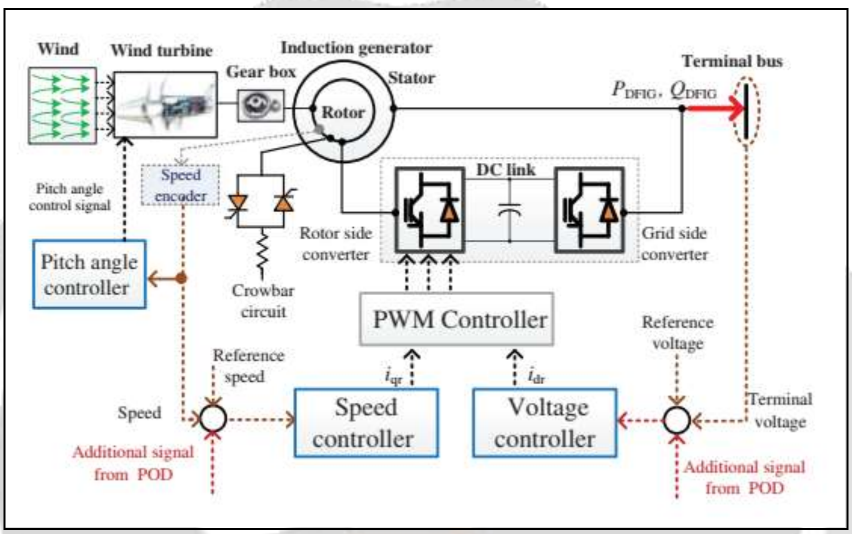

Fig 1. DFIG Wind Turbine

The speed controller, voltage controller, and pitch angle controller make up this control system. The main control goal of a DFIG in this case is to reduce power system oscillations. According to the findings in [9], the RSC control has a substantially larger dampening impact on the oscillation mode than the GSC control. As a result, the RSC is suitable for dampening power oscillations. The RSC's quadrature-axis current I qr) can be used to regulate the active power output by the speed controller, while the RSC's direct-axis current I dr) can be used to control the reactive power output by the voltage controller, as indicated in [8].

The DFIG's capacity to manage reactive power output eliminates the need for reactive power compensation, which is required in fixed-speed wind turbines [10]. This capability not only maintains the DFIG terminal voltage during steady state and grid disturbances, but also eliminates the need for reactive power compensating devices, which are costly to install. As indicated in Fig. 1, the rotor circuit is connected to the crowbar circuit, which is made up of antiparallel thyristors and a resistor. The crowbar circuit's goal is to reduce the rotor circuit's high current and create a bypass [11]. During and after a fault, the rotor circuit is protected without the converter being disconnected from the rotor or the power grid. As a result, the DFIG wind turbine's fault (low-voltage) ride-through performance has been enhanced. Overvoltage at the converter terminal should be mitigated by a low resistance. It should, on the other hand, be sufficiently high to limit the rotor's high current.

In [14] and [15], a multilevel reactive power control is used for the wind farm. In [16], this approach is improved by using a probabilistic method to predict the available reactive power reserve, thus well adapted to the fluctuating nature of wind speed. A coordinated control of DFIG and other reactive power sources is proposed to improve the voltage stability in [17] and [18]. However, the existing methods are implemented according to the fixed RPC of DFIG. The influences of active power on RPC and voltage are ignored, the reactive power reserve may be insufficient. The RPC of DFIG is affected by current and voltage tolerance levels [20], but enhancing tolerance levels was costly. Controller structure was modified in [21] to improve RPC, but the improvements was limited. System RPD and wind farm RPC are both affected by the wind farm active power, which is determined by the wind speed and control mode of wind turbines. Coordinating the active and reactive power controls of the wind turbine can minimize the threat of wind speed variations. Thus, a novel active control idea is proposed, which possesses the following advantages: the controllability of APV is distinguished according to the forecast of RPD and RPC, the RPC of wind farm is improved in advance to ensure sufficient reactive power reserve, and the various strategies are established to achieve high efficiency with consideration of different wind speed ranges.

The paper is divided into four sections. In Section I, a general introduction is given. In Section II, a summary of general wind power generation is given specifically Doubly fed induction generators (DFIGs) are widely used in wind power generation are discussed under different controlling parameter to analysis the active voltage control of DFIG based wind farm. In section III The idea and strategy of active voltage control under wind speed variations are proposed according to the co-constraints of DFIG active and reactive powers. And then the effectiveness of the method is verified by simulation result discussion finally, in Section IV, conclusions are drawn.

C. DFIG Wind Turbine

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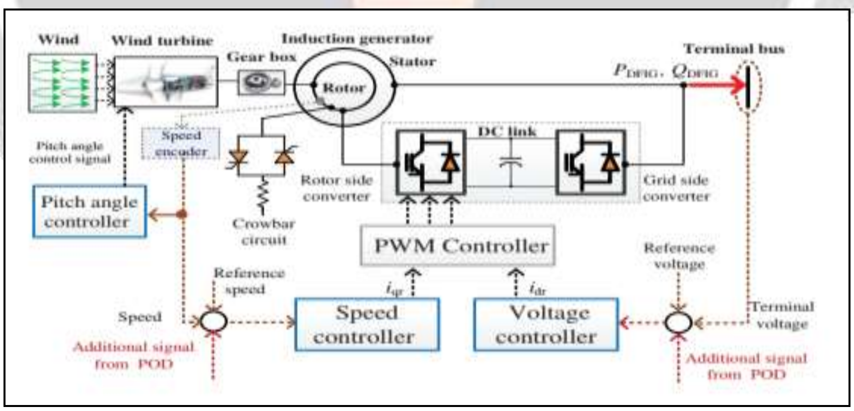

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II. MODELING of DFIG

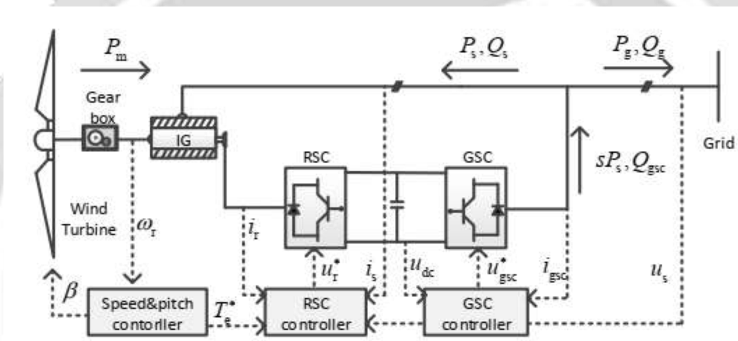


Fig.2. Schematic diagram of DFIG

Fig 2 shows the schematic diagram of DFIG. DFIG is composed of wind turbine, induction generator, and back-to-back converters. The wind turbine is used to capture aerodynamic power through pitch angle control, including pitch control and pitch compensation. The rotor side converter (RSC) realizes the decoupling control of the DFIG stator active and reactive powers by regulating rotor current. The grid side converter (GSC) controls the DC bus voltage and the reactive power. The double-loop design is adopted by the control system of the converters. The outer loop determines the current reference according to electromagnetic torque and reactive power references (RSC), or according to DC bus voltage and reactive power references (GSC). The inner loop calculates the required voltage according to current reference.

Power Characteristics of DFIG

The mechanical loss and converter loss are neglected. The motor convention is used for stator and rotor windings. According to Fig.1, the inner power relationship of DFIG can be obtained as

$$P_g = (s-1)P_s = P_m$$

where

Ps is the active power of stator,
Pg is the active power of DFIG.
S is the slip ratio.
Pm is the mechanical power of wind turbine, can be expressed as

$$P_m = k_1 v^3 C_p$$

The power characteristic curve of DFIG is shown in Fig. 3. DFIG adjusts the operating parameters according to the real-time wind speed. However, because of the limit of rotor speed and active power output, the operating characteristics under different wind speed ranges also vary, and they can be divided into the optimal speed zone (AB), constant speed zone (BC), and constant power zone (CD) [2]. Correspondingly, Vw1 , Vw2 , Vw3 , and Vw4 are the cut-in wind speed, the critical wind speed of the optimal speed zone, the rated wind speed and the cut-out wind speed.

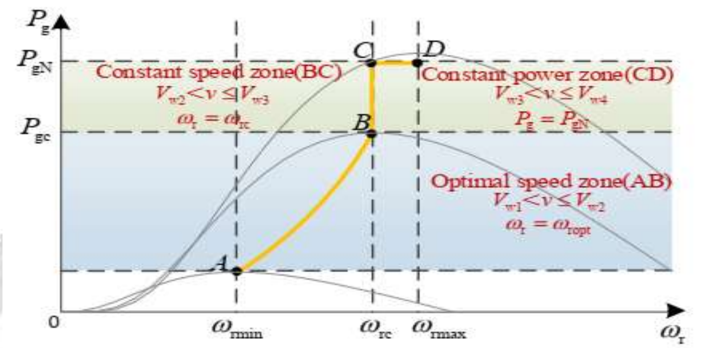


Fig. 3. Power characteristics of DFIG

Fig.4 shows the RPC of stator, GSC and the whole DFIG at different Pg under optimal speed zone and constant speed zone. The RPC of stator decreases greatly with the increase of Pg , while the RPC of GSC changes gently.

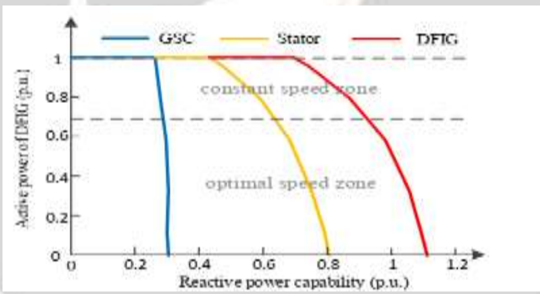


Fig. 4. Reactive power capability of DFIG

When the active power of DFIG increases from the minimum value to the rated value, the RPC of GSC only changes between 0.3 pu and 0.25 pu because the variation range of slip ratio is from 0.3 pu to -0.2 pu. Therefore, the minimum value is chosen as the RPC of GSC for the control to balance the control practicability and converter safety.

In the proposed prototype the System RPD and wind farm RPC are both affected by the wind farm active power, which is determined by the wind speed and control mode of wind turbines. Coordinating the active and reactive power controls of the wind turbine can minimize the threat of wind speed variations. Thus, a novel active control idea is proposed, which possesses the following advantages: the controllability of APV is distinguished according to the forecast of RPD and RPC, the RPC of wind farm is improved in advance to ensure sufficient reactive power reserve, and the various strategies are established to achieve high efficiency with consideration of different wind speed ranges.

III. ACTIVE VOLTAGE CONTROL STRATEGY

The maximum RPD of system during wind speed variations can be calculated according to the forecast information of wind speed. If the RPC of wind farm is exceeded, then active control needs to be initiated. The power control of DFIG is restricted by rotor speed and rated power. However, the corresponding active voltage control configuration should also consider the operational limit of DFIG under different wind speed ranges. To specify different wind speed ranges, Vw2 and Vwx should be calculated first. Vw2 can be solved according to (4). By using (12) and (13), under the condition of Q sd = Q wc Vwx and the corresponding active power output of wind farm Pwx can be solved. Vw2 is decided by the self-design of DFIG, Vwx is decided by the interaction between the wind farm and the system, they may have different relations, thus bringing different methods of wind speed zoning and active control configuration. Therefore, it is worth to discussing the relationship between Vw2 and Vwx

A. **Vwx ＜Vw2**

1. Active adjustment of Q_g* :

When the maximum forecasted wind speed $V_{fm} \in (V_{w1}, V_{wx}]$ the RPC of wind farm is larger than the maximum RPD of system, then the reactive power output of DFIGs can be controlled to suppress the voltage variation. DFIG gives priority to the RPC of GSC because of the fast response and low cost, so the reactive power reference value of the stator side and GSC can be expressed as

$$\begin{cases} Q_s^* = Q_{sd}/N - Q_{gscc} \\ Q_{gsc}^* = Q_{gscc} \end{cases}$$

2. Active speed control:

When the maximum forecasted wind speed Vfm＞Vwx , the RPC of wind farm cannot meet the RPD owing to the restriction of active power. Under these circumstances, the speed of DFIG, which is less than the critical speed, can be actively accelerated in order for the DFIG to operate at the non-optimal tip speed ratio, thus reducing the active power of DFIG. When DFIG operates at critical speed, its active power output is proportional to the wind speed, therefore the RPC of wind farm decreases whereas the RPD of system increases with the increase of wind speed.

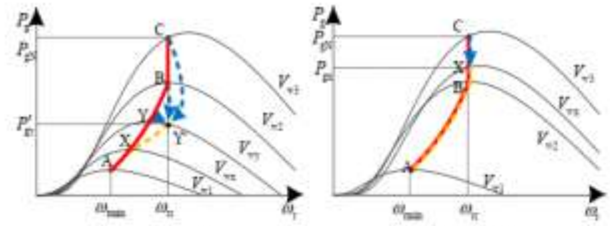
B. Vwx ≥ V w2

1. Active adjustment of Qg∗ :

When the maximum forecasted wind speed $V_{fm} \in (V_{w1}, V_{w2}]$, the voltage control can be realized by adjusting the reactive power of DFIGs.

2. Active pitch angle intervention:

When the maximum forecasted wind speed V fm V wx V w3 ∈(,], DFIG has been running at the critical speed and cannot be accelerated. The active power of the DFIG can only be reduced by the pitch angle intervention. The reference value of pitch compensation is Pgx . The power characteristics of DFIG in such circumstances are shown in Fig. 5(b). When the wind speed is greater than Vwx , the operation points converge to point X through the active pitch angle intervention. The active voltage control scheme and logic are shown in Fig. 5 Vf is the forecasted wind speed. Once the maximum forecasted wind speed satisfies certain conditions, the reference values of rotor speed and active power are modified, DFIGs adjust the active power output by tracking these reference values. Then, the RPCs are improved actively. When the APV is lower than the threshold value Uth , the reactive power reference values of the stator side and GSC are adjusted according to the system RPD, and the voltage variation of power grid can be suppressed on the premise of a sufficient reactive power output.



(a) $V_{wx} < V_{w2}$ (b) $V_{wx} \geq V_{w2}$

Fig. 5. Power characteristics of DFIG under active voltage control

IV. SIMULATION

The simulation model is built in Matlab/Simulink, as shown in Fig. 7. The wind farm is integrated by a 25 kV/220 kV transformer and a 300-kilometer transmission line. The wind farm is composed of 108 DFIGs (1.5 MW), which are equivalent to 9 DFIGs by capacity weighting. Three collector feeders are connected to the access point, three DFIGs are connected to each feeder. The distance between the neighboring DFIGs is 0.6 km. Vw2 is 11 m/s, the rated wind speed is 15 m/s, and the critical speed is 1.2 times the synchronous angular velocity. The threshold value of APV is 0.97 pu [2], the control objective of APV is 1.03 pu. To verify the performance of the proposed active voltage control under different situations, i.e., Vwx ≥V w2 and V wx ＜Vw2, another source and load are connected to the access point.

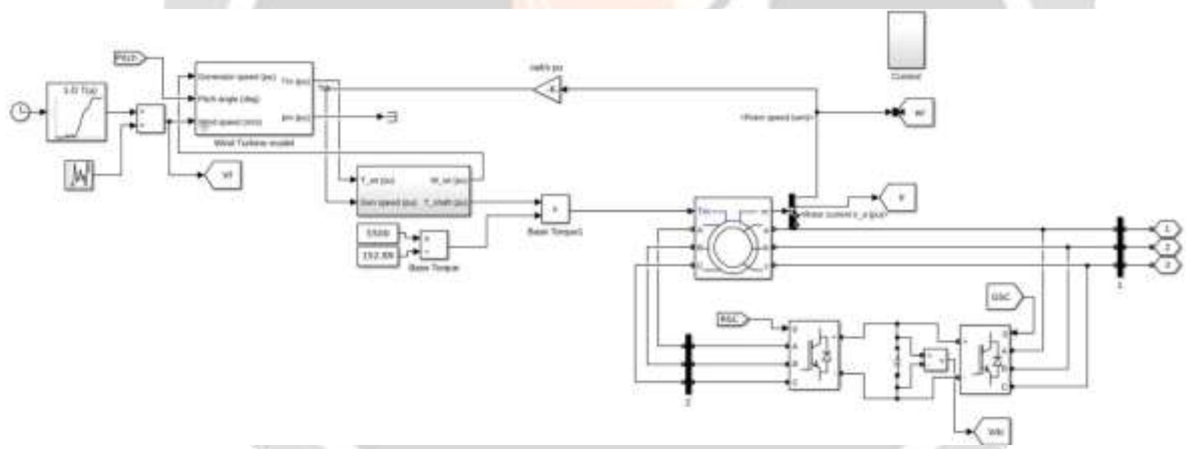


Fig. 6. Simulation system of proposed system

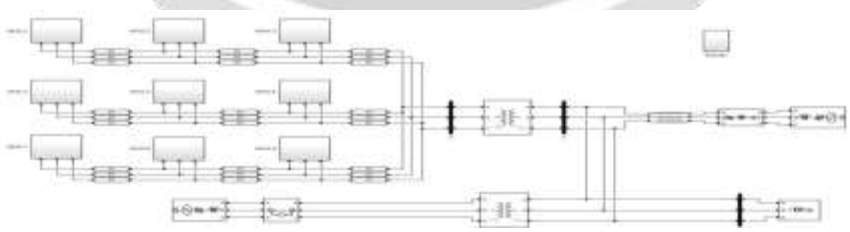
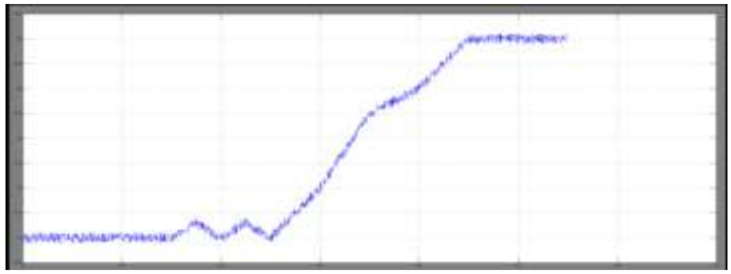
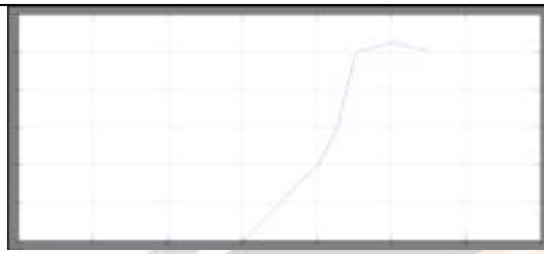


Fig. 7. Subsystem simulation of DFIG

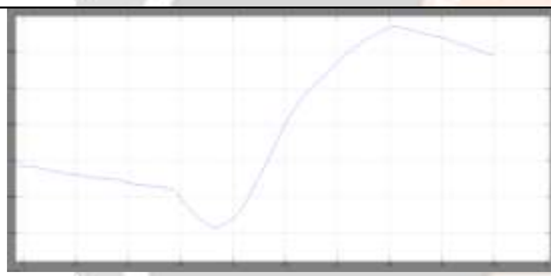


(b) Wind Speed

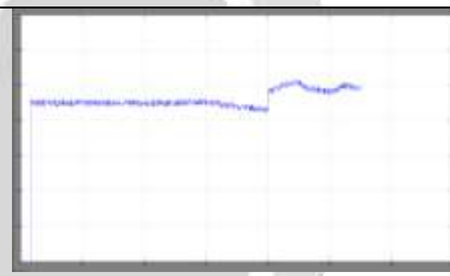


(d) Pitch angle

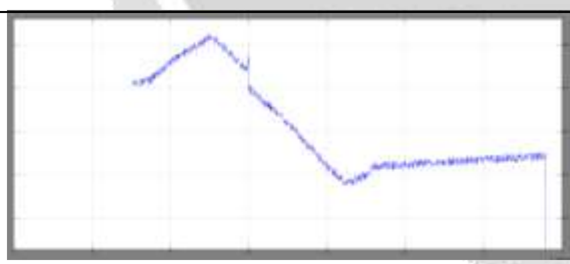
(c) Rotor Speed



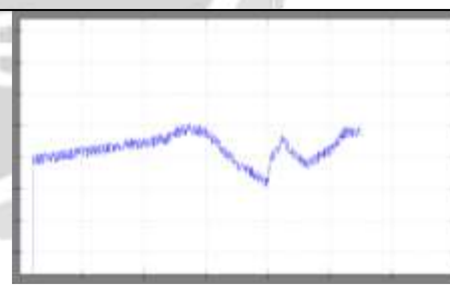
(e)Active power



(f)Reactive power



(i)Rotar current



(h) Voltage amplitude

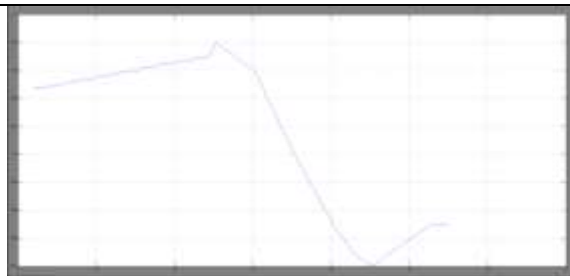
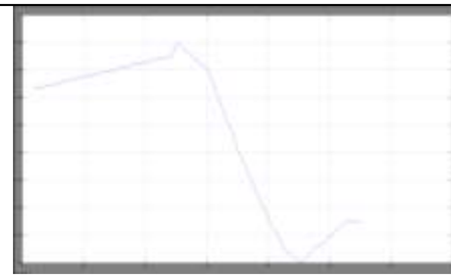
P of wind farm(p.u.)	 (a) RPC	DC voltage of DFIG1,5,9(p.u.)	 (j) DC voltage

Fig. 8 Simulation results of proposed System

The RPD curve of the system and the RPC curve of the wind farm are shown in Fig. 8 when the source generates 165 MW and the load absorbs 15+j48.76 MVA (a). Pwx is 0.59 pu, Vwx is 10.5 m/s, and V wxV w2 is satisfied. The wind speed is predicted to grow from 9 to 13 m/s in 4 seconds in this example, as illustrated in Fig. 8. (b).

The rotor's rotational speed is proportional to the wind's velocity. The mechanical torque is lowered, and the dynamic process of rotor acceleration is prolonged, since the real-time rotor speed exceeds its reference value, causing the pitch control output to be a positive pitch angle, as illustrated by the dashed lines in Fig. 8(d). The rotor speeds of DFIG1, 5, and 9 reach critical speed after 25 seconds, as demonstrated by the dotted lines in Fig. 8. (c). Furthermore, the power coefficient improves with rotor speed, resulting in a progressive increase in the active power output of the wind farm from 0.35 pu to roughly 0.9 pu. The APV reduces from 1.03 pu to 0.86 pu in 20 seconds if the reactive power output of a wind farm is not changed in time, as indicated by the yellow line in Fig. 8. (h). The blue and red lines in Fig. 8 indicate the real-time RPC of the wind farm and RPD of the system under classical reactive power control (f). The RPC drops from 0.79 pu to 0.54 pu when active power increases. During this time, the RPD increased from 0.6 to 0.88 pu. When the APV reaches the threshold value of 13.3 s, the reactive power control is turned on. The RPC, however, is unable to fulfil the system's RPD, leading the APV to rise to nearly 1.03 pu before falling below 0.97 pu again, as illustrated by the blue line in Fig. 9. (h). The real-time rotor speed is smaller than the critical speed, as demonstrated by the solid lines in Fig. 8(c) and (d), causing the pitch control output to become zero and the mechanical torque and rotor speed to inversely improve. As illustrated by the red line in fig 8 (e), the rotor speed is closer to the ideal speed, which enhances the power coefficient and active power of the wind farm. The active power exceeds 0.62 pu at 8 s, and the pitch compensation outputs a positive pitch angle, resulting in a slower increase in rotor speed and active power. The pitch angle of the wind farm continues at 7.4° after the transition procedure, while the active power of the wind farm remains at 0.62 pu. Then, as illustrated by the yellow and black lines in Fig. 8, the RPC of the wind farm grows dramatically and practically satisfies the lowered RPD of the system (f). The faster active power increases, the faster APV decreases. The threshold value is reached after 9s, and the reactive power control is turned on. The APV is regulated around the goal value of 1.03 pu, as shown by the red line in Fig. 8(h). Figures 8(i) and (j) show the active management of the rotor current and DC-link voltage, which are kept within a certain range.

V. CONCLUSION

Wind speed changes can have a significant and detrimental impact on the voltage profile of DFIG-based wind farm integrated power systems, and these conditions have emerged as significant challenges to grid stability. the operation of electricity systems in a safe manner The dynamic in this investigation is a balance between the ability to control power and the ability to manage power the wind farm as well as the voltage requirement of the system Stability is taken into account. As an additional safeguard, An active voltage regulation approach is proposed for emergency situations. by synchronising the active and reactive controllers a wind generator The DFIG's voltage control capability can be extensively utilised and explored. Wind speed variations on grid voltage can be greatly reduced, providing efficient safeguards for the development and construction of massive renewable energy sources.

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