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

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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. This review is based on a variety of unique active control ideas. Coordinating the reactive power capability and active power output of the wind farm is the main solution for satisfying the reactive power demand of the system under wind speed variations. The wind farm's reactive power capability and the system's reactive power demand are also investigated, as are 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 approach also efficiently reduces the change in grid voltage caused by variations in wind speed.

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

I. INTRODUCTION

Wind power generation, which has become the most promising renewable energy resource, is widely used in power systems around the world. Somewhere at end of 2015, the global cumulative The capacity of wind power was almost 432 GW [1]. It is planned that By 2020, this figure will have risen to 760 GW [2]. When it comes to wind turbines,The doubly fed induction wind turbine is a variable-speed wind turbine. wind power has risen to prominence among the most important renewable energy sources, with enormous expansion potential around the world [1]. Indeed, global wind energy capacity is quickly increasing, making it the fastest-growing renewable energy technology [2]. Wind energy conversion devices have been created by researchers and businesses in response to the increasing growth of wind energy [3]-[4].

In comparison to onshore wind farms, offshore wind farms have a number of advantages. Stronger, less turbulent winds, the availability of huge sea regions, and less visual and noise effect from offshore buildings are only a few of them. These benefits result in increased energy output as well as reduced fatigue on the blades and structural components of wind turbines [5].

Due to its unique features, the generator (DFIG) has attracted the market's interest. due to the low cost of installation and the limited power capacity the converter's strong energy transfer capability at various temperatures speed of the wind There have been numerous assessments on the principles of the DFIG wind turbine. [3–7] turbines are available Nonetheless, the widespread use of DFIG wind turbines in power systems has negative consequences, such as a reduction in system inertia, interaction between DFIG converter controllers, low synchronised coupling, and synchronous generator displacement. As a result, the dynamic performance of the power system, such as frequency stability, power oscillation, transient stability, small-signal stability, and voltage stability, may be compromised. This research examines not only the influence of DFIG wind turbines on power system dynamics, but also the grid supports that DFIG wind turbines may provide, such as frequency and voltage management. The power oscillation dampening technologies used by DFIG wind turbines are emphasised in particular.

By the end of 2020, Europe's installed capacity is expected to reach 40 GW [6]. In terms of modest efficiency, high weight and scale of the offshore installation, cost of transportation, installation, and maintenance, offshore technology has a number of challenges [7]. HVAC and HVDC VSC [8] are the two options for integrating offshore power generation transmission at the moment. The advantages of HVAC include a simpler system layout and lower costs. However, as transmission distances get longer and the capabilities of offshore wind farms grow larger, the following issues arise [5]:

- As the transmission distance increases, the system's stability reduces.
- Reactive power compensation compensation is required, especially in the event of an AC malfunction.
- Cost increases with the increase of transmission distance. These problems can be overcome by using HVDC VSC which has the following advantages:
- Maximum capture of wind energy by frequency control
- Black-start capability.
- Independent control of real and reactive power.

Wind energy systems have the potential to be Europe's most cost-effective power source [8]. The EU's goals will necessitate a dramatic shift in renewable energy production over a relatively short period of time.[8] a brief length of time The Commission's findings are as follows: According to the Renewable Energy Roadmap, renewable energy accounts for 34% of total electricity generation. Renewable energy is predicted to meet consumption in 2020. Sources, with wind power accounting for about 12% of total generation. [9]-[10] on their own.

According to the global cumulative wind power capacity from 1999 to 2020, wind power has risen swiftly, reaching 283 GW in 2012 with 45 GW installed, and this number is predicted to reach 760 GW in 2020 based on a moderate development scenario [10]. Wind energy is growing at a faster rate than any other renewable energy source, and it is quickly becoming a significant part of the modern energy mix. Denmark, for example, has a significant penetration of wind power, with wind supplying more than 30% of the country's electrical energy today [10]. Denmark's goal is to generate 100 percent non-fossil-based electricity by 2050 [10]-[11]. Renewable energy is expected to account for 20% of energy in the United Kingdom by 2020. However, it is expected that wind energywill form a large proportion of the renewable energy increase [11]-[12]. Wind turbine consider in this reviews are on shore or off shore and DFIG Wind Turbine

A. Onshore Wind farms (OWF’s)

Onshore wind already plays a leading role in the generation of renewable electricity in the UK [09]-[10]. In 2010, it generated around 7TWh which is more than a quarter of the electricity provided by British renewables at that time and onshore wind is expected to generate up to 30TWh. The UK’s first commercial wind farm was built in Delabole, Cornwall in 1991. Since then, onshore wind energy has established itself as a mature, clean and productive technology. It is now the UK’s largest source of renewable energy. [14]. In the UK, there are numerous onshore wind projects, ranging from single turbines to larger, multi-turbine schemes. Projects are developed by an increasingly diverse range of people, from large energy companies and independent developers, to community groups or small businesses and farms [11]. Tallentire was also one of the very first operational wind farms to receive the RES’ Local Electricity Discount Scheme. Tallentire onshore wind farm, which was completed in June 2013, is made up of six wind turbines located on Tallentire Hill near Cockermouth, Cumbria [12].

B. Offshore Wind farms (OWF's)

The concept of offshore wind power is the extension of onshore wind power, and the main differences between offshore wind farms and the traditional onshore wind farms are as follows:

- High wind speed, large available areas
- Less restriction. Due to the less noise limit, higher speed turbines can be used
- Difficulties of offshore wind power transmission and integration to the grid [9].
- High cost of construction and maintenance. Structures need to resist huge disturbance, such as slat-spray and sea-waves, the initial investment is higher than that on the shore [17]

C. DFIG Wind Turbine

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].

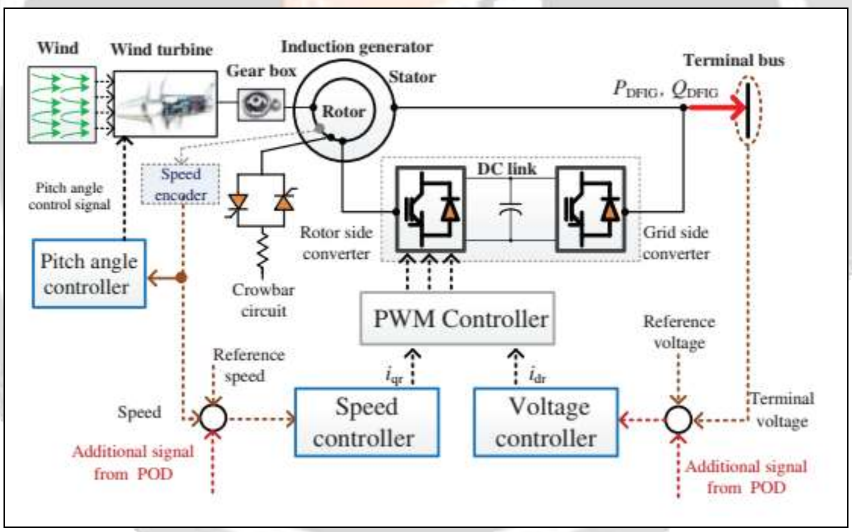

Fig 1. DFIG Wind Turbine

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.

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 In section III different methods of wind power collection schemes are also explained. Finally, in Section IV, conclusions are drawn.

II. IMPACT OF DFIG WIND TURBINE ON THE POWER SYSTEM DYNAMIC

The DFIG wind turbine can be applied to damp the power oscillation by equipping a power oscillation damper (POD) in the active power control loop (speed controller) and/or reactive power control loop (voltage controller) of the RSC, as shown in Fig. 1. Generally, the POD structure is the same as in the conventional PSS, which is a second-order lead/lag compensator with local input signal, as shown in Fig. 2.

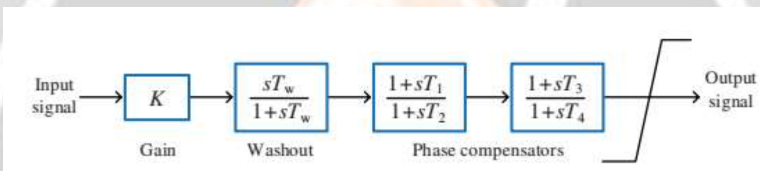

Fig.2. Structure of POD

Note that the stabilizing gain K conveys the amount of damping effect. The washout filter with time constant T w behaves as the high-pass filter to block the input signal at steady state. The time constants T 1, T 2, T 3 and T 4 imply the desired lead or lag phase angle of the phase compensator. The stabilizing signal from the POD is added to the speed controller and/or the voltage controller. Accordingly, the active and/or reactive power outputs can be modulated to damp out the power oscillation. Here, the power oscillation damping methods by the RSC of a DFIG wind turbine equipped with POD are classified into three groups based on the active and/or reactive power output control as follows.

A. Active power control

Study results in previous works can be described as follows

- **Input signal selection**

The local input signal of POD for active power control should have a high observability of the target oscillation mode. Available input signals are the rotor speed/slip [85,86], the DFIG power output/grid frequency [13] and the phase angle of terminal voltage of the DFIG bus.

- **POD control design**

Various control design methods of a POD for active power control have been proposed. In Refs. [7-8], the converter control is based on the flux magnitude and angle control. The POD is added to the active power control loop to produce a sufficient damping effect. The POD parameters are appropriately selected. In Ref. [13], the POD parameters are designed by the root locus and frequency response methods. To tune the optimal parameters of the POD, optimization techniques based on an enhancement of oscillation damping by heuristic methods such as genetic algorithm [11], bacteria foraging algorithm [12], and particle swarm optimization [9] have been presented. In addition, the POD with the proportional–integral–differential (PID) structure is proposed to depress the SSR oscillation of the nearby synchronous generator The PID parameters are optimally tuned by genetic algorithm so that the optimum damping in the entire sub-synchronous frequency band can be obtained. In Ref. [9] the POD as the supplementary SSR damping controller is designed by the observed-state feedback control for solving the SSR problem in a DFIG wind turbine. In Ref. [13], the damping effects of active and reactive power modulation controls are compared. Study results show clearly the interaction between the active power modulation and the torsional oscillations of the wind turbine. These results in the oscillation of the electromagnetic torque of a DFIG wind turbine and deteriorates the damping of the shaft mode. To lessen the interaction, the POD parameters should be optimized by considering the torsional dynamics. Alternatively, many researchers have used reactive power control for power oscillation damping instead of active power control.

B. Reactive power control

The reactive power modulation control of a DFIG gives satisfactory power oscillation damping without interacting with the torsional oscillation mode [94]. The main results from previous studies are summarized below.

- **Input signal selection**

The local input signal of POD for reactive power control utilized in previous works are the synchronous generator speed deviation [94] and the active power flow in a transmission line [95,96].

- **POD control design**

Many design methods of POD with fixed parameters have been proposed. In Refs. [93,94], the root locus technique is used to analyse the damping effect on the local, inter-area, and torsional oscillation modes. It is found that the reactive power modulation is not only able to augment the damping of both local and inter-area modes but is also immune to the torsional oscillation of a DFIG wind turbine. However, the reactive power modulation introduces terminal voltage oscillation. Besides, POD tuning schemes using the particle swarm optimization [5] and the modal analysis [6] based on an enhancement of the damping ratio of the oscillation modes have been presented. To augment the robustness of POD against system uncertainties such as various generating and loading conditions, system parameter variation, unpredictable network structure, etc., optimal tuning methods of POD by mixed H 2/H ∞ [9] have been presented.

The robust decentralized POD design based on the enhancement of the system robust stability margin using the inverse multiplicative perturbation is presented in Ref. [98]. Study results in Refs. [4,5] not only confirm the damping performance but also guarantee the robustness of the designed POD. In [9], the coordinated GSC and RSC controls are proposed to enlarge the system stability margin. The GRC is controlled as a static synchronous compensator (STATCOM) to contribute reactive power support during system faults. Besides, the POD is installed in the RSC control loop to damp out the following oscillation. The design techniques in Refs [93–99] are conducted in the linear system model at one operating state while the control effect of the designed PODs is evaluated at various operating states. Some research works have proposed an adaptive POD control design to enable a DFIG wind turbine to robustly operate under various conditions. In Ref. [100], a second-order sliding-modebased POD for a DFIG wind farm is proposed to modulate its output reactive power for inter-area oscillation damping. With a high degree robustness to system uncertainties and system unmolded dynamics, this POD can improve the grid stability over a wide range of operating conditions and system parameters. In Ref. [10], an adaptive decentralized-coordinated multiple model predictive control for the RSC of DFIG is proposed to cope with the nonlinearities and wide operating range. System damping and transient stability enhancement are confirmed. The POD in the reactive power control loop is also employed to eliminate the SSR oscillation. In Ref. [12], SSR mitigation by the DFIG with POD in nearby steam turbine generator with N multi-mass shaft parts and series capacitor compensation was carried out. The POD also comprised N channels, and the input signal of the ith control channel was the speed deviation of the ith shaft part. The parameter optimization of each channel of the POD was conducted based on the minimization of the speed deviation of the turbine generator rotating mass. In Ref. [13], a POD based on fuzzy logic control was presented to alleviate SSR in the system with DFIG wind turbine and series capacitor compensation. The fuzzy-logic-based POD showed superior stabilizing performance over a wide range of operating conditions to the POD optimized with one operating condition.

In Ref. [8], coordinated PODs in the reactive power control loop of DFIG and HVDC onshore modular multilevel converter of offshore wind farms are presented for mitigating subsynchronous interaction between DFIG wind farms. The POD parameters based on the second-order lead/lag compensator were optimized by the tuning method. In Ref. [10], the adaptive gain-scheduling method is used to optimize the POD parameter considering an optimal input control signal for SSR damping in a series-compensated DFIG wind farm. The proposed adaptive POD is less affected by the change of system dynamics in comparison with the POD deigned from only one operating point. Comprehensive reviews of SSR analysis and control of DFIG wind turbines can be found in Refs. [7]

The coordinated POD and conventional stabilizing devices such as PSS and flexible AC transmission systems (FACTS) devices for power oscillation damping have been studied. In Ref. [10], the coordinated POD and PSS with parameter optimization considering wind power output variation was considered by the extended probabilistic small-signal stability analysis. In Ref. [8] the optimal tuning of POD and PSS taking damping effect and robustness against system uncertainties into account was carried out. Furthermore, the coordinated DFIG with POD and static var compensator [9] and phase imbalanced series capacitive compensation [11] were presented.

III. PROPOSED METHODOLGY

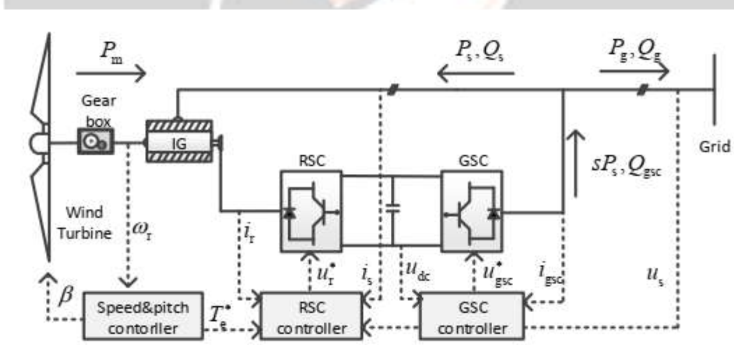

Fig.3. Schematic diagram of DFIG

Fig 3 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. 4. 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.

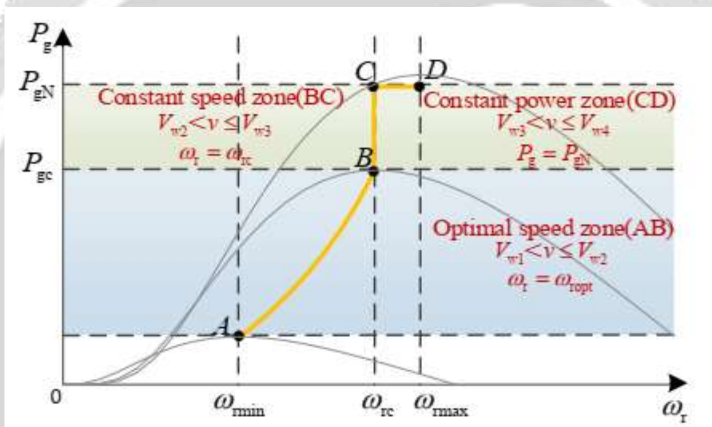

Fig. 4. Power characteristics of DFIG

Fig.5 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.

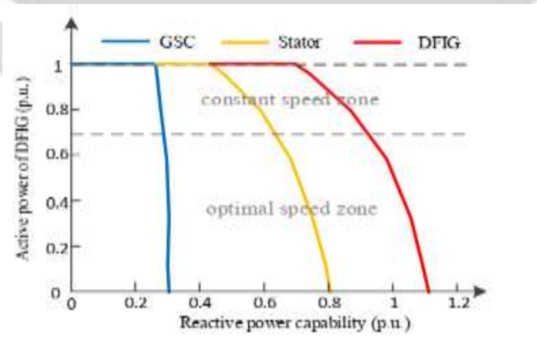

Fig. 5. Reactive power capability of DFIG

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.

IV. CONCLUSION

Various methodologies for analyzing the impact of DFIG wind turbines on system dynamic performance, like frequency stability and voltage stability, were discussed in this research. The DFIG's advanced grid service support control techniques, such as voltage control and power oscillations damping, have been disclosed. As per the co-constraints of DFIG active and reactive powers, an idea and approach for active voltage regulation under wind speed fluctuations is given. The APV's stability is increased by active reactive power benchmark value change, active speed management, & active pitch angle management throughout a wide range of wind speeds. By integrating the active and reactive controls of the wind turbine, an active voltage control approach is provided. The DFIG's voltage control capability can be increasingly employed and explored. Wind speed oscillations on transmission line voltage can be greatly reduced, providing efficient safeguards for the planning and design of substantial renewable energy projects.

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