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A Novel Method Control Sub Synchronous of DFIG Wind Turbine in a Power Grid

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ABSTRACT

Wind energy systems have numerous benefits, including simplicity in installation, high performance, and flexibility. However, one of the largest challenges in such systems is the occurrence of sub-synchronous oscillations (SSOs), which largely degrade power grid stability. This study examines recent advances in SSO mitigation techniques for Doubly-Fed Induction Generator (DFIG)-based wind energy systems, the most widely used emulated technology in recent wind turbines. Various control methods, such as intelligent controllers, adaptive control systems, and predictive models, are explained. Simulation experiments performed using MATLAB/Simulink software confirm the effectiveness of the suggested Direct Current Vector (DCV) control method to suppress SSOs as well as improve overall system performance. Apart from presenting current issues and research voids, the initiative here also emphasizes the imperative importance of sustaining research aimed at developing viable SSO mitigative techniques for grid-connected wind power systems. The results demonstrate that the implementation of advanced technologies and smart control strategies is a salient aspect of suppressing sub-synchronous oscillations and the operational efficacy of wind power systems.

1. Introduction

Wind energy has emerged as a significant alternative renewable energy due to its environmental benefits, sustainability, and increasing cost-effectiveness. Among all the technologies of wind turbines, Dual-Fed Induction Generator (DFIG) turbines have been used most widely in large-scale installations in Europe and North America. The advantages of DFIG are that it can extract the maximum power from changing wind conditions, reduce mechanical stress on turbine components, minimize noise, and provide independent control of active and reactive power for better integration into the grid [2,4].

Though these advantages exist, the behavior of DFIG wind turbines is highly dependent on the control strategy, especially in variable wind conditions. Classical vector control methods, used over a decade, reflect disadvantages whenever the system operates beyond the linear modulation limits of the converters [5]. Specifically, traditional control is parameter-uncertainty-sensitive and can induce SSOs, which have the potential to destabilize the power grid, create harmonics, and decrease turbine efficiency [9,10].

The new literature has highlighted the need for advanced control methods that are capable of overcoming such drawbacks. Intelligent and adaptive controllers and predictive control methods, for example, have been proposed to overcome SSOs and improve stability [8,12]. However, seemingly a gap still remains in finding a link between the advanced methods and the direct current vector control method that offers improved decoupling of d/q-axis currents, improved transient response, and improved voltage regulation at the DC link [16].

This essay presents a DCV-based control strategy for DFIG wind turbines and offers an integrated system with:

Maximum power extraction control; for optimal turbine speed and power.

Reactive power control; for maintain and increase voltage stability.

Grid voltage support control; for compensation against voltage sag or fluctuation.

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The balance of this paper is structured as below: Section II depicts the generic structure of a DFIG system. Section III presents the control topology, both rotor-side (RSC) and grid-side converters (GSC). Section IV presents the DCV approach and its advantages compared to conventional vector control. Section V describes integration of RSC and GSC controls for achieving the desired objectives. Section VI addresses modeling and simulation situations with wind variability. Finally, Section VII discusses results, evaluation, and conclusions, including suggested future work.
Relevance of Research:
Grid stability: SSOs tend to undermine grid stability, resulting in blackouts or equipment faults.
Renewable energy optimization: Proper regulation of DFIG systems optimizes the harvesting of wind energy and system stability.
Technological advancement: Enhanced control methods can lead to emergent algorithms and uses in the area of renewable energy.
Environmental advantages: Reliable and effective wind power systems help lower environmental effects and sustainable energy consumption.

2. System Modelling

Mathematical modeling and dynamic simulation of DFIG wind turbines are required for performance analysis and sub-synchronous oscillation (SSO) control of the former. The modeling process typically comprises the following three steps:

2.1. Mathematical modeling and dynamic simulation: The DFIG system is developed in MATLAB/Simulink, where dynamic simulation can be achieved with various wind and grid conditions. The induction generator, power converters, DC link, and turbine dynamics are included in the model. The dynamics of SSOs with the power grid structure as a whole have been given special attention because these oscillations have a significant effect on system stability [2,4].

2.2. Control strategy development: Various control strategies like fuzzy logic controllers, PI/PID controllers, and intelligent/adaptive controllers are considered. Control strategies are directed towards the minimization of SSOs, maximum wind energy capture, and regulation of reactive power and DC link voltage. Most appropriate control strategies are selected through stability analysis and numerical simulations.

3. Simulation and analysis

Developed models are validated with numerical simulations to compare the performance of the control approaches. Simulation results are analyzed to understand the effectiveness of control methods to alleviate SSOs, voltage and power stabilization, and improve the overall turbine performance. Statistical techniques are used for comparing different approaches and identifying patterns or correlations in data.

4. DFIG System Parts

There are three basic parts in a standard DFIG wind turbine:

- **Rotating Wind Turbine:** The turbine blades capture the kinetic energy from the wind and transfer it to the rotor via a gearbox.
- **Induction Generator:** The generator converts mechanical energy to electrical energy. The stator windings supply the grid directly, while the rotor windings supply through a rotor-side frequency converter.
- **Electronic Power Converter:** Two voltage converters of voltage sources are encompassed within it: The Rotor-Side Converter (RSC) and the Grid-Side Converter (GSC), which are common to a DC link (Figure 1) [2,4]. Figure 1 illuminates Schematic of a typical DFIG wind turbine.

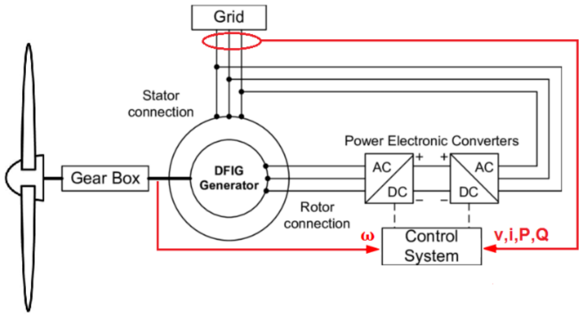

Fig. 1. Schematic for a doubly-fed induction generator

5. DFIG Control Structure

Control structure of a DFIG wind turbine comprises three main components:

- **Generator Control:**
  - The RSC regulates the rotor currents to provide maximum active power harvesting and reactive power regulation.
  - GSC provides constant DC link voltage and reactive power supply to the grid.
- **Turbine Control:**
  - **A speed controller** delivers optimal speed of rotation for peak power at low wind speed.
  - **A power limiter** limits blade pitch angle at high wind speed to prevent over nominal turbine power.
- **Wind Farm Control:**
  - **A central control system** allocates power setpoints to individual turbines as per grid demand. Local turbine controllers ensure that each turbine follows the reference power accurately.

- **GSC Vector Control and Direct Current Vector Control (DCV)**

The GSC regulates the DC link voltage and supports reactive power control or grid voltage support. Two main approaches are available:

- **A) Transient and Stable Mode GSC Models.**
- The GSC model is integrated with a DC link capacitor and a three-phase voltage source representing the Point of Common Coupling (PCC) with the AC grid (Figure 2).
- The dq reference frame (Park transformation) voltage and current vectors are used for controlling active and reactive power exchange between the grid and the DFIG system.

Table 1. Simulation Parameters of the DFIG System

Parameter	Symbol	Value	Unit
Rated Power of DFIG	PratedP	2.0	MW
Stator Voltage (line-line, rms)	Vs	690	V
Grid Frequency	f	50	Hz
DC Link Reference Voltage	Vdc	1500	V
Filter Resistance	RfR	0.01	p.u.
Filter Inductance	Lf	0.15	p.u. (~2 mH)
RSC Proportional Gain	Kp,RSC	0.2	–
RSC Integral Gain	Ki,RSC	50	–
GSC Proportional Gain	GSC	0.3	–
GSC Integral Gain	GSC	40	–
Switching Frequency of Converters	fsw	1980	Hz
Wind Speed Range (simulations)	vwv	8 – 10	m/s

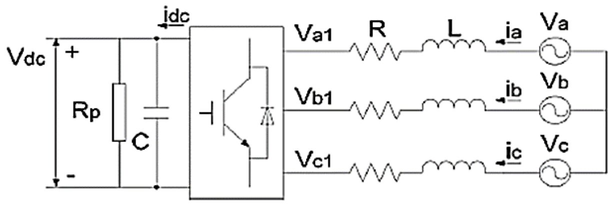

Fig. 2. Grid-connected converter schematic.

In the dq Voltage Balanced Grid coordinate system as:

$$\begin{bmatrix} v_d \\ v_q \end{bmatrix} = R_f \begin{bmatrix} i_d \\ i_q \end{bmatrix} + L_f \frac{d}{dt} \begin{bmatrix} i_d \\ i_q \end{bmatrix} + \omega_s L_f \begin{bmatrix} -i_q \\ i_d \end{bmatrix} + \begin{bmatrix} v_{d1} \\ v_{q1} \end{bmatrix} \quad (1)$$

Ws are angular voltage frequency of the filter network (PCC), Lf, Rf, inductance and recitation. With the Vdq spatial vector, and Vdq1, the spatial vector of PCC voltage, the line current and the output voltage of the converter are given.

In the steady state, equations 2 and 3 with Vdq, Idq, and Vdq1 as for permanent state space vectors of PCC voltage, network current, and converter output voltage.

$$v_{dq} = R_f \cdot i_{dq} + L_f \frac{d}{dt} i_{dq} + j\omega_s L_f \cdot i_{dq} + v_{dq1} \quad (2)$$

$$V_{dq} = R_f \cdot I_{dq} + j\omega_s L_f \cdot I_{dq} + V_{dq1}. \quad (3)$$

In the PCC convergent model of [3] and [11], the active and reactive energies for a limited time are supplied from the grid by the GSC proportionally to the grid dq axis currents, which are represented as follows by (4) and (5):

$$p(t) = v_d i_d + v_q i_q = v_d i_d \quad (4)$$

$$q(t) = v_q i_d - v_d i_q = -v_d i_q \quad (5)$$

Under some stable state conditions, Vdq=VD+j0 is valid if it is on the d-axis of the reference frame on the voltage Pcc. For any network filter resistance, assuming Vdq=Vd+jVq, then the current from PCC to GSC according to (3) is expressed as follows:

$$I_{dq} = (V_d - V_{d1})/(jX_f) - V_{q1}/X_f \quad (6)$$

That's the XF Reactance Network Filter. Supposing that the power is passing positively in the direction of GSC, then the power is being consumed by GSC in the PCC as presented below:

$$P_{\text{conv}} = -V_d V_{q1}/X_f, Q_{\text{conv}} = V_d(V_d - V_{d1})/X_f \quad (7)$$

B) GSC Control Degree:

The conventional vector control method of GSC is constant internal current loop type with a slow outer loop as presented in Figure 3. It is used in [3], [4], and [11] where d-axis loop is utilized to control the DC link voltage and the q-axis loop is used. It is used for controlling the reactive power or supporting the grid voltage. The strategy of the inner loop of the current of the present moment has been developed by rewriting:

$$v_{d1} = -\left(Ri_d + L \cdot \frac{di_d}{dt}\right) + \omega_s L i_q + v_d \quad (8)$$

$$v_{q1} = -\left(Ri_q + L \cdot \frac{di_q}{dt}\right) - \omega_s L i_d \quad (9)$$

Here, the yarn material of the crochet as the input voltage and output current transfer function of the d and q rings and the rest of the relations as compensators are utilized regarding references.

These assumptions verify that Vd1 does not affect Iq (8) and Vq1 on Iq (9) does not affect Id.

But a lacking assumption is described below. From Figure 3, voltages Vd1 and Vdq are linear in proportion to the output voltages of the Vd1 and Vq1 converter, such as the Vdq voltages, are produced by the current loop controllers along with the compensating components displayed in relation (10).
Therefore, the location of this control tries to control Id and Iq through Vq and Vd, consequently. However, from (7), (4) and (5), d axis voltage has an effect only for reactive power or Id control, and the q axis voltage has an effect only for active power or Id control. So, the use of the standard control mechanism is mainly mixed with the compensatory terms of PI loops. It competes to control the D and Q axis currents by a control mechanism. But compensating components will not be used in the control principle.

$$v_{d1}^{*} = -v_d' + \omega_s L_f i_q + v_d$$
$$v_{q1}^{*} = -v_q' - \omega_s L_f i_d \quad (10)$$

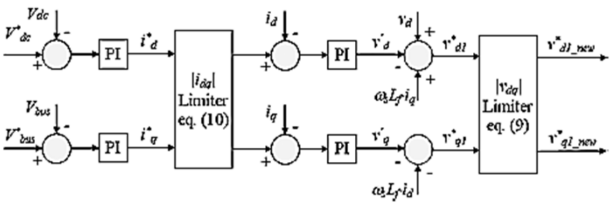

Fig. 3. Conventional standard GSC vector control structure

The following are the common things that are taken into account while designing a nested loop control system:
1. To prevent the transducer from going into nonlinear modulation mode, a saturation mechanism is provided on the output voltage controller. This is with the assumption that the reference voltage provided by the internal current loop controller limits the linear modulation of the transducer.
2. In order to prevent the GSC from being greater than the nominal current relative to the reference current, the q-axis should be controlled such that when the range of the reference current from the outer control loop is greater than the nominal current. The common method of keeping the id on the boundary of the reference current is to keep the DC link voltage constant. To the extent possible, as mentioned in references.

$$i_{d\_\text{new}}^{*} = i_d^{*} i_{q\_\text{new}}^{*} = \text{sign}(i_q^{*}) \cdot \sqrt{\left(i_{dq-\max}^{*}\right)^2 - (i_d^{*})^2} \quad (\mathbf{11})$$

6. Straight Control of GSC:

The theoretical basis of the current vector direct control method for GSP is equations (4) and (5), i.e., by using the d and q axis currents as control variables to regulate the active and reactive power.
However, unlike the conventional method of obtaining d or q axis voltage from a GSC current loop controller, the output of the current vector direct control is a d and q current signal of the current loop controller. That is, the output of the controller is the d and q current.
While the fault indication of input notifies the controller about the quantity of regulatory current to inject during dynamic control. Implementations of traditional intelligent control principles are the ones that advance the idea of regulatory current control strategy. For example, vector control aims at diminishing the effective value (RMS) caused by the deviation between the actual and theoretical values of current. The d-axis and q-axis are controlled by a regulating system. This regulating current is different from the actual measured d and q current. For example, for a reference d-axis current, the regulating process continues till the actual d-axis current is converted into the d-axis reference current. Reach. It can be noted that a fast-current loop controller is vastly important in GSC to enhance the quality of power during imbalances and harmonics. Therefore, eliminating the current loop cannot be done in the proposed current control design. But due to the character of the voltage source converter of the d and q-axis regulatory current signals generated by the current loop controllers, the d and q axis voltage signals need to be switched to Vd1 and Vq1 to control the GSC. It is achieved through design (12). dq's transitive equation (1) is applied directly to the converter by a low-pass filter upon process start-up for the purpose of removing the high DQ reference voltage oscillation.

$$v_{d1}^{*} = -R_f i_d' + \omega_s L_f i_q' + v_d$$
$$v_{q1}^{*} = -R_f i_q' - \omega_s L_f i_d' \quad (12)$$

The overall configuration of the GSC control is shown by Figure 4. It consists of a D-axis ring to control the DC link voltage and a Q-axis ring to control the reactive power and control the network voltage support.

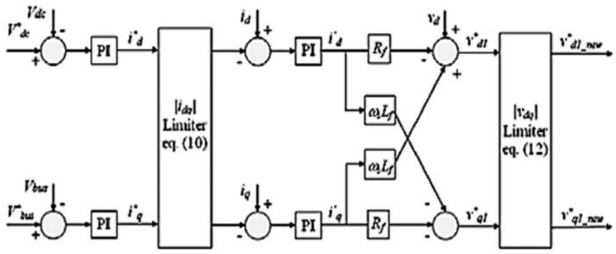

Fig. 4. GSC dc vector control structure

Signal processing technique, DC link voltage measured, and d- and q-axis currents will be utilized to inhibit the harmonics of the internal controllers from escalating. Adaptive and fuzzy PI control technologies can be employed by the current loop controller for the improvement of the GSC dynamic performance. The PI component of the controllers functions based on a direct target control. Adaptive and Fuzzy Parts of Controllers PI Parameters It is tuned based on error between controlled variable and set point and rate of change of errors.[13].The initial PI controllers' values are chosen based on simple intelligent control principles, e.g. by minimizing the effective value (rms) error between the reference value and the measured value.

In addition, the nonlinear programmed strategy is carried out as provided below. it is used to prevent the nominal current from saturating by GSC and to block the transducer from going into nonlinear modelling. Ironed is the rms nominal GSC phase flow and Q(GSC) is the reference reactive power drawn by the network from the GSC. The basic principles of developing nonlinear programming in the nominal GSC flow are and the system linear modulation constraints work well to supply the DC link voltage control. Reducing the difference between the actual and the reference reactive power as much as possible is as follows:

$$\begin{aligned} &\text{Minimize} : |Q_{\mathrm{GSC}} - Q^*_{\mathrm{GSC}}| \\ &\text{Subject to} : V_{\mathrm{dc}} = V^*_{\mathrm{dc}},\ \sqrt{(I_d^2 + I_q^2)/3} \le I_{\mathrm{rated}}, \\ &\qquad \sqrt{(V_{d1}^2 + V_{q1}^2)/3} \le V_{\mathrm{dc}}/(2\sqrt{2}). \end{aligned} \quad (13)$$

The nonlinear programming method is implemented as follows. In case the output from the $\left|{i_{dq}}^*\right|$DC link and reactive power control loops is higher than the rated current, the reference Iq and ID are regulated by (11). In case the output from the internal current control loops is higher than the transducer linear modulation, the voltages $\left|{V_{dq1}}^*\right|$of the d and q axis are decided by (14).

$$v^*_{d1_{\text{new}}} = \text{sign}(v^*_{d1}) \cdot \sqrt{\left(v^*_{dq1_{\max}}\right)^2 - \left(v^*_{q1}\right)^2} \quad v^*_{q1_{\text{new}}} = v^*_{q1} \quad (14)$$

As can be seen, the recalculating of the q-axis control voltage will be the same, in order for the q-axis control loop not to be affected. Thus, according to (7) the active power or the DC link performance will be maintained. Yet, the re-computation of the d-axis control voltage won't follow the control voltage generated by the d-axis current loop controller is affected.

7. Section VI: RSC for DFIG Speed Control and Reactive Power Control

The RSC controls are for DFIG wind turbine induction generators for energy harvesting, and the GSC is for reactive power control or backup voltage control of the DFIG system as a whole.

The control is realized through a nested loop structure with an inner current loop and an outer reactive power output and speed. similar GSC, the requirement of the current control loop RSC isn't a choice in this paper so as to enhance the power quality when there is an unbalanced and harmonic DFIG.

Fig. 5 shows the standard form of RSC control with a convergent stator flux frame. [2]-[6] DC control is not utilized because the electrical frequency of the rotor close to the synchronous speed tends to zero. In the reference mode, the speed is generated on the basis of the extraction of the maximum power. While the power reference is generated on the basis of the reactive power requirement of the wind power plant, along with the coordination of the reactive power control with the GSC. The reactive power reference is directed to the current reference of the d-axis of the rotor. Through a reactive power controller and the torque reference is transmitted to the q-axis current reference of the rotor by the produced speed controller.

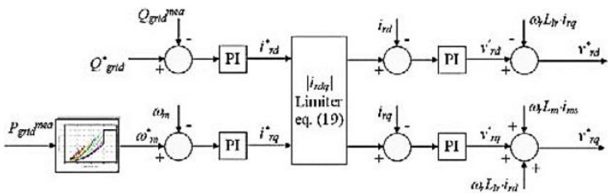

Fig. 5. DFIG speed and reactive power control structure of RSC.

There are current loop controllers present which generate d- axis and q-axis voltages based on the fault signals between the reference current and the current of the d and q axis. The final voltage control of the d and q axis includes the dq axis voltage which is from the Vrd and Vrq current loop controllers, as well as the compensated items shown in Figure 5. If the reference current range generated by the output torque and the reactive power ring control is larger than the nominal current of the rotor, it is controlled from the relationship (15). In fact, (15) is a direction control rule without changing the IRQ to continue using wind power, whereas for reactive power control the requirement The Ird is offset as much as possible. RSC is not an issue that fundamentally occurs in the normal speed range of DFIG.[19]

$$i^*_{rd_{\text{new}}} = \text{sign}(i^*_{rd}) \cdot \sqrt{\left(i^*_{rdq}\right)^2 - \left(i^*_{rq}\right)^2} \quad i^*_{rq_{\text{new}}} = i^*_{rq} \quad (15)$$

8. RCS and GSC regulate integration of wind turbines

Important requirements of control of DFIG wind turbines are:

1) Maximum extraction of wind power control
2) Control of reactive power
3) Grid backup voltage control

A: Control Extract had greater iPad

For a given wind speed, regarding references the objective of maximum wind power extraction is to regulate the rotor speed of the turbine to an optimal speed.
This reference power of speed is fed back to the speed loop controller until the maximum power drawn is equal to the speed point.

B :Control Tuan Ratio

Both RSC and GSC, as unveiled in Sections 3 and 5, can engage in reactive power control. The configuration of a reactive power control mechanism in the current vector direct control structure has the following methods:
1. The GSC support is encompassed in the desired reactive power control, and the RSC provides the rest of the required reactive power control.
2. The role of the GCS control is to keep constant the reactive power production, while the role of the RSC control is to keep constant the overall reactive power generation of the wind turbine in accordance with the reactive power requirement of the grid. 3. In case the GSC is at its physical limits, with respect to the power transfer from the rotor of DFIG to the grid via GSC, the transducer operation will be through sustaining the constant DC voltage link, which is of the highest priority. Reactive power control demand is addressed as much as possible, as discussed in Section 6 c. In such a scenario, the reactive power is absorbed by GSC, so that RSC has to absorb reactive power for both, i.e. GSC. and produce the required reactive power of the wind power plant. Control mechanism cannot be applicable for the conventional GSC control structure. (Figure 3) The results can be seen in high and unbalanced fluctuations due to the nature of the control complexity in the third part.

C: GSC and RSC control with wind change

In AC power systems, faults often cause a voltage drop at the Point of Common Coupling (PCC). Similar to conventional synchronous generators, a DFIG-based wind turbine must be capable of supporting the PCC voltage during such events. The GSC operates like a STATCOM, providing reactive power to stabilize the voltage. The Rotor-Side Converter (RSC) complements the GSC to meet the remaining reactive power requirements.
Under the direct current vector control (DCV) strategy:

1) The GSC provides maximum reactive power support while maintaining the DC link voltage as the main precession.
2) The RSC supplies the remaining reactive power needed to stabilize the PCC voltage.
3) If either GSC or RSC reaches its physical limitations, DC link voltage control remains the highest priority, while RSC ensures maximum power extraction is maintained.

Using conventional GSC control, the voltage support loop reacts slower than the RSC, which can lead to excessive linear modulation and stability issues. In contrast, the DCV method ensures faster response and superior adaptability to dynamic grid conditions.

9. Comparison and Evaluation of Control Strategies

In order to compare and contrast peak power tracking, reactive power regulation, and PCC voltage support, comprehensive power converter and switching models were employed to execute a transient simulation of the DFIG system. Steady-state operating conditions in addition to wind fluctuations were addressed.
Two models were utilized:
1) Average model: For preliminary analysis for performance.
2) Mean switching model: For realistic and detailed simulation with converter losses along with DC link capacitor effects.
The system parameters such as grid impedance, equivalent impedance, and the converter switching frequency of 1980 Hz are provided in Table1. The simulations consider 100 identical wind turbines under the same operating conditions [22,23].

A: Reactive Power Control and Peak Power Tracking

in steady wind conditions using conventional and DCV methods are presented in Figures 7 and 8. The following findings are noteworthy:

- At 7 m/s wind speed and reference of reactive power at 0 kV, the turbine output is close to maximum extractable power (Figures 7b, 8b).
- DC link voltage settles at a level of 1500 V reference (Figures 7d, 8d).
- With fluctuations in grid reactive power demand (for example, -200 kV at t=5 s), the DFIG system responds instantly, with minimal impact on rotor currents and generator speed (Figures 7a–f, 8a–f).

  The DC vector control method offers faster DC link voltage stabilization and reactive power follow up compared to conventional control.

B: Peak Power Tracking and PCC Voltage Backup Control

In backup voltage control, the dq-axis currents of the GSC are dynamically controlled to avoid over modulation.

- The DC vector control method offers faster DC link voltage stabilization and reactive power follow up compared to conventional control.
- In backup voltage control, the dq-axis currents of the GSC are dynamically controlled to avoid over modulation Conventional GSC control

requires slower PI adjustments to stabilize the DC link during voltage drops.

- In contrast, DC vector control maintains PI coefficients constant, allowing faster adaptation under varying conditions.
- Figures 9-12 demonstrate the system performance under high and low PCC voltage drops.
- Under a moderate voltage drop, DCV ensures smooth tracking of peak power, DC link voltage, and PCC voltage backup. Conventional control shows greater DC link fluctuations, especially when GSC output reaches linear modulation limits.

C: Impact of Wind Variations

Wind speed fluctuations are modeled using a stochastic approach:

The DCV-based integrated control of GSC and RSC adapts effectively to changes from 8 m/s to 10 m/s, maintaining maximum power extraction, reactive power regulation, and DC link stability. Conventional methods fail to respond adequately to rapid wind changes, leading to voltage deviations and suboptimal

In fact, the wind speed is constantly changing over time, and during a period of less than an hour, the wind speed can be approximate as follows:

$$v_w(t) = V_w + \sum_{i=1}^{N} A_i \cos(\omega_i t + \phi_i) \qquad (16)$$

In (16) ω_i is a random variable described by (17)

$$S_{vv}(\omega_i) = \frac{0.475\sigma^2 \left(\frac{L}{V_w}\right)}{\left[1 + \left(\frac{\omega_i L}{V_w}\right)^2\right]^{\frac{5}{6}}} \qquad (17)$$

$$A_i(\omega_i) = \sqrt{\left(S_{vv}(\omega_i) + S_{vv}(\omega_{i+1})\right)(\omega_{i+1} - \omega_i)} \qquad (18)$$

Using (17) and (18) under the conditions of the generated winds, as shown in Figure 13, we can see that before t=4ms, the wind speed is equal to 8 m/s. Wind blowing starts at t=4s with a speed of 8 m/s in Figures 14 and 16 Comparison of the GSC and RSC integrity control performance for peak power tracking and reactive power regulation using the proposed and conventional control methods under changing wind conditions. Even after applying the same conditions it is shown in Figures 7 and 8. Due to wind speed variations, the maximum available power that can be produced by a DFIG wind turbine is changing. However, we obtain optimal turbine speed and output power with the peak power control strategy benefit table. Sub synchronous oscillation control of wind turbine systems using dual-feed induction generator (DFIG) is extremely significant research as a basic issue in the field of renewable energy and power grids. Sub synchronous fluctuations can be detrimental to the stability of the network and the performance of the equipment. Due to the increase in the exploitation of wind energy resources, the need to implement and advance control strategies to manage these fluctuations is more felt than ever.

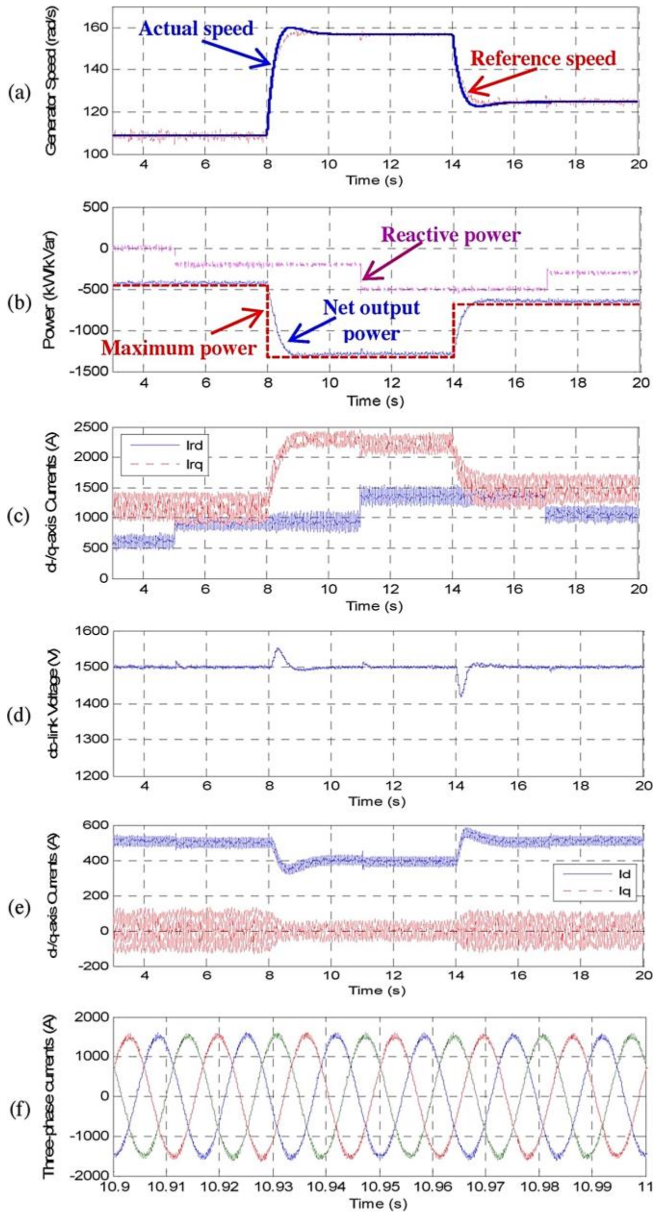

Fig. 7. GSC and RSC for maximum power extraction and reactive power controls using conventional control method (steady wind).

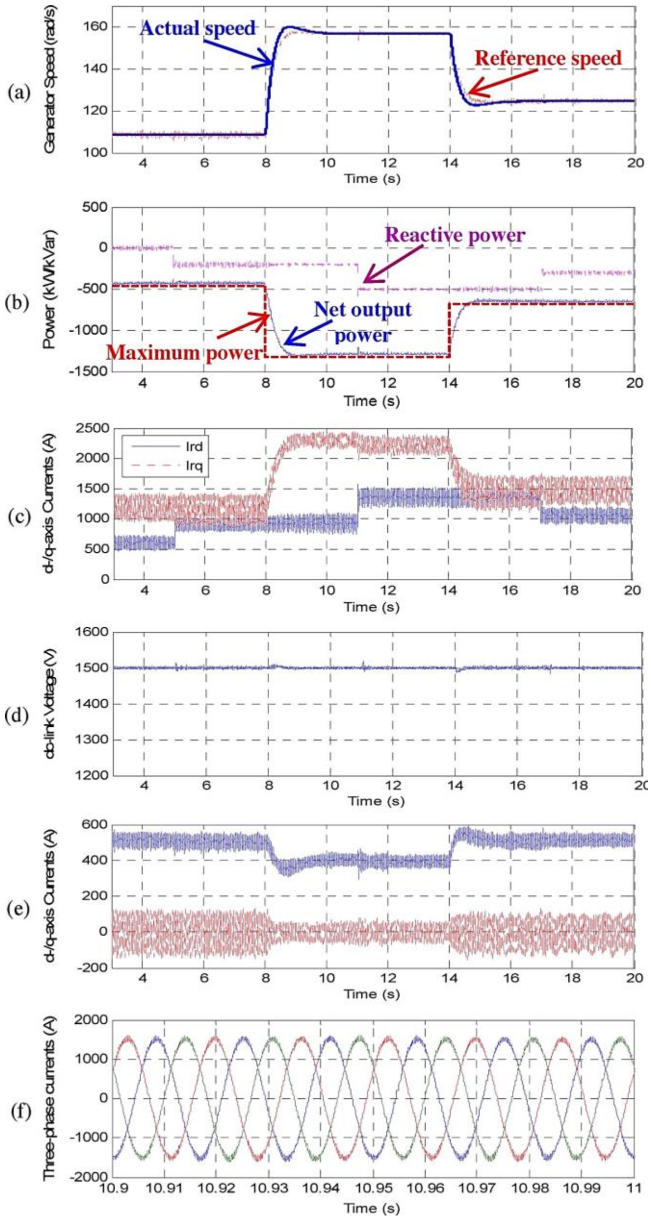

Fig. 8. GSC and RCS for maximum power extraction and reactive power controls using proposed control method (fixed speed wind)

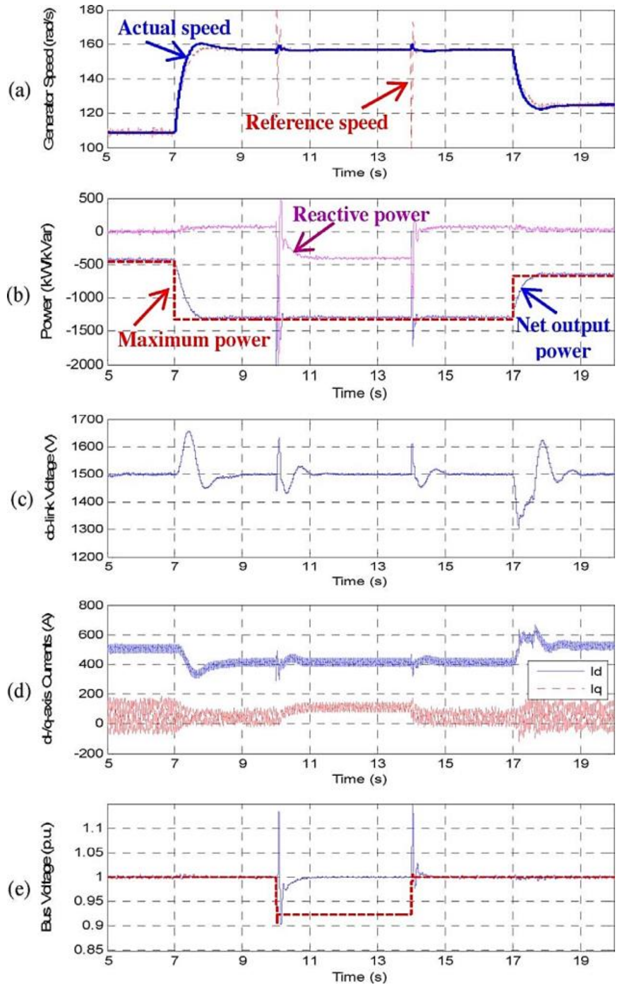

Fig. 9. GSC and RSC for maximum power extraction and voltage support controls during a low voltage droop (conventional approach).

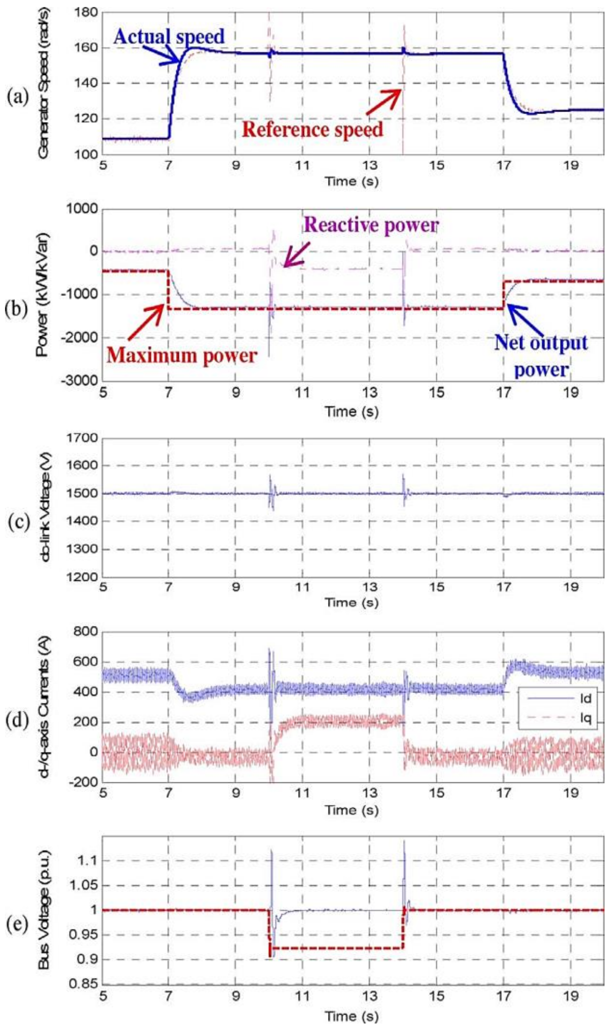

Fig. 10. GSC and RSC for maximum power extraction and voltage support controls during a low voltage droop (proposed approach).

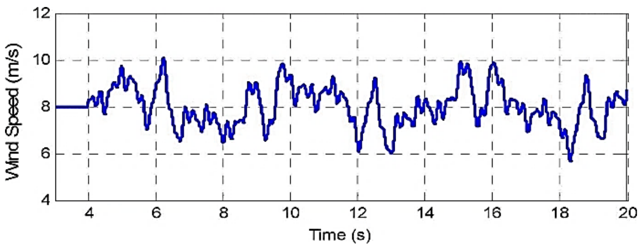

Fig. 11. Variation of wind speed pattern.

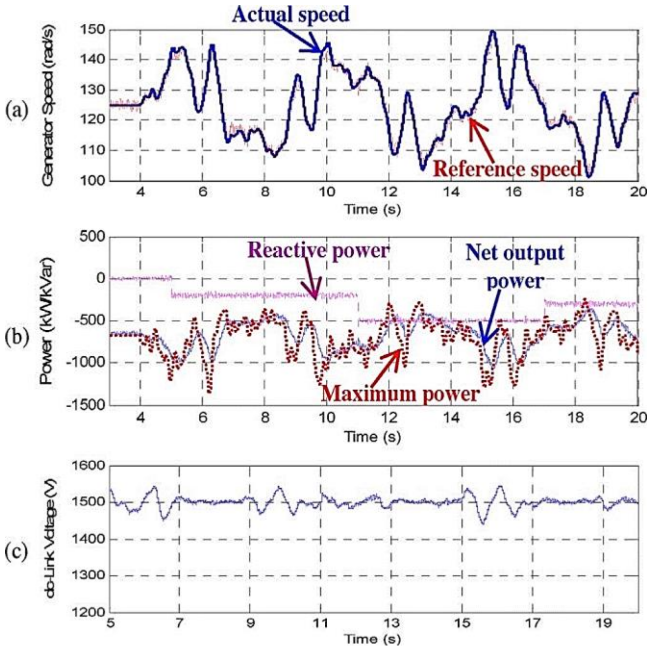

Fig. 12. Tracking of generator speed parameter when moderate voltage drop on the PCC bus occurs.

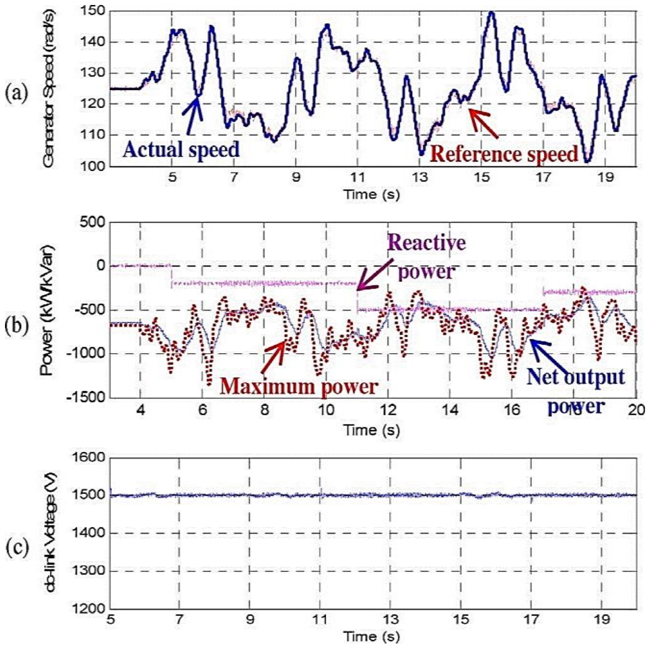

Fig. 13. The conditions of the changes in the winds produced

10. Conclusions

In this study, by the review of the literature at hand and the discussion of different control mechanisms, it was shown that the implementation of intelligent algorithms, fuzzy controllers, and other advanced methods can help in increasing stability and reducing sub synchronous oscillations. In addition, numerical simulations and dynamic modelling of DFIG systems have been effective as a proper way to appraise the effectiveness of control mechanisms.

The findings of the study indicate that with proper control methods and emerging technologies, it is possible to effectively dampen the sub synchronous oscillations and enhance the performance of wind systems. These findings not only advance science in this field, but also provide practical and effective solutions to grid operators and power sector decision-makers.

Overall, research in the discipline has to continue and include further research into optimizing and applying advanced control strategies, economic and environmental analysis, and the development of new communication standards among systems. This can help in the development of a more stable and efficient power grid.

One of the major issues with Wind power systems is subsynchronous oscillations that lead to interference in the stability of power grids. Subsynchronous oscillation control recently developed in DFIG-based wind systems is what this study examines and discusses various methods like intelligent controllers, adaptive controls, and prediction methods. The results show that the use of advanced technologies and advanced control techniques would help reduce subsynchronous oscillations and improve the performance of wind power systems. The paper not only enumerates challenges and opportunities, but also points out the necessity of future research on the subject. Simulink modellings cancel out the effectiveness of the proposed method.

11. References

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