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Advance Control strategies for DFIG Wind Turbines for Power System faults

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Abstract

Due to many benefits, including its tiny power converter rating, capacity to vary output power, etc. There is a significant amount of interest in wind energy conversion with variable frequency and a double fed induction generator (DFIG). The effect of the DFIG wind turbine on the electricity system's dynamic performance, particularly current consistency. Small-signal stability, frequency stability, transient stability, and dynamic stability, is discussed in detail in this work. The issue of conventional energy resources' shortage has been addressed to a great extent by wind energy systems. a controller for low voltage ride through (LVRT) that is enhancedmethod is the suggested course of action. It allows for the digital storage in the turbines of a fraction of the wind energy that has been captured during grid faults. The grids can acquire momentum and remaining energy, but the necessary levels of DC-link voltage and rotor current are maintained. In this research study, control methodologies adapted to wind energy systems are topically evaluated. The control method makes sure that the surplus inertia energy from the rotor after the network problem has been fixed, seamlessly discharged into the grid. The results show how well even without voltage control, a DFIG wind farm with voltage control can help a nearby static stalled wind turbines pass through some kind of grid fault. Any further ride through management techniques are being implemented by a dynamic stalled wind turbine. The suggested control approach can help maintain ongoing control of the DFIG's active and reactive power throughout grid disturbances. Additionally, as opposed to conventional crowbar security, the LVRT capabilities of the DFIG wind turbine are improved.

Keywords DFIG, LVRT, wind turbine, power oscillation damping, transient stability, voltage stability.

1. INTRODUCTION

Due to its availability, cleanliness and ability to be renewed, wind generating electricity has received a great deal of attention recently. Due to the use of wind turbines and doubly fed induction generators (DFIG), which consume significant voltage. Power ratings are rising [1]. Large wind farms are therefore being built or projected all over the world [2]. Most grid rules, up until five to six year ago, only allowed turbines to be disconnected from the grid when an aberrant voltages was noticed, they were not obliged to sustain the electricity supply during grid disturbances. With windy energy's capability in the electrical system having grown over time. When wind farm dispersion causes grid faults, there may be a sudden significant loss of power result in issues with the system's ability to regulate frequency and voltage, and in the most extreme case scenario, a system breakdown. As a result of the growing worry over the effects of wind energy on the dynamic behavior of the power system, penetration of wind energy over the past ten years. In essence, such grid rules advocate for a more responsible approach to communication network and operational behavior for wind power that is more in line with ordinary electricity production.

Both the wind turbine grid support capabilities as well as the faults ride-through capabilities, or their ability to provide other services to support the electrical grid, are highlighted in the specifications of of wind turbine. The electricity system must ensure reliable and secure grid stability operators must provide a variety of ancillary services, such as voltage control. The primary focus of faults ride-through capabilities is on designing the controlling the windmills to allow the wind farm may maintain network connectivity when a grid fault is occurring (e.g. short circuit faults). Adding windmills to the power system and its effects is dependent upon both

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the design of the wind farm control to meet grid requirement. Obviously, the technology of the wind turbine/wind farm determines its capability. This fact has prompted research into how well various wind turbine ideas can adhere to the demands of high-power system operators and challenging various wind turbine manufacturers. There is currently a lot of study being done around the world using model simulation studies to determine how systems disruptions affect wind turbines and ultimately the power system. Different countries have created distinctive solutions that have lessened the negative effects of extensive wind power integration on the dependability of power networks. The specifications of a wind turbine emphasize both the grid support capabilities and the faults ride-through capabilities, or their capacity to offer additional services to support the electrical system. Providers must offer a number of ancillary services, such voltage regulation, in order to maintain a stable and dependable grid. The capacity of wind energy to power the electrical system has increased over time. When grid failures are brought on by wind farm dispersion, there may be a sudden considerable loss of power that results in problems with the system's ability to manage frequency and voltage, and in the worst case, a system failure.

1.1 DFIG WIND TURBINE

The monitoring system and structural layout of the DFIG wind turbine are shown in Figure 1. Winding, while RSC and GSC are used to interconnect. The advantage of removing the rotors from the electrical grid is that the conversion produces 30% more energy than a wind farm [3]. As a result, converters and the harmonic filter are much less expensive. Additionally, the reduced converter size contributes to improved efficiency as well as decreased power loss. The distinguishing characteristic of a DFIG wind turbine is its capacity to control [4].

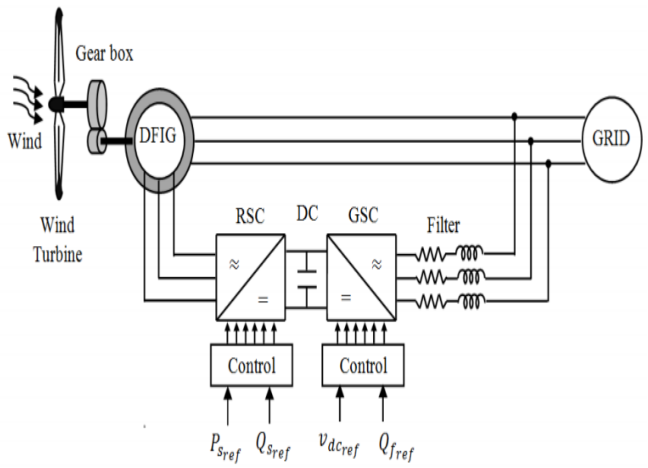

Figure 1: DFIG wind turbine

The controller output here, reducing oscillation in the electricity system is the primary control goal of a DFIG. According to the study's findings in, the regulation in the RSC dampens the oscillatory mode significantly more than it does in the GSC. The voltages operator's output voltage can be controlled using the direct-axis current (I dr) of the RSC. Reactive output power, the speed controller's active power output can be managed by the RSC's quadrature-axis current (I qr). Power factor correction is not necessary thanks to the DFIG's capacity to adjust reactive power production [5]. This capability avoids the need for the costly installations of reactive power balancing equipment while also supporting the DFIG terminal voltage during constant current and grid failures [6]. During and following a breakage, the rotor circuits are. Instead, it should be high enough to accommodate the rotor's greater voltage's potential limitations.

Reduced mechanical stress on the wind turbine as a result of its good energy utilization [7] (WT), and reasonably priced, generally low-voltage power technology converters. Among WT technologies, the doubly fed induction generator (DFIG) is frequently utilized. The windy power grid connections rules in the vast majority of nations mandate in order In order to sustain efficiency during and after a temporary fault, that WTs stay linked to the grid due to the growing of WT penetration into the grid [8]. Low-voltage ride-through (LVRT) capability refers to WT's capacity to maintain grid connectivity when voltage drops. In a failure scenario, there are two major challenges that must be successfully. Prior to five to six years ago, the majority of grid regulations only permitted disconnecting turbines from the grid when abnormal voltages were discovered; they were not required to maintain the electricity supply throughout grid faults. The energy system has the potential to use wind energy has improved over time. With reference to the constrained capabilities of such a system, the LVRT capacity of the DFIG WT is particularly pertinent. In comparison to the power electronics converters in the DFIG system operate at a comparatively low power level. Numerous experiments have been conducted to enhance the DFIG, WT's and LVRT capacity [9].

2. METHODOLOGY

The LVRT capabilities of the Doubly - fed induction generator wind turbine can be increased without the need of additional current and voltage safeguards, this research provides an inventive control method both for the rotor and grid side converter. The main concept is to boost the generator rotor speed throughout a grid voltage dip by properly controlling the rotor side converter. In contrast to standard approaches, the proposed control strategy is based on a straight forward idea to convert imbalanced energy into kinetic energy rather of letting it disperse naturally. This item reflects the power converter's Dc-change links in output. When comparing to the LVRT solution in [10].

2.1 Modeling of a DFIG wind turbine

Figure 2 depicts the schematic representation of a DFIG wind turbine system that is grid-connected. The management system, and the wind energy are all components of the system. A DC-chopper is inserted inside the DC-link to safeguard the converter and capacitors from overvoltage [11]. Both the grid-side conversion and the inducement generator's stator are concurrently linked to the grid. Two components make up the management system, one for WT and the other for DFIG. The management system, and the wind energy.

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When there are strong wind gusts, the WT will continue to run at its rated speed thanks to the control scheme the cut-off wind speeds are reached. Both active and reactive power output of the DFIG separately in accordance with the grid code mandated rotor reference speed and boost converter specifications is utilized in the study and simulations that follow [12].

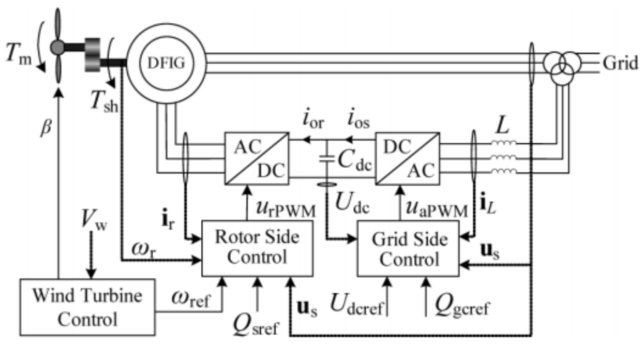

Figure 2: Schematic diagram of a DFIG WT system.

2.1.1 Generator

In a d-q reference frame revolving at constant speed, the voltage equations of the stator and rotor circuits of the induction generator can be obtained.

$$\begin{cases} u_{ds} = R_s i_{ds} - \omega_s \psi_{qs} + \dfrac{1}{\omega_b}\dfrac{d\psi_{ds}}{dt} \\ u_{qs} = R_s i_{qs} + \omega_s \psi_{ds} + \dfrac{1}{\omega_b}\dfrac{d\psi_{qs}}{dt} \\ u_{dr} = R_r i_{dr} - (\omega_s - \omega_r)\psi_{qr} + \dfrac{1}{\omega_b}\dfrac{d\psi_{dr}}{dt} \\ u_{qr} = R_r i_{qr} + (\omega_s - \omega_r)\psi_{dr} + \dfrac{1}{\omega_b}\dfrac{d\psi_{qr}}{dt} \end{cases}$$

where $\mathbf{i}_s = i_{ds} + j i_{qs}$ is the stator current vector

$\mathbf{i}_r = i_{dr} + j i_{qr}$ is the rotor current vectors

The base, stator, and rotor angular frequencies are denoted as _b, _s, and _r, accordingly.

2.1.2 B. Drive Train

The Doubly - fed induction generator WT's present constancy can only be determined using the double and of the drive train compared to the typical turbine generator shaft seen in conventional power plants, this shaft seems to be much gentler [2]. The two-mass model of the drive train is described by these formulas.

$$\frac{d\omega_r}{dt} = \frac{1}{2H_g}(T_{sh} - T_e - B\omega_r)$$
$$\frac{d\theta_t}{dt} = \omega_b(\omega_t - \omega_r)$$
$$\frac{d\omega_t}{dt} = \frac{1}{2H_t}(T_m - T_{sh})$$

where ω_t is the wind turbine speed. H_g and H_t are the generator and turbine inertia constants, respectively, the wind generator's torque input, are

$$T_e = L_m(i_{qs} i_{dr} - i_{ds} i_{qr})$$
$$T_{sh} = K_{sh}\theta_t + D_{sh}\omega_b(\omega_t - \omega_r)$$
$$T_m = \frac{0.5\rho\pi R^2 C_p(\lambda, \beta) V_w^3}{\omega_t}$$

where V w is the wind speed, C p is the power coefficient, R is the turbine radius, and is the pitch angle,are

$$C_p = 0.22\left(\frac{116}{\lambda_i} - 0.4\beta - 5\right)e^{-12.5/\lambda_i}$$
$$\lambda_i = \frac{1}{\dfrac{1}{(\lambda + 0.08\beta)} - \dfrac{0.035}{(\beta^3 + 1)}}$$

Where,C p (,) has a maximum value C pmax for the ideal tip speed ratio _"opt" and optimised pitch angle _"opt ", where =_t R/V w is the blade tip speed ratio. The best power-speed characteristics shown in Figure 2, By regulating the power speed, which corresponds to the maximum energy captured from the windy, the wind turbine is managed.

3. DFIG CONTROL SCHEMES

The commonly utilised DFIG conventional control technique produces an acceptable outcome for the system's robustness with a respectable settling time when simulating nonlinear management of a double-fed induction generator. The stator voltage reference frame is used for Grid Side Controller operations and parameters.

3.1 Crowbar Protection Mechanism

Power devices are utilized to manage a sequence of three-phase resistors in the crowbar system found in current wind turbines. When there is a DC-link overvoltage or overload on the rotor, the crowbar mechanism is engaged [13, 14]. Crowbar and DC choppers typically operate as follows: The DC rotor, which is likewise a collection of resistors controlled by a transistor, dissipates the unbalanced power of Pr and Pg. Crowbar security is the control technique that is most frequently used. When the two converters converter fails, it is shut off by the crowbar circuit, which is activated to lower the fault currents in the rotor circuit. It is distributed throughout the connectors of the rotor. Crowbar is a typical control approach that employs a number of external digital equipment, whereas the conventional control scheme To preserve the stability of the DFIG power system, only PI controllers are used and does not call for any further electronics installation.

The most frequently employed control method is crowbar security. The crowbar circuit, which is is engaged to reduce the fault currents in the rotor circuit while the rotor side converter is shut off through malfunctions. It is placed throughout the rotor's connections. As a result, the generator runs like a regular induction machine and takes generally, the chopper circuit and crowbar are used together. The chopping circuits wastes extra electricity from over DC [15].

By developing more sophisticated control algorithms for the rotor and grid side converters, several researchers have proposed novel ways to reduce the current flow [16, 17]. Moreover, several of these methods rely heavily on layout of the control settings with precision, which may have detrimental impacts on its resilience, and are too complex to execute in industrial applications.

3.2 Improved Control Scheme

The voltage level falls and the electricity production falls as a result of a brief or disconnecting issue in the electrical grid. When the mechanically power generated significantly, surplus electricity flows into the rotor and causes a spike in the rotor current. From a macro perspective, DFIG power systems obey the energy saving law [18]. If the sudden increase in current is too severe, Damage to the rotor windings and possibly other mechanical parts is possible. less industrial energy from the wind turbine must be generated in order to maintain the power balance in the DFIG system. This can be accomplished by changing the power control module in the rotor side microcontroller to a hybrid pattern, which will lessen the disparity between power supply and consumption. The following expression can be used to modify Pref in equation (23): (Suppose that the rotor speed is not at or over the angular limitations).

4. RESULTS AND DISCUSSION

4.1 Simulation Results

A straightforward test system comprised of a DFIG and a tiny transmitting system has been developed, as illustrated in Figure 3. The models described in Section 2.1 are the foundation of the DFIG system. A three-phase symmetrical fault, as depicted in Figure 3, occurs where the arrow points, generating voltage drops at the PCC bus. Each of the models used in the following simulations were constructed using common building components.The three strategy are:

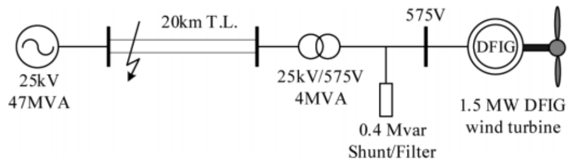

Figure 3: Single line chart of the test system

Strategy A: The proper safety system has a both a DC-link helicopter and a crowbar.
Strategy B: the RSC-only recommended control method.
Strategy C: The RSC and GSC's recommended control approach.
The DFIG WT has indeed been modelled using 3 alternative control algorithms to make comparisons while taking into account potential scenarios with various voltage dips. The capacity to support LVRT and reactive power is the main focus. The same control of reactive power method used in Strategy C is used to both Strategies A and B to ensure a fair assessment for all three approaches, and the rotor and stator electrical protection levels are both set to 1.7 p.u.Low voltage problems can last for 1723 milliseconds, 635 milliseconds, or 160 milliseconds, depending on whether the voltage drops by 47%, 87%, or 100%, respectively. In the aforementioned three conditions, In the aforementioned 3 conditions, the capacitive reactive current of WTs must be no less than 90% of the set capacity.

4.2 Result analysis on Low-Voltage Ride-Through Techniques.A radial link connects the transmitting level of the DFIG WT under investigation. The Supplement contains a list of the study's DFIG WT's characteristics, most of which are based on already-available data from various productions and literatures.

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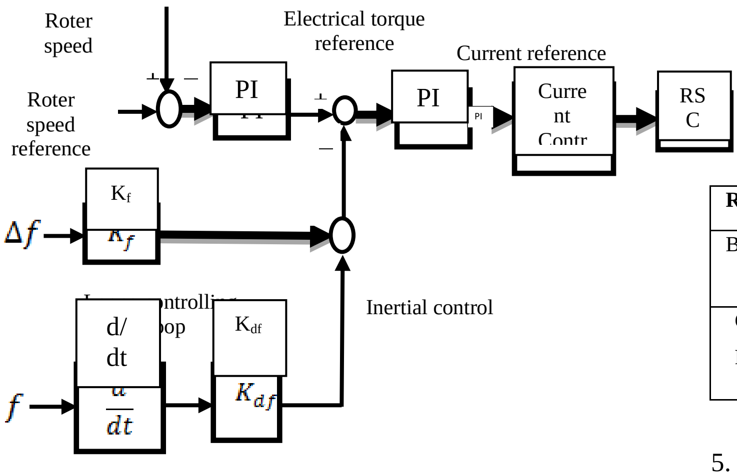
To examine their effects, three distinct LVRT control schemes are compared to how well the examined DFIG WT performed under various symmetrical three-phase short-circuit failures.Both the rotor and stator conventional protection thresholds. The detailed strategy for the crowbar protection is described in [19]. These grids standards essentially promote a more responsible strategy for communication networks and operational behavior for wind power that is more in line with standard electricity generation. Crowbar safety systems, which are made up of a DC chopper and a crowbar, are commonly used in a variety of energy systems. Additionally, when using crowbar, Output current will accumulate in large volumes and be gathered by doubly fed induction generator, which could have a negative influence on the grid. Another economic factor is the power dissipation in the DC oscillator and crowbar resistor [20]. The LVRT performance of the DFIG WT has been improved with the use of improved crowbar techniques based on the standard crowbar security [21]. The rotor converter's controllability despite the crowbar, a temporary loss of the DFIG active and reactive power occurs circuits' ability to safeguard the machines and the converters during faults. Additionally, using a crowbar and a chop saw actually adds extra hardware to the DFIG, which can raise prices and reduce system reliability doubly fed induction generator wind turbine's traditional inertial control system is shown in Figure 4.



Figu ind turbine inertial controls

4 **w Wind Conditions**

In the analysis that following, the transmitting electric grid is subjected to two usually a three short-circuit defects that cause the PCC value to decrease from 15% of its nominal voltage for 625 milliseconds to 0 for 150 milliseconds, accordingly [22]. The Voltage regulation capabilities is contrasted with the success of the conventional crowbar protection control approach A. With the control schemes C, the generating rotor speed accelerates during the fault more quickly than in the cases with the strategy A, which results in substantially fewer changes in stator and rotor current, voltage regulation, and Voltage sources. For instance, in the situation of technique A, the rotor position soars to 2.2 p.u. The suggested control technique C can only lower the rotor current by 0.96. Fault, which is less than the crowbar's activation threshold [23]. Additionally, it is noted that with the suggested control technique C, the oscillations are effectively dampened once the fault is cleared and the speed of the rotor returns to its base value. Methods for a wind system using LVRT is shown in Table 1. The increase in rotor speed is related to the mechanical energy $\Delta E_m(t)$ that is stored in the generator rotor at time t and can be represented as follows:

$$\Delta E_m(t) = \frac{1}{2} J_g[\omega_r(t)^2 - \omega_r(t_{start})^2] \; t \geq t_{start}$$

where Jg is the rotor's inertia and tstart is the time the defect first appeared. Once the turbine speed surpasses the rated value under high wind conditions, the pitch control is expected to result in increased, thus reducing the amount of wind energy generated.

When operating in variable speed mode, the generator rotor's reference speed is set at [20] to implement MPPT control.

$$\omega_{r.ref} = \sqrt[3]{\frac{P_t}{K_{t.opt}}} = \sqrt[2]{\frac{T_t}{K_{t.opt}}}$$

where T_t is the electromagnetic torque, P_t is the output power and $K_{t.opt}$ is a construction dependent constant.

TABLE 1: LVRT methods for a wind system

Real methods	Passive methods
Blade pitch angle control	Storaged Energy
	Crowbar
Control advancement (GSC, RSC)	FACTS devices (DVR, SVC)
	Capacity sizing

5. EFFECT OF DFIG WIND TURBINE ON THE DYNAMICAL POWER SYSTEM

5.1 Frequency stability

According to the definition given in Reference [24]. Whether you react will depend on your capacity to keep or regain the

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balance between generation and load. Consistent frequent fluctuations that trip generating units and/or loads are indicative of instability. Because of a number of factors, Voltage regulation instabilities is made worse by the expansion of DFIG wind turbines in power systems. The severe system frequency variation is caused by the huge output current swings as DFIG wind turbine integration in energy systems grows. As a result, the frequencies relays that are put at wind farms cause the farms to be disconnected from power systems [13]. DFIG and turbine parameter values are shown in Table 2.

Table 2: DFIG and turbine parameter values [25]

C	Dc bus capacitor (F)	0.038
F	Turbine total friction coefficient (Nm·s/rad)	0.0024
fn	Nominal frequency (Hz)	50
Lr	Rotor inductance (mH)	12.1773
Ls	Stator inductance (mH)	12.241
M	Mutual inductance (mH)	12.12
Np	Polar pairs	2
Pn	Nominal power (MW)	3
Rr	Rotor resistance (mΩ)	3.82
Rs	Stator resistance (mΩ)	2.97
Un	Nominal voltage (V)	690
Vw n	Nominal wind speed (m/s)	13
Vdcn	Nominal dc-link voltage (V)	1200

The back-to-back converters decouple the power grid the DFIG rotor, making it impossible for the rotor to c changes in grid frequency. As a result, the perceived system inertia is significantly reduced by the extensive installation of DFIG wind parks. This intensifies the nadir of frequencies decline caused by the loss of producers as well as accelerates the rate of system frequency change [26]. This suggests that the period of time needed for the rotating reserves, used to offset the imbalance of power, is dwindling.

5.2 Voltage stability

Voltage stability refers to an electric system's ability to maintain steady voltages at all buses within allowable limits in the wake of a disruption. Current performance can be improved by using a Controllable reactive current output of doubly fed induction generator wind farm. Following is a summary of earlier studies that looked at how Voltage stability in transmission and distribution networks is impacted by DFIG wind turbines. Their results show how, during normal operating conditions, the doubly fed induction generator wind turbine can produce or absorb reactive power which enhances the steady-state voltage regulation of the local network. When compared to a wind turbine with an identical-rated induction machine, the DFIG wind turbine performs better in terms of voltage recovery. Examined using the time-series AC power flow their findings demonstrate that using the right voltage control schemes advances buses as well as distribution level buses. The P-Vcurve was used to examine the effects of various DFIG wind farm penetration levels and dispersion on voltage stability. The tolerance for voltage instability is increased at low exposure levels. On the other hand, the voltage stability suffers at penetration level. Additionally, the voltage stability is improved across all DFIG wind farm locations [27, 28]. By using dynamic analysis and time-domain modelling, takes the place of a synchronous generator, the margins for static voltage regulation are not considerably impacted. On the other side the voltage quality tolerances are reduced.

5.3 Power Oscillation Damping Methods by DFIG Wind Turbine

By including a powered oscillation dampers (POD) in the RSC's either a reactive power compensation loop or an active power control loop (voltage controller). As illustrated in Figure 5, the POD construction is usually similar to the conventional PSS. Keep in mind that the stabilising gain Kconveys how much dampening effect there is. The voltage controller and/or speed controller are both given the stabilising signal from the PODIn order to lessen power oscillation, the outputs of active and/or reactive power can be adjusted. Here, the proactive and/or reactive power output control is used to divide the three methods utilised by the RSC of a DFIG wind turbine with a POD to reduce energy fluctuations.

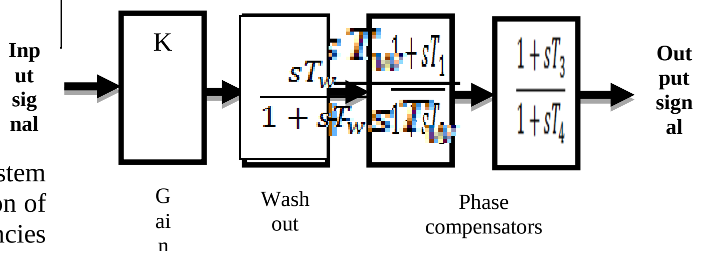

Figure 5: Structure of power oscillation damper (POD)

5.4. Active power control:

5.4.1. Choosing an input signal: The goal oscillations pattern ought to be easily visible in the active power control for indigenous input indication of POD.

5.4.2 POD control design: There are several controller design approaches for a POD for active power control. For the active power control loop to generate an enough dampening influence, the POD is included. The resonance frequency and root locus approaches are used to design the POD parameters. Additionally; it is suggested that the POD could suppress the neighbouring synchronous generator's SSR oscillation. In order to provide the best damping across the full sub-synchronous frequency band, the PID parameters are genetically optimized. The POD's ideal parameters have been optimised using particle swarm optimization, bacteria foraging algorithms, and other techniques. In order to provide the best dampening across the full sub-synchronous frequency band, the PID parameters are genetically optimised. The observed-state feedback control is used to construct the POD. This worsens the shaft mode damping and causes the electromagnetic torque of a DFIG wind turbine to oscillate. The POD settings should be tuned with torsional dynamics in mind to reduce interaction. As an alternative to active power management, many studies have investigated reactive power control to dampen power oscillations.

5.5. Reactive power management: A DFIG's reactive power modulator control offers adequate power oscillations reliever without compromising with the torsion oscillations mode.

6. CONCLUSION

In this article, we have described a full method for using an inductive generator that is double fed with power from a turbine. The outcomes show that the suggested controlling method can effectively prevent nonlinearities in the DC-link voltage and rotor value of current which increases the LVRT capability of the DFIG WT. The controller technique is suggested in this publication as being novel and advantageous. In the event of a brief grid voltage dip, the DFIG WT fitted with the suggested control technique provides superior transient performance than the typical crowbar protection. As a benefit of this work, the unique control strategy that was suggested has demonstrated significant benefits in lowering oscillations and spikes in current and voltage. With the right controls, the DFIG wind turbines' variable output power can be used to improve the dynamics of the electricity grid. DFIG wind turbines don't just cause the frequencies nadir when it comes to their effects on frequency stability worse but also speed up the rate at which frequencies shift (ROCOF). Main energy flow routes are affected, Synchronization turbines, PSS-equipped or not are replaced or reduced, and DFIG controllers combine to cause these effects on small-signal stability. Future research may include the examination of estimation-based control techniques for DFIG wind generators during severe electric and mechanical failures using different estimating techniques.

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