Performance Analysis Of Grid Connected DFIG Under Unbalanced Grid Voltage Conditions

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ABSTRACT: DFIG has become an major component in today's wind power industry. It is able to operate at different speeds and has controllable active and reactive power. [1]. They allows the amplitude and frequency of their output voltages to be maintained at a constant value. Controlling the power factor while maintaining the power electronic devices in the wind turbine at a moderate bus is another advantage. To analyse how the DFIG behaves under various fault situations, such as Three phase faults, and at various voltage sag and swell levels, Distribution Static Compensator (DSTATCOM) [2] and Dynamic Voltage Restorer (DVR) are two examples of custom power devices that may be used to mitigate various power quality issues [3]. This paper describes the technique of correcting the supply voltage sag and swell distributed system. DVR based on VSI principle [4]. By injecting a voltage in series with an injection of current, a DVR is a series compensation device that resolves power quality problems in the system[5]. This paper presents a power system operation with PI controller with abc to dq0 convertor approach. Dynamic voltage restorers (DVRs), which are complex static devices that function by supplying the "missing" voltage during a voltage sag, are used to maintain grid voltage. Essentially, it injects electricity into the system to restore the voltage to the level required by the load[6]. The model was developed in MATLAB/SIMULINK, and the system with the proposed theory has been determined for non-linear loads.

KEYWORDS: Active and Reactive Power, Dynamic Voltage Restorer, Compensation, Voltage Sag and Swell, Non-Linear Loads.

1.INTRODUCTION:

DFIG's are wound rotor induction generators with variable speeds that employ two back-to-back bidirectional power electronic converters[7]. The territorial winding of the three-winding generator step-up transformer comprises one converter connected to the ac network at the generator stator terminals, while the other converter is connected to the windings of the rotor via sliprings[8]. The aim of the rotor side converter is to provide the rotor circuit with a three phase voltage at slip frequency. The converter controller can change the amplitude and phase of the injected voltage, which regulates the rotor currents very instantly. This serves two key purposes. First, there is a change in the generator's rotor speed and electromagnetic torque[9]. The second option is to control the constant stator reactive power output, stator power factor, or stator terminal voltage. the typical speed range for a modern wind turbine Dfig may be 70% and 120% of the nominal synchronous speed. Dfig needs only 25-30% of the total power to pass through converters. the remaining 70-75% passes through stator winding, hence reducing the power electronics rating to 25% of the system[10].

Double fed induction generator (DFIG) technology is required for operation in a limited speed range and capture the maximum amount of wind energy. In addition, in order to maintain connectivity during grid interruptions, wind power must be controlled in terms of both active and reactive power.[11]. However, dfig's are extremely susceptible to grid disruptions. As a result of the sudden increase and decrease in voltage, the rotor windings encounter over voltages and over currents[2].. which results in the absence of protection measures, could possibly cause the converter to fail. Grid code criteria, of which low voltage ride through capability (LVRT) is of special relevance, must also be met by wind energy conversion systems. The stator of the DFIG has poor low-voltage ride through (LVRT) capabilities since it has a direct connection to the ac grid, which may shorten the lifetime of the dc capacitance due to poorly damped flux oscillations during grid voltage dips in the dc link of back-to-back VSC[12].

The most significant LVRT issue of the DFIG during the symmetrical fault is determined to be transient overcurrent in the rotor because of the rotor side voltage source converter's greater risk of thermal overload. In order to protect the rotor VSC and reduce oscillations faster, active crowbar protection was developed to short circuit the rotor during symmetrical grid voltage falls[1].However, in contrast to symmetrical problems, asymmetrical faults occur far more frequently.

The most significant risk in an unbalanced grid voltage situation is not just transitory overcurrent, but also electric torque pulsation, which breaks down gearboxes, and excessive voltage ripple in the back-to-back vsc, which can shorten the lifespan of DC capacitances. For the purpose of maintaining voltage levels, The design and integration of the dynamic voltage restorer (DVR) is achieved. Series voltage injection maintains the voltage at the reference level by means of DVR. The method used to handle voltage control is to use a dynamic voltage restorer (DVR). The DVR is a particular type of specializing power equipment for maintaining continuous distribution power quality. They use solid state switches in a series of voltage boost techniques to reduce voltage sags. The majority of DVR applications are for sensitive loads that could be drastically affected by fluctuations in system voltage[13].

2.GENERAL FORM OF GENERATION SYSTEM:

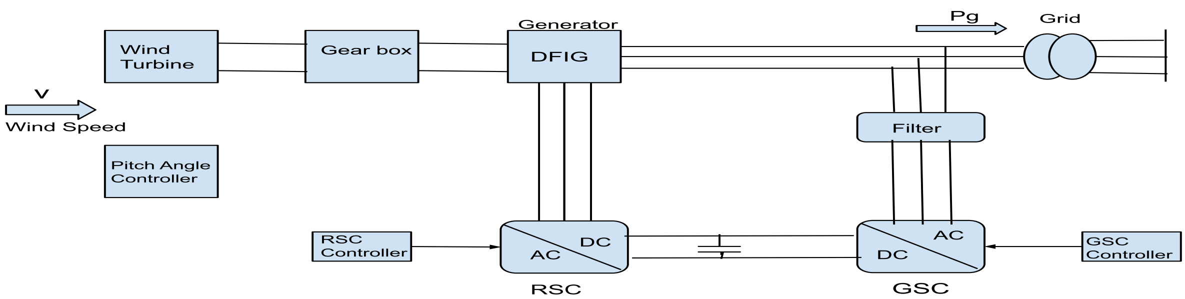


Fig.1. Schematic diagram for Doubly-fed Induction Generator

A DFIG wind turbine is shown in the schematic, as seen in Fig. 1. In the above configuration, the rotor connects to the grid through a converter, while the stator is connected directly to the grid. This method requires a lower rated converter since it regulates 20% to 30% of the total power. Therefore, the converter will have reduced power losses when compared to other different kinds of wind systems. Thus, the converter's cost is lower. The rotor side converter regulates power flow through the rotor at varying rotor speeds, while the grid side converter keeps the dc link voltage constant. Grid side converters are PWM inverters, and rotor side converters are current regulate-voltage source inverters.

About thirty percent of the synchronous speed is operated at variable speed using the system that is displayed below[14].Power electronic converters regulate 20–30% of the total power entering via the grid or vice versa. The total system power factor will be one.

A transformer connects two converters in a back-to-back configuration to the grid. A dc capacitor has been inserted between the two converters to reduce voltage swings or swell in the connection voltage.

3.MODEL AND EQUATIONS OF WIND TURBINE:

The following represents the amount of electricity that wind turbines can collect from the wind:

$P_{m=}C_p P_w$

$P_{w=}1/2\ \pi\rho R^2 V_w^3$

Pw is the actual wind power, whereas Pm is the mechanical power extracted from the wind by the wind turbine. The variables Ro, R, Vw, and Cp represent air density, wind turbine blade radius, wind speed and efficiency index, respectively. The efficiency index (Cp), which depends on the aerodynamic shape of the blades, represents the portion of the real wind energy that the wind turbine can pick, as explained by:

$Cp = f(\lambda,\beta)W$

$\lambda = RW_R / V_w$

where TSR, or tip speed ratio, is the ratio of wind speed to turbine blade tip speed expressed as λ. The blade angle is indicated as β, while the mechanical angular velocity (WR) of the turbine rotor is measured in rad/sec. Wind speed (Vw) is measured in meters per second. The rotation determines the angular velocity.

Based on the turbine characteristics, the following equation is used to calculate Cp.

$$Cp\ (\lambda,\beta)=(c_1(\frac{c2}{\lambda 1})-c_3\ \beta-c_4)e^{-c5/\lambda i}+c_6\ \lambda$$

$$\frac{1}{\lambda i}=\frac{1}{\lambda+0.08\ \beta}-\frac{0.035}{\beta 3+1}$$

From experimentally it is found that $c_1 = 0.5176$; $c_2=116$; $c_3=0.4$; $c_4=5$; $c_5=21$; and $c_6=0.0068$.

For a high-rating wind turbine, the maximum mechanical power extracted at optimum values of TSR.

λ_{opt} in range of 5 to 8. It is shown that $c_p<0.6$ and the maximum value of c_p is 0.5926 which is Betz limit. In practice, for the best TSR value, power coefficient c_p is considered about 0.51 for high rating wind turbine systems.

Wind turbine simulation models for generating torque in variable-speed turbines shown below:

$$Ta = \frac{Pm}{WR} = \frac{1}{2}\frac{\lambda\pi R*R*Cp*Vw3}{WR}$$

Where Ta is the torque in turbine shaft.

4.Modelling of DFIG:

There are various studies focusing on DFIG modelling. The present research is going to address the most important aspects of the modelling. The system has been modelled and simulated using the Simulink MATLAB toolbox extension..

It is decided on a reference frame to model the DFIG. The fifth-order two-axis representation, also referred to as the "Park model," serves as the basis for the induction machine concept. A synchronously rotating reference frame's direct axis revolves in the direction of the stator flux location. It results in the decoupling of control between the rotor excitation current and electrical torque. Both the stator voltage and the reference frame rotate at the same speed. The generator convention, which states that currents are outputs and that real and reactive power have a positive sign when supplied into the grid, will be utilized when modelling the DFIG[15]. The set of equations that follow gives the results listed below using the generator convention.

The following is the equation for induction machines in the dq reference frame, considering a speed of ω and ignoring the zero parameter is given by[16]:

$$V_{ds}=R_s i_{ds}-\omega\psi_{qs}+\frac{d\psi ds}{dt}$$

$$V_{qs}=R_s i_{qs}+\omega\psi_{ds}+\frac{d\psi qs}{dt}$$

$$V_{dr}=R_r i_{dr}-(\omega-\omega_r)\ \psi_{qr}+\frac{d\psi dr}{dt}$$

$$V_{qr}=R_r i_{qr}-(\omega-\omega_r)\ \psi_{dr}+\frac{d\psi qr}{dt}$$

Where V_{ds}, V_{qs} are the d-axis and q-axis stator voltages,

V_{dr}, V_{qr} are the d-axis and q-axis rotor voltages.

i_{ds}, i_{qs} are the d-axis and q-axis stator currents.

i_{dr}, i_{qr} are the d-axis and q-axis rotor currents.

The rotor and stator per phase resistances referred to stator are denoted by Rs and Rr, respectively.

ψ_{ds}, ψ_{qs} are the d-axis and q-axis stator flux linkages.

ψ_{qr}, ψ_{dr} are the d-axis and q-axis rotor flux linkages.

ω is the speed of rotation of the dq frame.

ω_r is the rotor electrical angular velocity.

The stator and rotor flux are :

$\psi_{ds}=L_s i_{ds}+L_m i_{dr}$

$\psi_{qs}= L_s i_{qs}+L_m i_{qr}$

$\psi_{dr}= L_r i_{dr}+L_m i_{ds}$

$\psi_{qr}= L_r i_{qr}+L_m i_{qs}$

The rotor electrical angular velocity is related to the rotational speed of the machine through the relationship $\omega_m=(\frac{2}{p})\ \omega_r$, where p is the number of machine poles.

The developed electromagnetic torque T_{em} is given by:

$T_{em} = \frac{3P}{4} (i_{qs}\ \psi_{ds} - i_{ds}\ \psi_{qs})$

The following is the equation that relates the machine's rotational speed to the applied mechanical and electromagnetic torques:

$J\frac{d\omega m}{dt} = T_{mech}+T_{em}$

In this relationship, the prime mover refers to the induction machine shaft, and J represents the machine's polar moment of inertia.

Active and reactive powers of stator:

$P_s=\frac{3}{2}(V_{ds}i_{ds}+V_{qs}i_{qs})$

$Q_s=\frac{3}{2}(V_{ds}i_{qs}-V_{qs}i_{ds})$

5.DYNAMIC VOLTAGE RESTORER:

Dynamic voltage restorers (DVRs), series-connected power electronic devices, are capable of quickly minimizing system voltage dips and restoring the load voltage to its pre-fault level. DVR has been proven to be the most successful approach to solving this kind of problem. The DVR, a specialized power tool, has been designed to minimize voltage fluctuations and swells. By adding compensating voltages in series with the grid voltage, it efficiently restores it to the necessary levels.

A versatile power quality equipment known as a dynamic voltage restorer (DVR) can quickly detect voltage fluctuations, generate compensating voltages, and inject them into the grid in order ensure that sensitive loads receive constant, high-quality power[17]. Dynamic voltage restorers (DVRs) are series-connected power electronic based devices that can quickly mitigate the voltage sags in the system. DVRs are essential for protecting essential facilities and industrial processes against the damaging effects of power failures and fluctuations.

A.BASIC PRINCIPLE OF DVR:

At the DFIG's point of common connection (PCC), the DVR typically has a connection to the grid[18]. In order to maintain voltage balance, the DVR continuously measures the grid voltage and injects or absorbs voltage as needed.

The specific control strategy employed in the DVR, such as Proportional-Integral (PI) control, hysteresis control, or custom algorithms, determines how the error is calculated and how control signals are generated. These control methods have the purpose to protect the connected equipment from voltage-related problems by ensuring that the load voltage stays within a specified permissible range[19].

DVRs are electronic devices that employ a VSC to produce an ac voltage, similar to STATCOMs. The DVR, on the other hand, allows for separate control over both the reactive and active power. DVR systems can additionally generate and absorb active and reactive power as they are bidirectional. It is possible to achieve this bidirectional capability because a DVR may inject a series voltage with the proper magnitude and phase. DVR systems are often installed upstream of a sensitive load to safeguard it from supply side disruptions. DVR systems are known for their quick responsiveness to system interruptions and zero real power consumption during steady state, in addition to real and reactive power control. The injection of harmonics into the system from the VSC, which requires filtering, is one disadvantage of DVR systems[20].

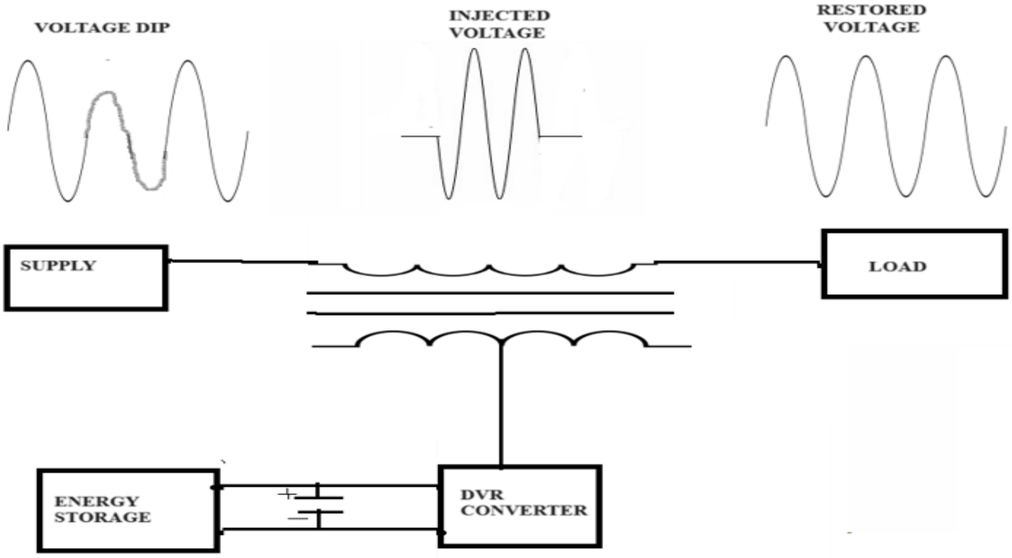


Fig.2. Example of a standard configuration for a DVR

B.SIMULINK MODEL OF THE DVR:

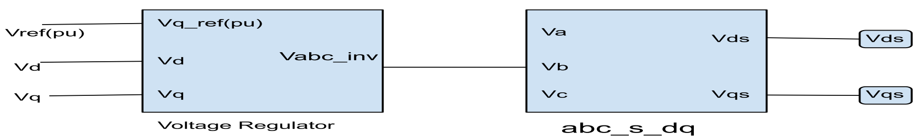


Fig.3. SIMULINK MODEL OF THE DVR

The objective of the project is to reduce voltage sag occurred in load voltage profile due to occurrence of fault in system. A PI control technique based control scheme with a series compensating device named DVR is used[21].

The working principle of a Dynamic Voltage Restorer(DVR) involves continuous voltage monitoring, rapid detection of disturbances, energy storage, real-time compensation, and injection of compensating voltage For keeping the voltage at a stable level for sensitive loads. This ensures that voltage sags, swells, and interruptions do not disrupt the operation of critical equipment, making DVRs valuable for maintaining quality of power and reliability.[21].

C.MODEL OF THE DFIG WITH DVR:

The DFIG uses wind power to create electrical energy as a component of a wind turbine. To achieve the greatest power collection under various wind conditions, its rotor-side power converter regulates the rotor current[22]. The grid obtains electricity from DFIG's stator windings, which is connected to it. However, the quality of power provided by the DFIG might be affected in the case of grid interruptions or voltage sags.

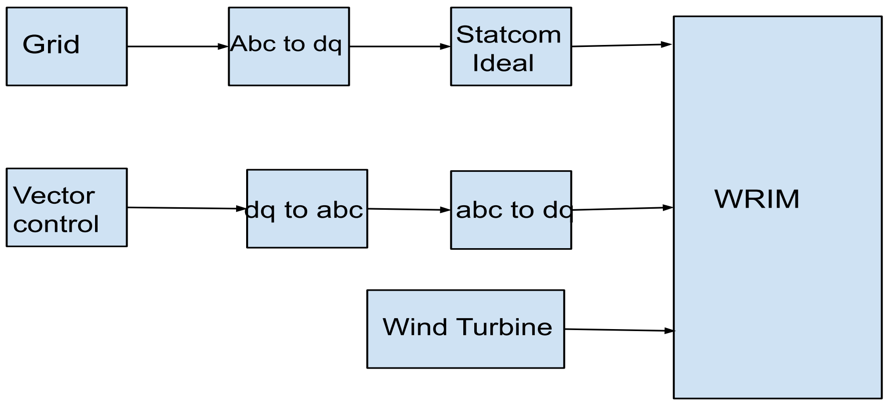


Fig.4. Block Diagram Of The DFIG With DVR

The DVR detects any voltage deviations by continually monitoring the grid voltage. It rapidly injects compensatory voltage to reduce the disturbance when it detects a voltage dip or interruption. The DVR provides the compensating voltage by means of its energy storage components [23]. By assisting to keep the voltage at the necessary level, this injected voltage guarantees that sensitive loads connected to the grid receive high-quality electricity. Even when the grid experiences voltage dips or problems, the DFIG and DVR collaborate to provide a steady and high-quality supply of electricity[24].

Control Structure Used in Series Compensator:

Applying the Theory of Control in Series Compensator The main drive for the nonlinear load, which is parallel to the sensitive load, connects to the load terminals where harmonics are generated using a six-pulse converter with a specified firing angle. Three phase faults at load terminals produce voltage sag. The sequence analyzer analyzes all of the voltage problems mentioned above after being detected independently. The magnitude component is compared using the reference voltage (Vref).The pulse width modulation (PWM) control mechanism is used by the inverter switching technology to deliver a three phase, 50 Hz sinusoidal voltage at the load terminals. The frequency of chopping is limited to a few KHz. To maintain the voltage at the load terminals at one per unit, the IGBT inverter is managed by a PI controller. In order to operate the plant, a closed-loop controller known as a proportional integral controller (PI controller) adds up the weighted sum of the error, or the difference between the output and the desired set point, and the integral of that number. Another advantage of using a proportional plus integral controller is that the integral term in a PI controller makes the steady-state error for a step input comparable to zero. The actuation signal received by the PI controller is the one that distinguishes Vref from Vin. The output of the controller block is represented by δ.

Comparator's output = Vref – Vi

where the voltage Vin at the load terminals in p.u. equals 1 p.u. voltage (1 p.u. = Base Voltage) Vref.

To achieve the required firing sequence, the PWM signal generator is given the angle δ.

The angle δ is used to phase-modulate the control of the sinusoidal signal V.

This produces the angle δ in three stages.

i.e., $VR = \sin(\omega t + \delta)$

$VY = \sin(\omega t + \delta + 2\pi/3)$

$VB = \sin(\omega t + \delta + 4\pi/3)$

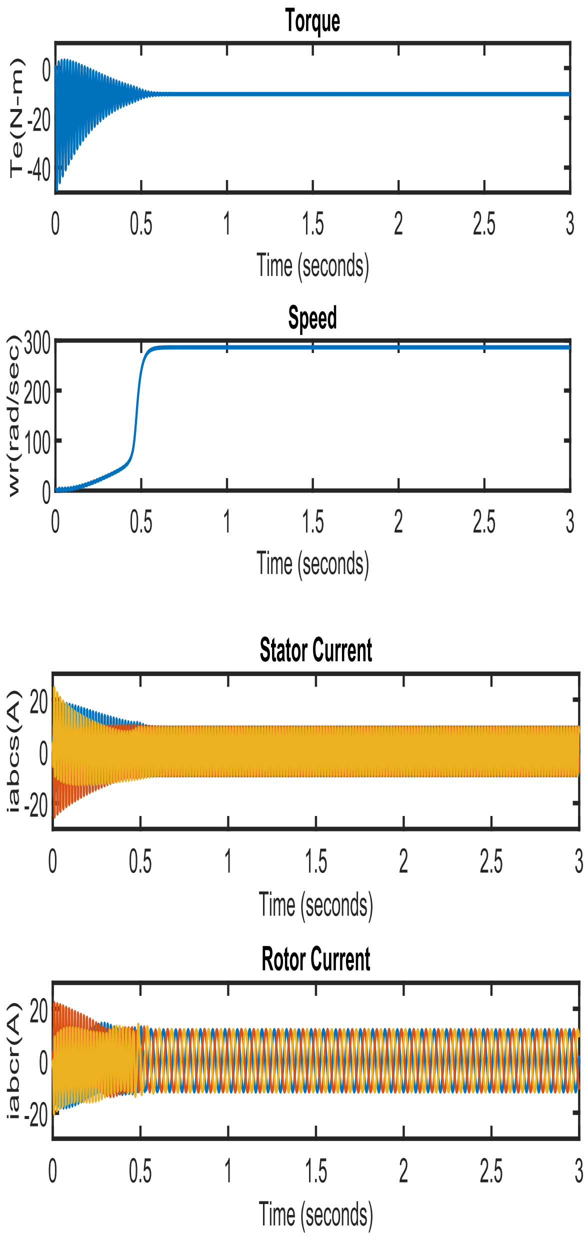
6.SIMULATION AND RESULTS:

The DFIG machine is simulated with MATLAB/SIMULINK environment by taking various cases into account.

CASE I: SIMULATION UNDER NORMAL CONDITION:

The simulation results under the normal voltage conditions is shown in figure(5)

The below waveforms shows the Torque, Speed, Stator three phase current, Rotor three phase current, Active power, Reactive power.



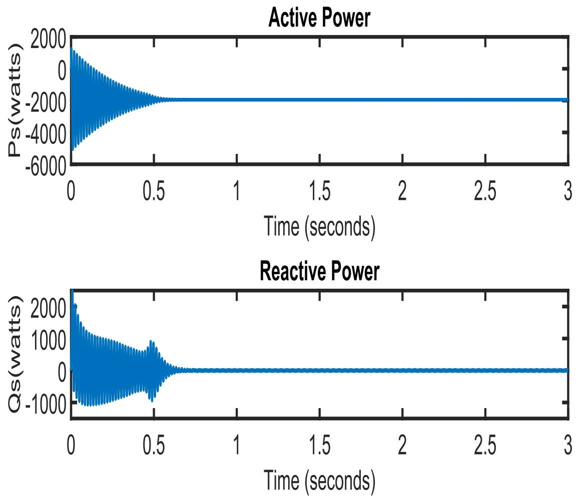


Fig.5.Waveforms Under Normal Condition

A.VOLTAGE SAG:

Voltage sag is a word used to denote a voltage dip to 10-90% of its rated value. Voltage sag is another term for low voltage situation. The primary cause of all voltage sags is an unexpected increase in current. This is the most typical kind of grid problem, which occurs by quickly turning on large inductive loads including motors or electrical heaters, or by suddenly increasing the source impedance due to a loose connection[25].In order to determine the effect of sag on the turbines based on DFIG technology, symmetric sag results in rise in the grid voltage at 1 to 2 seconds, and a voltage dip of 40% is taken into account.

The dfig's respond can be observed in the image below. When beginning voltage sag instant, the motors torque increase very sharply and then drop at end of the sags. Motor torques drop at the same point then oscillate in several seconds and drop again before reaching steady-state, it takes time to recover after the end of voltage sag.

The current is approximately 40% higher than the its nominal current.as seen, the magnitude of current before and after the voltage sags has increased

The reduction in voltage causes the d-q components of rotor currents to increase. The stator injects reactive and active powers that vary from their predetermined values. Due to its high voltage dependency, reactive power is particularly subject to the impacts of voltage sag. Dim light, fluctuating power, and relay and contactor failure are the results of voltage sag.[26]

COMPENSATION OF VOLTAGE SAG:

CASE-1:SIMULATION DIAGRAMS UNDER VOLTAGE SAG:

Figure (6) displays the simulation results during the voltage sag.

The below waveforms shows the Torque, Speed, Stator three phase current ,Rotor three phase current, Active power, Reactive power.(Fig.7)

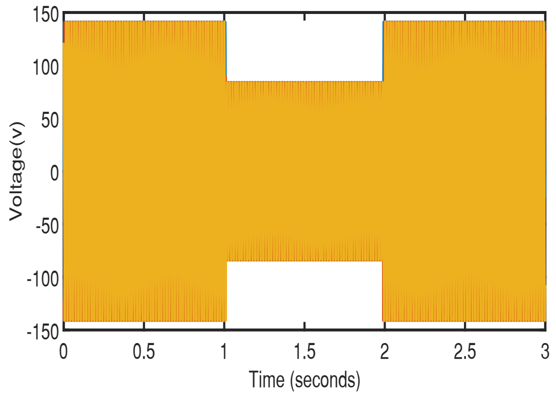
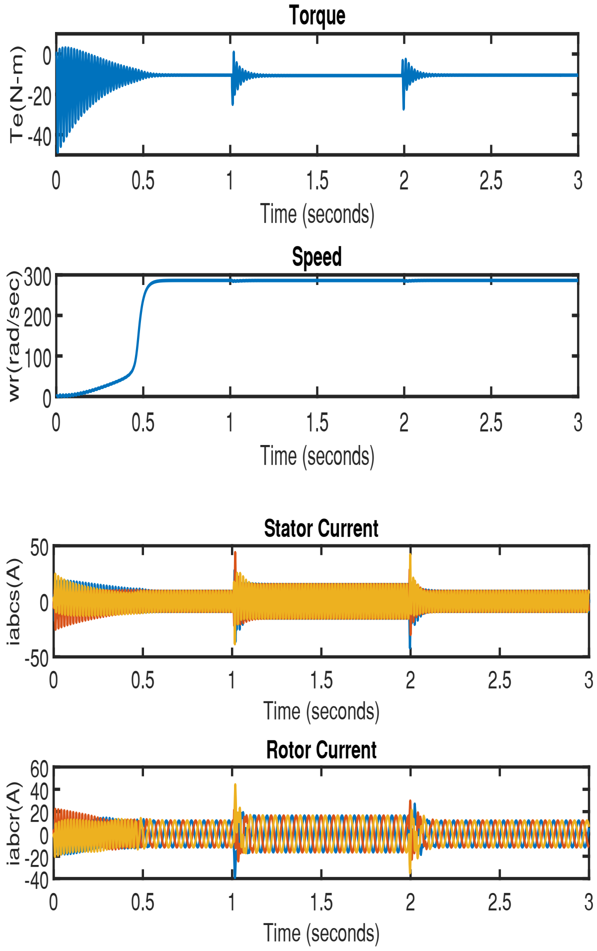


Fig.6. Voltage sag



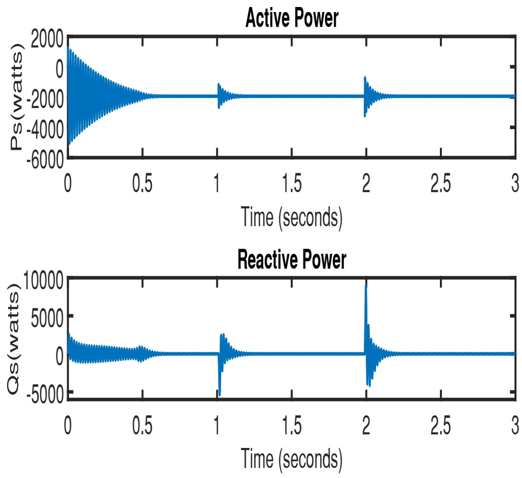
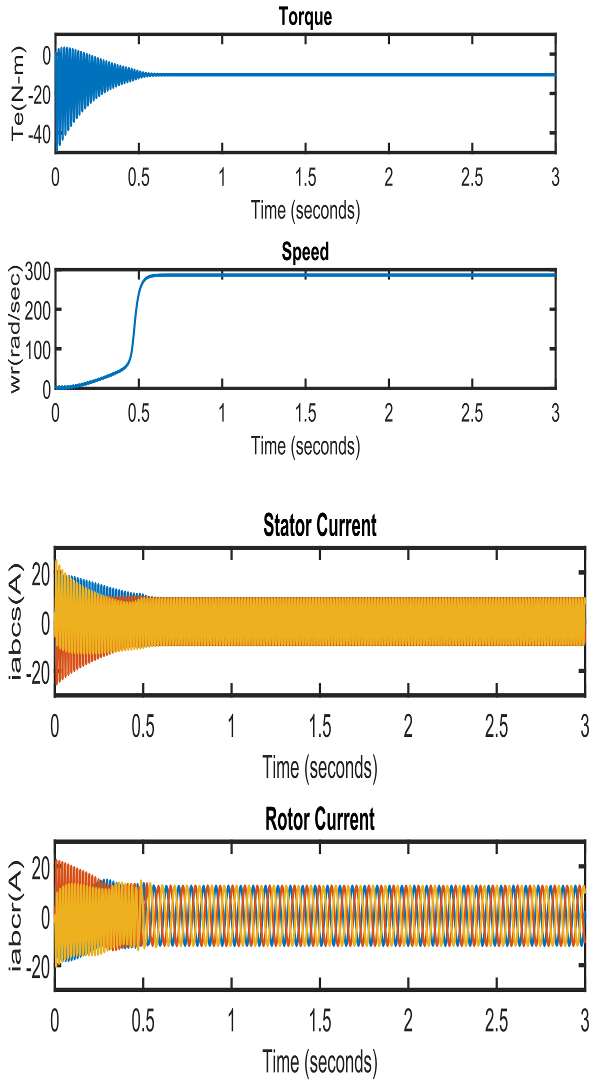


Fig.7.Waveforms Under Voltage Sag Condition

CASE-2:AFTER COMPENSATION(BY USING DVR)

The below waveforms(Fig.8.) shows the Torque, Speed, Stator three phase current ,Rotor three phase current, Active power, Reactive power.



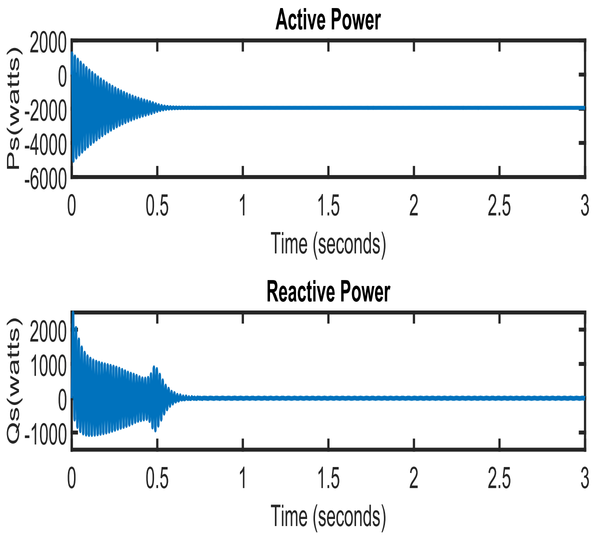


Fig.8.waveforms after compensation

VOLTAGE SWELL:

The voltage swell is a sudden increase in voltage over a few cycles. This kind of failure becomes worse by unexpectedly switching on or off capacitive or heavy loads.[25]. The 40% of the voltage is created between 1 and 2 cycles to investigate the dynamic behaviour of the dfig for the symmetrical voltage swell analysis.

The reaction of the Dfig may be observed in the figure below. As the grid voltage rises, the rotor and stator currents increase as well. Currents increase to two or three times their typical levels during the fault phase. The reactive and active power reference levels have not been achieved. These excessive currents can damage the converter.[26]

The dfig's respond can be observed in the image below. When beginning voltage sag instant, the motors torque increase very sharply and then drop at end of the sags. Motor torques drop at the same point then oscillate in several seconds and drop again before reaching steady-state, it takes time to recover after the end of voltage sag.The current is approximately 40% higher than the its nominal current.as seen, the magnitude of current before and after the voltage sags has increased

CASE-1:SIMULATION DIAGRAMS UNDER VOLTAGE SWELL:

The simulation results under the voltage Swell conditions is illustrated in figure(9).

The below waveforms(fig.10) shows the Torque, Speed, Stator three phase current, Rotor three phase current, Active power, Reactive power.

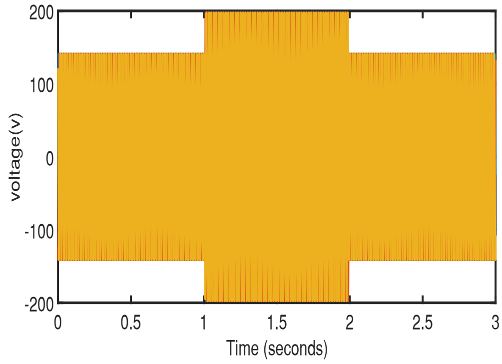


Fig.9. voltage swell

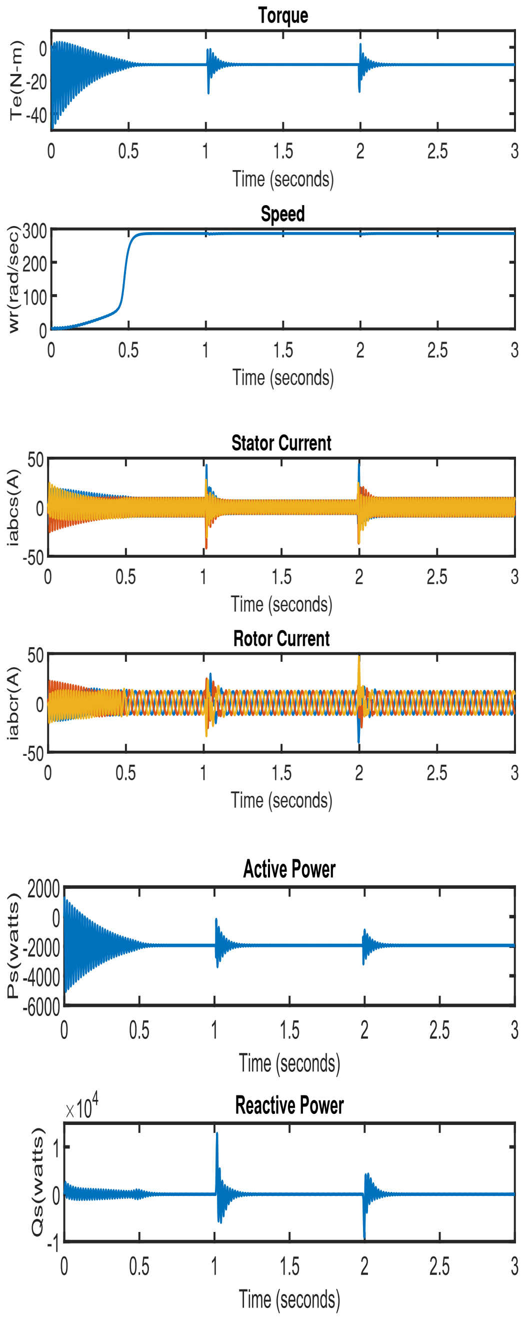


Fig.10.Waveforms Under Voltage swell Condition

CASE-2:AFTER COMPENSATION(BY USING DVR)

The below waveforms shows the Torque, Speed, Stator three phase current ,Rotor three phase current, Active power, Reactive power(Fig.11).

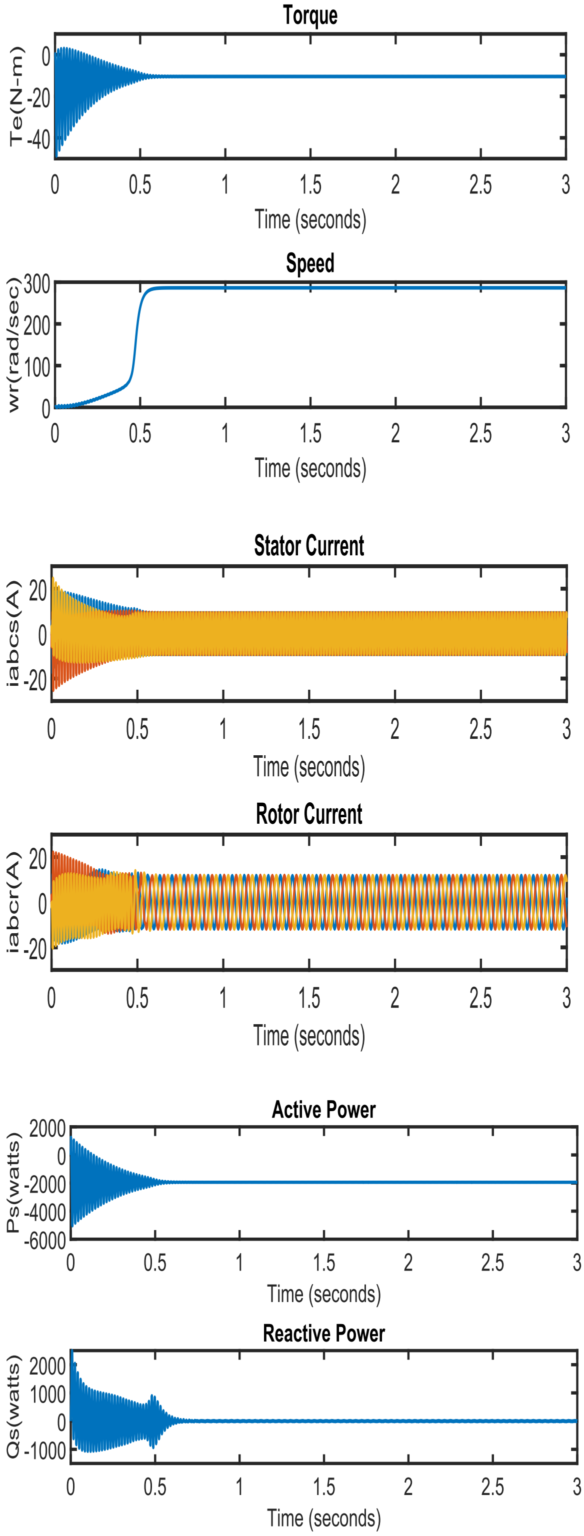


Fig.11.waveforms after compensation

C.THREE PHASE FAULT:

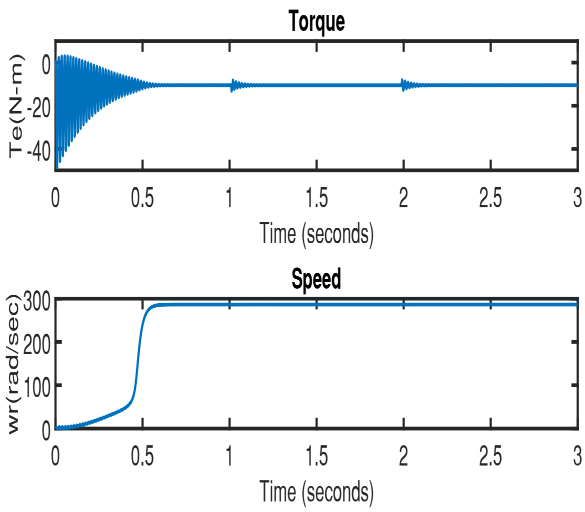
The transmission system between the grid and dfig is considered to have a three-phase fault. This is the most serious issue. A 10% voltage swell is induced between 1 and 2 cycles to evaluate the changing behaviour of dfig for symmetrical three phase fault analysis. The dfig's response can be observed in the image below. The torque produced by the DFIG is proportional to the product of the stator current and rotor magnetic field strength. During a fault, the sudden change in stator current and voltage can result in a transient change in the electromagnetic torque.

The speed of the DFIG is influenced by the mechanical torque and the electrical torque. Any disturbance in the torque will affect the speed of the generator. The speed waveform may exhibit transient behaviour during and after the fault.

During the breakdown, the rotor, stator currents reach an extremely high value, when the typical value is 10A.In a three-phase fault, there is a sudden change in the voltage across the stator windings. The stator currents will be affected accordingly. The fault causes a significant increase in the stator current magnitude. The waveform of the stator current will exhibit high peaks and may contain harmonics. when the typical value is 10A. During this time, both the reactive and active abilities vary considerably. The rotor currents will also experience transient changes due to the fault. These changes can affect the torque produced by the generator.

CASE-1:SIMULATION DIAGRAMS UNDER THREE PHASE FAULT:

The below waveforms shows the Torque, Speed, Stator three phase current, Rotor three phase current, Active power, Reactive power(fig.12).



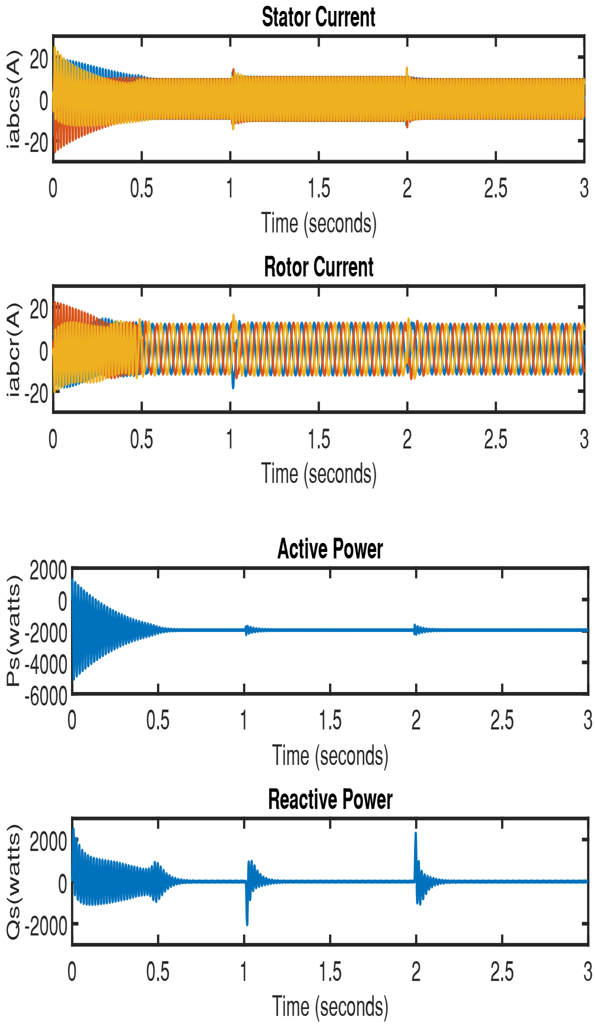


Fig.12.Waveforms under three phase fault

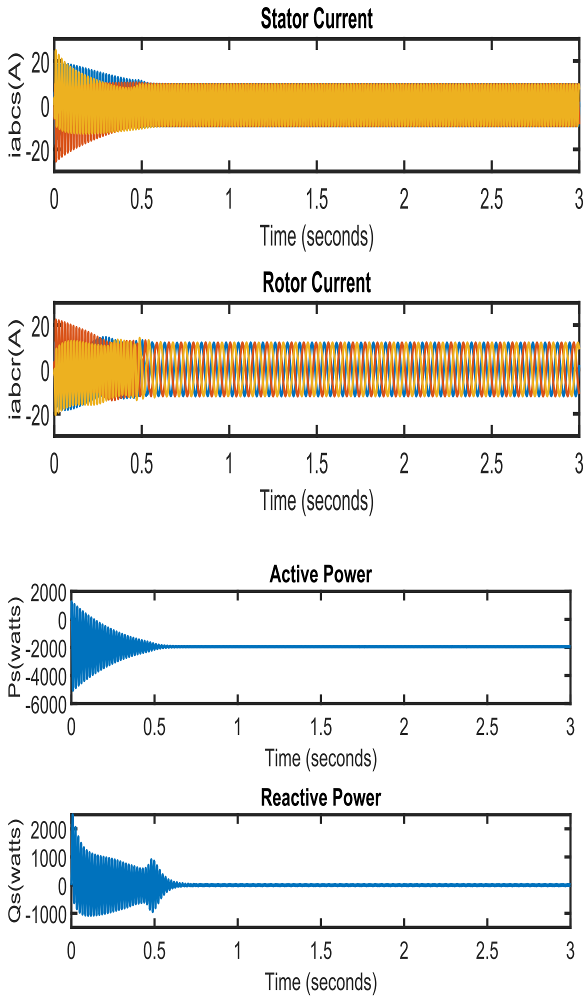
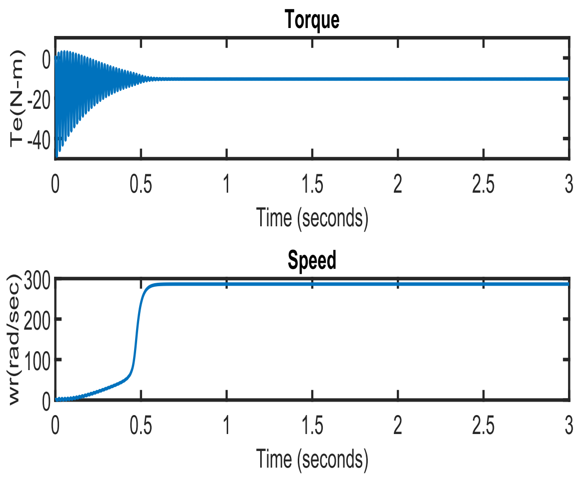


Fig.13.Waveforms After compensation

CASE-2:AFTER COMPENSATION(BY USING DVR)

The below waveforms shows the Torque, Speed, Stator three phase current, Rotor three phase current, Active power, Reactive power.(fig.13).



7.CONCLUSSION:

Integration of energy from renewable sources, particularly wind energy, is essential for a sustainable energy future. DFIGs are common wind turbine elements, although being sensitive to unbalanced grid voltage situations. The use of Dynamic Voltage Restorers (DVRs) for maintaining grid voltage quality and the dependability of DFIG systems is a potential approach. DVRs can respond quickly to voltage swings, improve power quality concerns, and reduce stress on DFIG components, ensuring that wind energy systems perform safely and efficiently. For DFIGs, DVRs provide many benefits such as increased power quality, much greater stability, and greater efficiency. It is important to address the challenges provided by unbalanced grid voltage conditions as the electrical system keeps evolving. DVR technology, when coupled with modern DFIG control methods, can play a significant role in achieving these goals as well as speeding up the development of energy generation from renewable sources.

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