Fuzzy Logic and Synchronous Reference Frame Controlled LVRT Capability Enhancement in Wind Energy System using DVR

Subash Ranjan Kabat[a], Dr.Chinmoy Kumar Panigrahi[b],BibhuPrasadGanthia[c]

[a] PhD Scholar, School of Electrical Engineering, Kalinga Institute of Industrial Technology,Deemed to be University Bhubaneswar, India
[b]Professor, School of Electrical Engineering, Kalinga Institute of Industrial Technology, Deemed to be University, Bhubaneswar, India
[c]ProfessorAssistant Professor, Electrical Engineering, Indira Gandhi Institute of Technology, Sarang, Dhenkanal, Odisha, India

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Abstract: This paper gives a complete assessment of the various strategies used to decorate the skills of Low Voltage Ride Through (LVRT) of Double Fed Induction Generators (DFIG) primarily based wind turbine systems (WT). As the world is using about 20% to 25% of renewable energy from wind using DFIG primarily based Type-III WT machine is at once connected to the grid without the digital interface of power, as a result the terminal voltage or reactive electricity output can't manage. Therefore, unique LVRT approaches based at the implementing additional active interface technologies had been proposed within this paper. Many approaches are now being researched to tackle this fault problem of low voltage. This report seeks to determine such working ways by bridging the gap in terms of the total adaptive performance, operative complexity of controllers and cost-effectiveness by analysing LVRT techniques for DFIG-based WECS. This study highlights the techniques to increase LVRT's ability to depend on the relationship setup in three main areas based on their grid integrations. In this work, FACT device connections are employed by WECS to evaluate its efficiency and advantage. MATLAB simulink is used to simulate the mathematical models of the entire system and examine its outcomes.
Keywords: LVRT, DFIG, WT, FACT, WECS

1. Introduction

People's use of wind or wind power has a long history. In Persia, the earliest windmill design for grain grinding and water pumping in approximately 500-900 A.D. The first wind turbine producing electricity in the world was installed at the end of July 1887. A major benefit of wind power is the fact that it is a renewable energy source. Renewable energy is generally defined as energy from resources which, on a human schedule such as thermal, wind, hydraulic and tides, are continuously refilled with nature. The use of renewable energy for electricity production has been developed worldwide due to heavy pollutants produced from traditional fossil energy sources. It is estimated that approximately 208 GW of renewable energy generated electricity were installed worldwide and a total of 1360 GW of renewable energy capacity was achieved in 2011. For non-hydro-powered renewable, the capacity exceeded 390 GW, an increase of 24% over 2010. Worldwide, wind energy accounted for nearly 40% of renewable energy, solar photovoltaics for nearly 30% and hydropower almost 25%. By the end of 2011, renewable energy generation was more than 25% and it supplied around 20,3% of the world's electricity supply. Wind as a source of renewable energy has been given more and more attention and is now playing an increasingly important role as a source of energy because of its inherent characteristic of carbon-free electricity generation. In total, 306 wind farms had operated in the UK up to 2011, producing 5,737,60 MW of grid power. Over 35 GW were added to wind power in 2013, for a total of more than 318 GW. All types of renewable energy have significantly increased in the last five years, but wind energy generation has increased the greatest amount of renewable technology over that period.The WT produces electricity from cinematic power. Commercial electricity generation usually employs three-bladed WTs and is generally controlled by computers. A WT consists generally of: the base, turret, nacelle, rotor and blade. In nacelle are placed the gear box and generator. The wind turbine parts are shown in Fig.1. An important problem is the high operating and maintenance costs of a WTS(**Akbari et al 2021**). The objective of this paper is decreasing ozone depleting substance discharges is the vital issue which related with the development and entrance of sustainable power sources. Introduced Wind Turbines (WTs) are focused on power system stability using grid integrations to enhance the power quality during faults . However, grid integration into the wind energy system of large WTs can cause serious side effects in poor or weak grids. The inclination towards more WT integration is to build the present degree of the unbalancing just as decline the voltage over the wind generators system, which can prompt the fault clearances of the WT. As of late, many power system techniques are in everywhere throughout the world have started to grow and alter their correspondence prerequisites for wind cultivates by specialized models, known as grid codes which is one of the significant necessities with respect to grid voltage control is the capacity of the Low Voltage Ride Through (LVRT), which is remembered for a few new grid codes. Figure 1 delineates the LVRT bend in activity for grid associated WTs. Depending on this principle, the WT must be connected to the grid where the voltage stays at a level more than 20 than the nominal operating value for length less than as 0.5. WTs can be disconnected from the grid only when the voltage normal profile dropped in Region B, close to the LVRT requirements, here grid codes additionally needs huge WTs to reply throughout error and retrieval. Inject strength of the machine to contribute to the protection of the voltage of the energy devices**(Munteanu et al 2008).**

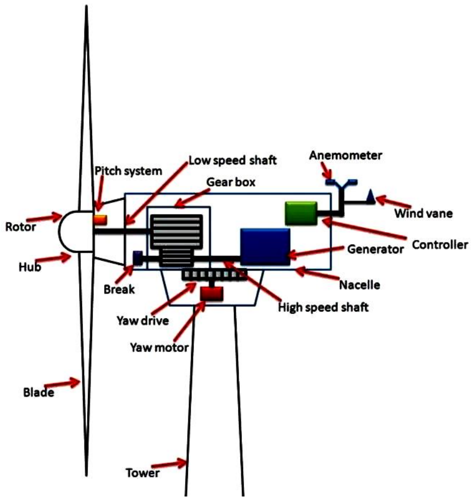


Fig.1: Wind Turbine Components

The majority of wind turbine components shown above in figure 1, are located in remote areas with hard-to-access structures which would increase maintenance costs for wind turbine systems. In addition, the availability of wind power is reduced by the lack of reliability. Reliability is therefore extremely necessary for cost reduction. The condition surveillance and fault diagnosis are introduced to achieve the goal. Condition monitoring and fault diagnostics is important techniques that minimize downtime and enhance the energy supply and lifetime of WT components to reduce operation and maintenance costs(**Blaabjerg et al 2005**).

2. Wind Energy Conversion System

Wind generates sporadic sunshine, which heats the atmosphere. The formation of hot and cold air regions results in pressure levels. The air movement from a high pressures area in a low pressure area is responsible for the wind flow. Water's kinetic energy is referred to as "energy in motion." The diagram of the network wind power conversion block with both parts is seen in Figure 2. This cinematic energy affects the wind turbine's aerodynamically engineered blades, which cause it to rotate. Wind speed is always insufficient to drive the blades at a pace that is electricity-neutral. In certain WECS topologies, the gearbox aids in increasing the rotor shaft's rpm. The generators convert the shaft's mechanical energy into electricity. This energy is transmitted to the grid(**Marques et al 2003**).

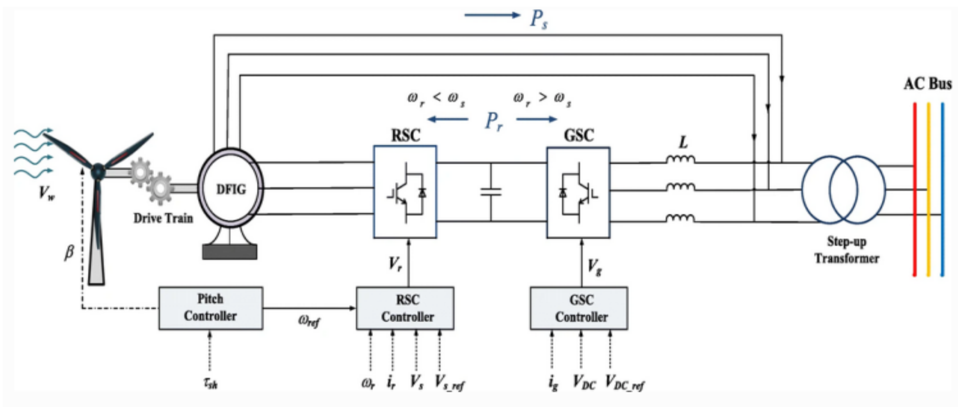


Fig.2: Model of Wind Energy Conversion System

A wind turbine variable speed system with a Double Fed Induction Generator is the second kind (DFIG)(**Chinchilla et al 2003;Iyasereet al 2012;Benchagra et al 2012**). The winding rotor electric converter has a power rate of around 30%, and the DFIG winding stator is directly connected to the grid. A variable wind turbo with a fully rated synchronous generator or SCIG electronic conversion system is the third kind. A multi-stage transmission is typically used by two generators. Synchronous generators, such as permanent synchronous magnet generators, can be powered directly by low-ratio gearbox systems (PMSG). A single- or two-phase gearbox is an intriguing option **(Sedighizadehet al 2004;Nguyen et al 2012).**

3. Doubly-Fed Induction Generators

The DFIG mathematical model is depicted below in figure 3. It includes all of the model's equations, such as the flux, voltage and torque equations. The stator current is believed to be positive to outflow and the rotor current to be positive to inflow in this article. The positive orientation of current is described in this way. The architecture of DFIG implemented in a d-q synchronous rotating coordinate system is seen in the diagram below(**Sedighizadehetet al 2012**).

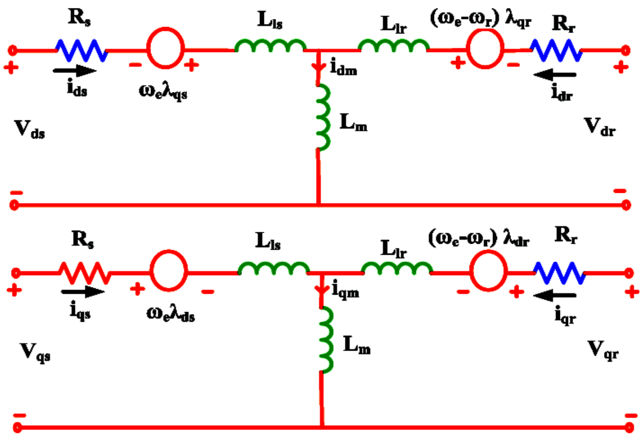


Fig. 3 Equivalent Circuit Diagram of DFIG for both direct Axis and quadrature Axis

$$V_{ds} = R_s i_{ds} + d\Psi_{ds}/dt - \omega_{dqs}\Psi_{ds} (1)$$

$$V_{qs} = R_s i_{qs} + d\Psi_{qs}/dt + \omega_{dqs}\Psi_{qs} (2)$$

$$V_{dr} = R_r i_{dr} + d\Psi_{dr}/dt - \omega_{dqr}\Psi_{qr} \quad (3)$$

$$V_{qr} = R_r i_{qr} + d\Psi_{qr}/dt + \omega_{dqr}\Psi_{dr} (4)$$

$$\Psi_{ds} = L_{ss} i_{ds} + L_m i_{dr} (5)$$

$$\Psi_{qs} = L_{ss} i_{qs} + L_m i_{qr} \quad (6)$$

$$\Psi_{dr} = L_m i_{ds} + L_{rr} i_{dr} \quad (7)$$

$$\Psi_{qr} = L_m i_{qs} + L_{rr} i_{qr} \quad (8)$$

$$\text{(Torque) } T_m = 1.5 p L_m (i_{qs} i_{dr} - i_{ds} i_{qr}) = 1.5p(\Psi_{ds} i_{qs} - \Psi_{qs} i_{ds}) \quad (9)$$

In the equations given below; u, i, ψ refers to the voltage, the instantaneous current and the flux in each stator winding and the rotor winding in d-q synchronous reference system respectively. R_s and R_r refers to stator resistance and rotor resistance of the windings respectively. Lls and Llr refers to the leakage inductances of the DFIG model of stator and the rotor respectively.L_mSymbolizes mutual inductance.L_{ss} symbolizes the stator side self-inductance, satisfying L_{ss}=$L_m + Llr$.L_{rr} symbolizes the rotor side self-inductance which based on the following model equation, $L_{rr} = L_m$+Llr.ω_{dqs} and ω_{dqr} symbolizes stator side magnetic fields and the rotor side magnetic field's rotating angular velocity respectively**[Astolfi et al 2008;Nguyen et al 2018]**.

The equation of the motion of the rotor is defined as follows:

$$T_m - T_e = \frac{J}{P}\frac{dw_r}{dt} (10)$$

where,T_m represents the mechanical torque. It acts the input torque to the DFIG; Te represents the DFIG's electromagnetic torque; J represents the DFIG's rotational inertia; p represents the DFIG's polar logarithm;w_r represents the DFIG speed. [13-15]

4. Low Voltage Ride Through Technique

The rotor side converter is seen in Figure 4, adding voltage to rotor windings for stimulation of the induction generator. The actual portion of the rotor current irq with the irqref is compared to a PI control with the internal control loop and is limited to zero. The vrq voltage of the rotor-side converter is the output of the current controller. A similarly operated portion of the ground and vrd, which drive the ground and the irq to their reference values, produces the required 3-phase voltages used for the rotor winding. In other words, the rotor side converter produces different frequencies of excitation, depending on the wind speed**(Ganthia et al 2020;Ganthiaet al 2020;Honrubia-Escribano et al 2017; Sun et al 2017;Guest et al 2017).**

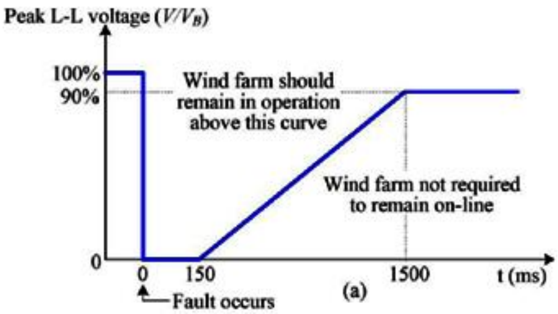


Fig.4. LVRT curve

A synchronous dq-axis framework with the d-axis is employed for one default implementation to run an induction generator in accordance with the stator-flux vector position. This is known as SFO's vector power. The name is SFO. Active and reactive controls can also be administered individually. The orientation frames such as rotor-flow orientation and magnetizing flux orientation may often be employed in typical vector control of inductor generators. Also commonly utilized in DFIG vector controllers is the stator-powered direction (SVO**)(Ganthia et al2018;Ko et al 2008; Ganthia et al 2017;Ganthia et al 2018).**

5. Dynamic Voltage Restorer Control & Operation

Power quality is nothing more than the ideal power supply in tolerances with voltage and frequency. The breakdown of consumer equipment might be the cause behind the quality electricity. These concerns are connected to concerns connected to voltage, such as voltage slope, swell, harmonics, inadequate power factor and voltage imbalance that affect electrical equipment efficiency. The energy quality issues include lightning, power, equipment, failures, interruption of switching, etc. Different filter technologies in the power system are utilized to provide desired power quality, but the user is not adequately satisfied.To prevent and overcome instability disadvantages, compensation is necessary and the dependability of the system increases, modern power electronic controllers have launched and given birth to bespoke power throughout the past several decades. The trend for effective voltage compensation is growing according to the IEEE and IEC standards towards Custom Power Units (CPDs). Voltage distortions are now one day the major difficulty for industrial customers, amongst other tension-correlated problems.The CPD is one of the finest strategies for reducing voltage-related issues. Different CPDs exist, each with its own special requirements and limits. In the industry, DVR has become more important to alleviate voltage-related concerns and preserve sensitive loads among other new CPDs. DVR is a serial-converter that protects sensitive electric appliances from problems in terms of power quality.The power and frequency in the load side are supplied by the DVR. It is used to offset distortion of voltage. It is also utilized as an electrical high power controller. For harmonic reduction, fault current restrictions and transient reductions, DVR is employed. A DVR includes an ICT, VSC, energy storing unit and filter as illustrated in Figure 5.(**Tohidi et al 2016; Ghennamet al 2009;Kimet al2010; Sirajet al 2014;Wei et al 2008)**

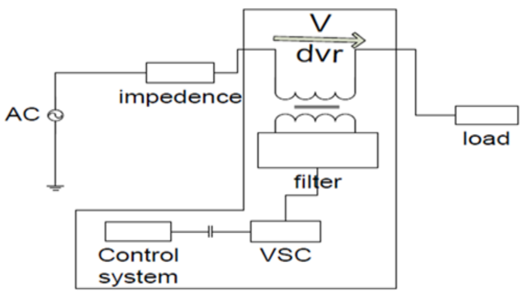


Fig.5. Configuration of DVR

6.Fuzzy Logic Controller

Figure 6 illustrates the flow diagram of the scheme presented. There are developed two related Fuzzy Inference Systems. Firstly, to detect the erroneous phase(s) and secondly, to detect the ground.

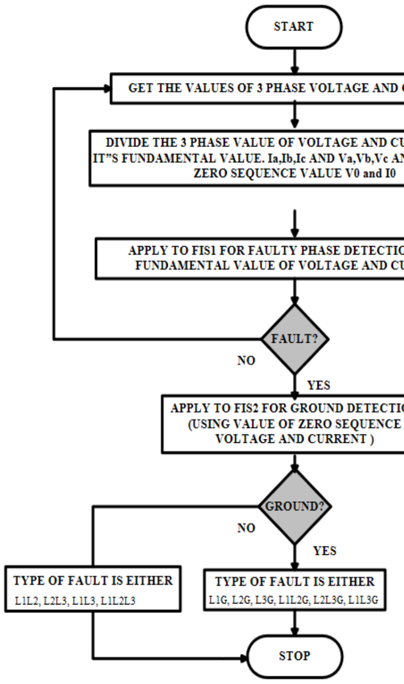
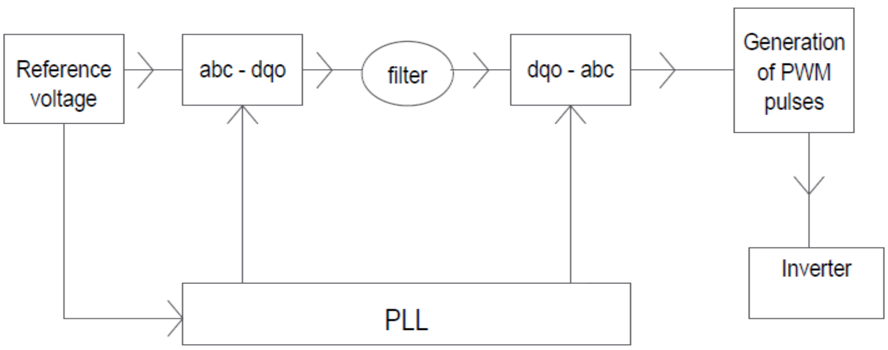


Fig.6. Flow chart for controller fuzzy logic fault current detection

The rules and methods for achieving success are seen in the table below. Each phase uses the tension and current inputs. The FIS file is in Mamdani format and is used as a function of triangular membership. The position of membership consists of three areas: low, medium and high membership rule. The performance has triple membership rules and is named 'trip.' The three categories of lines are low flight, edge journey and high journey**(Ganthia et al 2017;2019;2020;2021).**

7. Synchronous reference frame theory (SRF theory)

SRF Theory is the most predictable and suitable for DVR among DVR's multiple control schemes. The primary conception of the phrase is to have a frame rotating at synchronous velocity. Compared with other approaches, SRF-based controls have admirable characteristics, but need PLL technology. **[Ganthia et al2018;Kyung-Min Jin et al 2012]** The new technology for locking the phase is based on PLL and operates under distorted and uneven load situations. This methodology One of the major approaches used to reduce THD is SRF theory. The principal benefit of SRF-theory is that there is no time-dependent translation of spatial co-ordinates. The SRF theory uses the park equation. This process transforms the three phase current or voltages into a D-q reference frame synchronously revolving. The transformation of the parks produces a continuous essential component that is filtered with a filter system by removing high frequency components. No phase error is caused by the DC component of the filter



circuit**(Ganthia et al 2021;Ganthia et al 2016;Ganthia et al 2018; Kyung et al 2012)**.

Fig.7. Basic proposed diagram of SRF theory

The load current in SRF theory is transformed to the synchronous d-q referral frame from three phases. The d-q currents have a basic and harmonic component. Three phase harmonic signals are produced by means of reverse park transformation.The work suggested DVR based on SRF theory may be utilized to prevent linked voltage concerns such as sag, inflammation, etc. The work presented includes transformations from a-b-c to d-q-o, filters, inverters and PLL as shown in fig 7. DVR controls the voltage injected by the injection transformer in this technology. The utilities are sent into d-q-o, and filter circuits are utilized for the components necessary, and reverse transformations are carried out to gain a-b-c. PLL is also utilized for the calculation of reference voltage**(Pire et al 2011;Satpathy et al 2021;Pragati et al 2021;Kohilaet al 2015).**

8 . MATLAB Simulink Design

The voltage source converter is a dynamic voltage restorer illustrated in figure 8 below. It is frequently linked to the grid via a line filter (typically an LC type) and a serial coupling transformer to fix deteriorating routine voltages to reduce probable load or generator issues. Various DVR topology with relation to power and voltage ratings are compared here. The crowbar protection and DVR protection system is compared here. In each of the systems the positive and negative sequence voltage components are tracked with good steady-state sinusoidal errors.

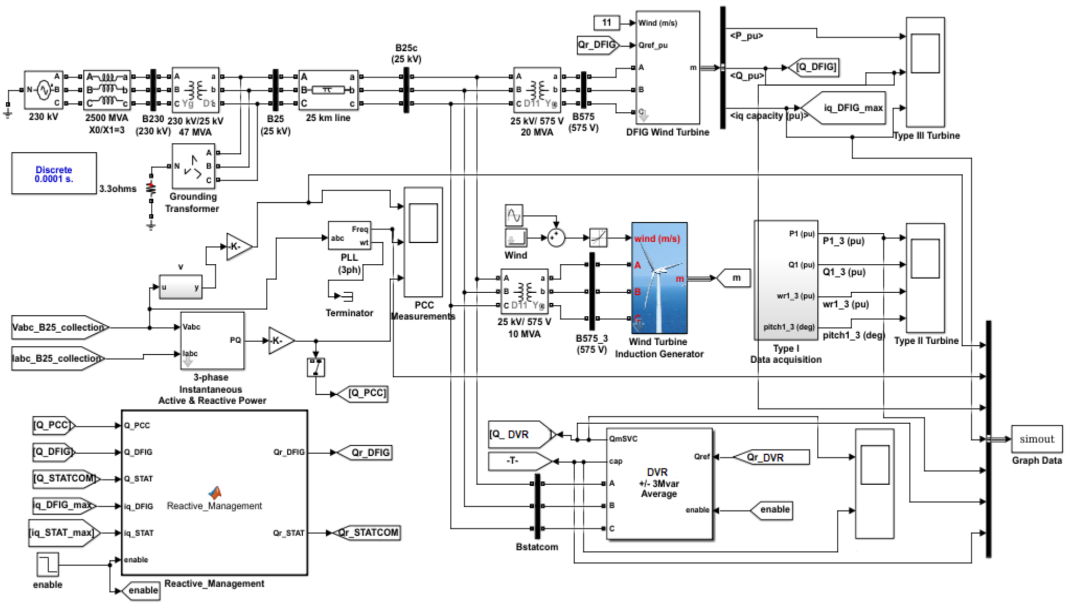
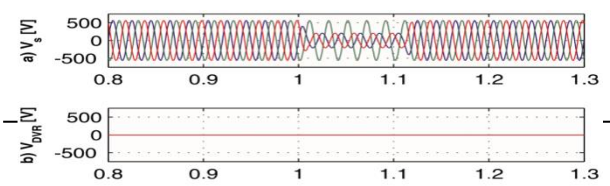
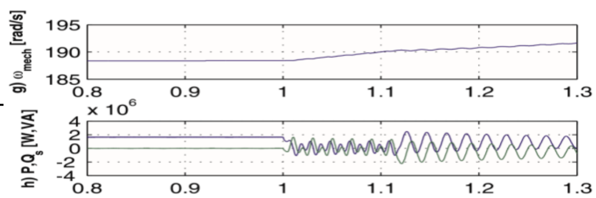


Fig.8: Flow chart for fuzzy logic fault current detection



9 SIMULINK RESULTS



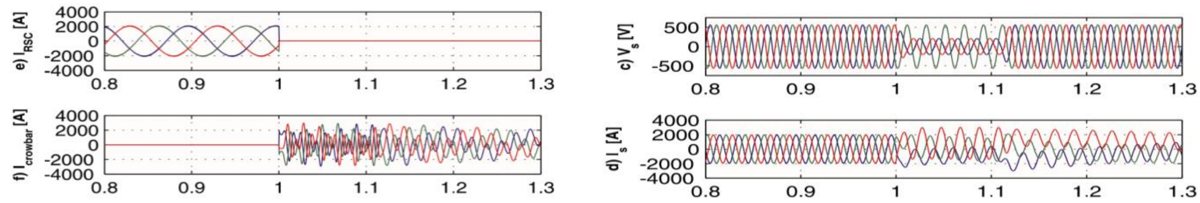


Fig. 9. Simulation Results under 5% voltage dip: a) voltage (Supply Line) b) voltage (Stator line) c) current (stator Line) d) current (rotor side converter) e) current (crowbar) f) stator power (P & Q) g) speed (mechanical) h) voltage across the DVR i) DVR power (P & Q)

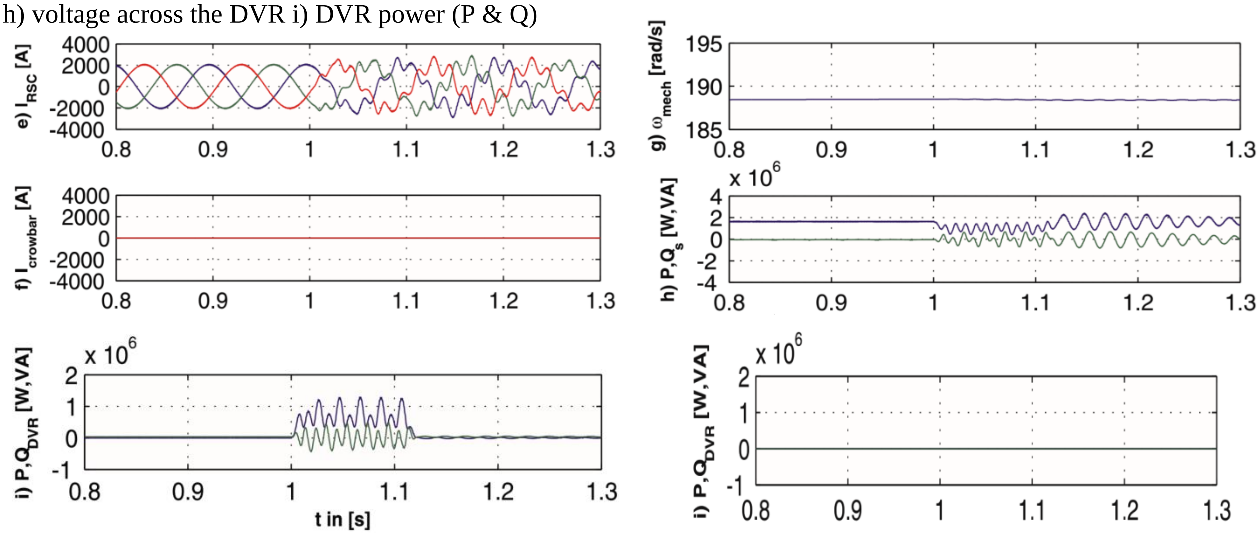


Fig. 10. Simulation Results under 10% voltage dip: a) voltage (Supply Line) b) voltage (Stator line) c) current (stator Line) d) current (rotor side converter) e) current (crowbar) f) stator power (P & Q) g) speed (mechanical) h) voltage across the DVR i) DVR power (P & Q)

10. **Conclusion**

This paper seeks to protect a DVR during failure drive for a DFIG wind turbine system. The DVR's performance is controller-based. The synchronous reference framework (SRF) theory was established to manage DVR, injected into active power, and to reduce three-phase disturbances in the utilities side. DVR performance was examined using the three-stage distortions generated by the three-stage defective block. The PWM sinusoidal technology is employed to supply the inverter gate signals. One of the most frequent techniques of detecting phase angle, frequency and amplifier of the three-phase system voltage is the PLL design based on the synchronous referencing frame and the PI controller. A DVR device was used to test the proposed PLL structure and immediately allows the utility voltage to lock. Set the reference direct axis tension to 0 results in the PLL output being locked in the utility tension vector phase angle. The overall performance and dynamic behavior of the suggested PLL construction have been demonstrated to confirm the theoretical expectations. The overall ability to safeguard the charge from utility voltage difficulties is good.

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