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Solutions for Voltage SAG in a Doubly Fed Induction Generator Based Wind Turbine: A Review

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Abstract

Harnessing energy from the wind is a conventional method. Innovations have been made in the mechanical structure for the effective production of energy. To increase the electrical efficiency, losses due to fault in the system must be reduced. One such fault is the Voltage sag/dip. This paper throws light on the complexities of the voltage sag in Doubly Fed Induction Generator (DFIG) wind turbine and how this fault has been rectified over a period of time by different researchers. A brief description about the problems encountered and the feasible measures taken is presented.

Keywords: Doubly Fed Induction Generator (DFIG), Low Voltage Ride Through (LVRT), Voltage sag, Rectification, Wind Turbine, Faults

1. Introduction

Wind energy harnessing is an age old technique and was used by Persians soon after civilization. In the recent years, interest towards renewable energy sources is gradually increasing as there is low availability of coal and tar. This work will elucidate the importance of DFIG based wind energy system with a focus on mitigation of voltage sag.

The protection of wind turbine has been the major concern and impact of this on the power system is seldom considered. However, the rise in the number of turbines and its varied utilization has now led us to focus on the grid support that the turbines have. One of the prominent areas is the voltage sag ride-through. It dominates the link of the wind turbine and the power system[1].

Due to the property of the Doubly Fed Induction Generator (DFIG) (Figure 1) to operate in varying speed and at constant frequency, low cost and weight makes itself unique with respect to other generators available in the market[2]. The mechanical structure of DFIG and the complex rotor circuitry introduces high voltage sag during grid fault conditions. During the period of fault occurrence, high fault current entering the inverter will damage the power semiconductor devices[3]. Conventional connections will aid the turbine to disconnect when voltage sag was below 0.8 p.u. (Per unit)[4]. In recent days, instead of disconnection, the wind turbines are required to support the grid during voltage sags as new regulator codes require low voltage ride through capability for the turbine[5]. This paper reviews the solutions to avoid the voltage sag that takes place in the wind turbines.

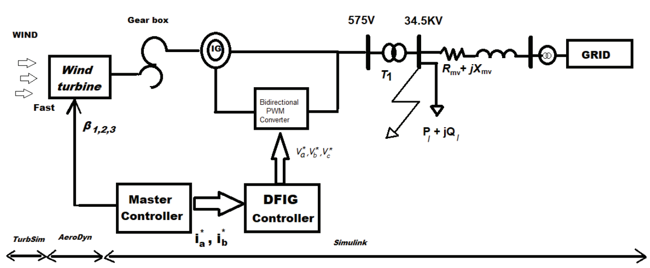

Figure 1. Structure of the variable-speed wind turbine with DFIG and grid connection.

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2. Voltage SAG

Voltage sag (also known as voltage dip) is the drop in voltage for a brief time period between half cycle to 60 seconds due to load variation or short circuit and transformer energizing. The dips that persist for less than 0.5 cycle are known as low-frequency transients and the sags that last more than 60 seconds are called under-voltage[6]. Even with the minute time period of the dip, a lot of problems take place for a wide range of devices, as wind turbines, adjustable speed drives, computers and process control devices. The sags have a stochastic behavior as these are usually caused by short circuit faults. Collectively, voltage sag or voltage dip is delineated by its magnitude and its time period[6].

A large number of guides have been projected to evaluate the performance of a power system. It is done by counting the event frequency and the interval, the undelivered energy during events and the magnitude of hindrance.

2.1 Classification of Voltage DIP/SAG

At any point, when a fault takes place in the power network, the grid voltage will drop to the lower levels until a security gadget trips and circuit breakers detach the fault. Amid this interim, wind generators associated with the same bus as the fault feeder will encounter a voltage sag condition. This segment plans to describe and group the voltage droop conditions caused by diverse flaws in the network.

2.2 Impact of Voltage SAG on Wind Turbine

The impacts of voltage sag on wind turbine frameworks are considered in this segment. In this examination, the voltage droop happens while the wind turbine is creating rated power at unity power factor. The System control layer and X/R proportion of the power framework connection have been viewed as 50 MVA and 5 respectively. The voltage and currents of the induction generator are shown in Figure 2. The stator voltage dips to 80% at $t = 15$ seconds, in view of a three-phase fault at 34.5 KV side and recoup to normal voltage level at $t = 15.2$ seconds, when the fault is cleared[7].

As can be found in Figure 2, the voltage sag creates some transients on the stator and rotor currents and the rotor voltage. Be that as it may, the circumstance after

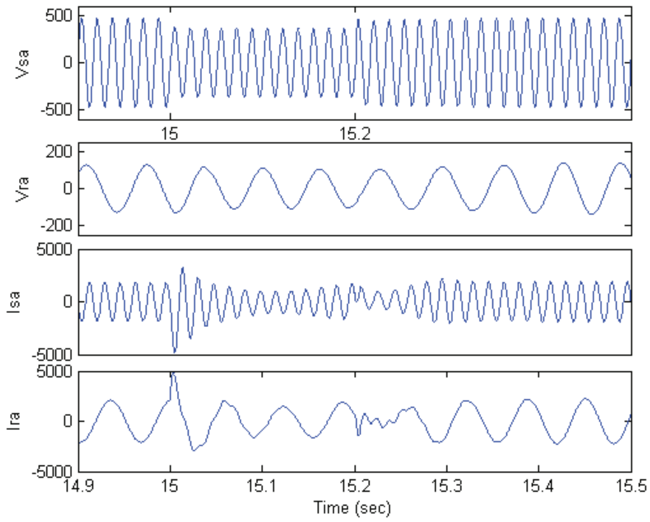

Figure 2. Voltage and current of stator and rotor at the fault duration of 15 to 15.2 sec[7].

this voltage sag isn't critical enough to trigger the rotor security gadgets. The control plans of the DFIG work as ordinary and attempt to re-establish the turbine's typical activity after the unsettling influence is cleared.

The voltage and current transient significantly change the generator active and reactive power during the fault duration of 15 to 15.2 s, which are appeared in Figure 3. The lateral tower acceleration at top, generator torque and the low speed shaft twist angles at the fault duration of 15 to 15.2 s are appeared in Figure 4.

It additionally portrays how an electrical disturbance causes side to side vibration on the tower.

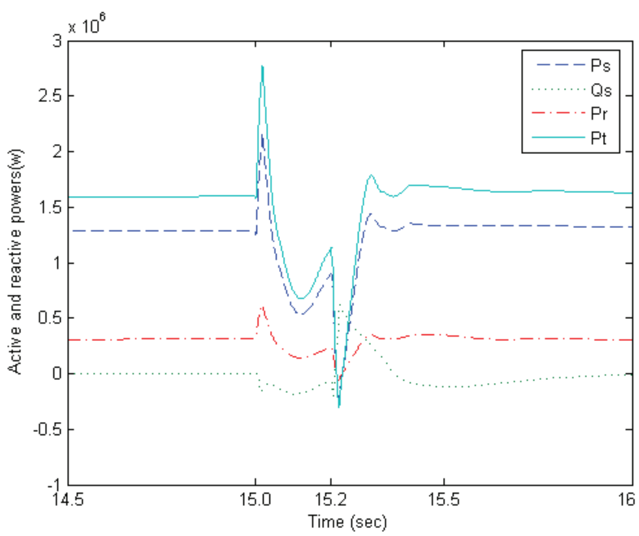

Figure 3. Stator active and reactive powers during fault duration of 15 to 15.2 sec[7].

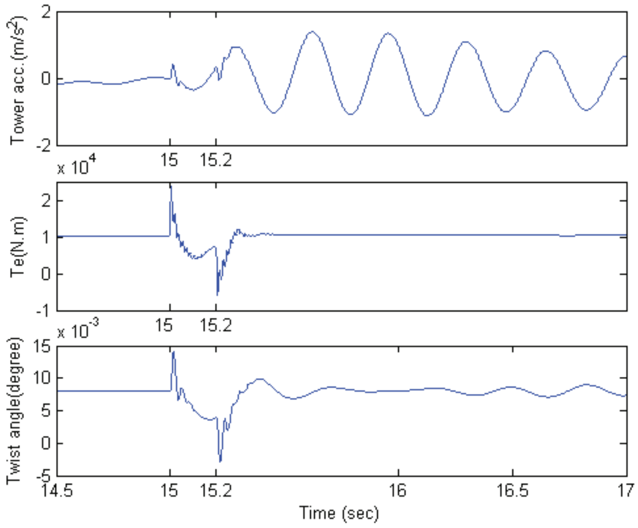

Figure 4. The effect of voltage SAG on generator torque during fault duration 15 to 15.2 sec[7].

2.3 Effect of Voltage SAG on Rotor Current

In any case, in light of the fact that the stator of a DFIG is directly connected to the electrical grid, it is to a great degree sensitive to grid voltage disturbances. Voltage sag at the stator because of grid fault that is injected during the fault duration of 15 to 15.2s, prompt over voltages in the rotor windings, bringing about over currents of the rotor circuit, which may extremely harm the vulnerable rotor-side power electronic converter and expansive fluctuation of the DC-link voltage. Such a vast rotor inrush current, DC-link over voltage and torque oscillations caused by grid faults are very destructive for the DFIG-based wind turbines, and damage to the converter and mechanical parts. Generally, once over currents happen in rotor windings, the crowbar is utilized to secure the rotor converter by short circuiting the rotor winding. The crowbar comprises of resistors, which are controlled by power electronic gadgets.

In this segment, an enhanced control methodology is proposed to decrease the rotor current amid grid voltage sag. The proposed control framework comprises of a typical vector controller, LVRT controller, and reactive power calculation module, voltage sag identification, and controller switching module. Stator-flux oriented control scheme is utilized as an ordinary vector controller, which can understand dynamic and responsive power decoupling control under typical condition. Magnetization control scheme was proposed, which depends emphatically on the parameters of the DFIG; since the leakage of the DFIG is little, the rotor current could be huge amid voltage dip, especially, deep dip[8].

3. Crowbar Protection

To shield the Rectifier side converter from tripping due to over current's in the rotor circuit or over voltage in the DC link during grid voltage dip, a crowbar is introduced in ordinary DFIG wind turbines, which is a resistive system that is connected with the rotor windings of the DFIG. The crowbar confines the voltage and gives a safe path for the current through the rotor resistor. When the crowbar is initiated, the Rectifier side converter's pulse are debilitated and the machine carries on like a squirrel cage induction Machine directly coupled to the grid. The magnetization of the machine that was given by the Rectifier side converter in ostensible condition is lost and the machine assimilates a lot of reactive power from the stator, and in this way, from the network, which can further reduce the voltage level and isn't allowed in the grid. Activation of the crowbar circuit implies high stress to the mechanical segments of the system as the shaft and the gear. Point by point examinations on the DFIG conduct during voltage dip and crowbar protection can be found in[9,10]. Along these lines, from system and machine perspective, a crowbar triggering ought to be stayed away from.

Anyway, to contrast the exhibited method here and a traditional DFIG wind turbine system protected by a crowbar circuit. Crowbar resistances are also designed as per[10,11].

There are two limitations that give an upper and a lower limit to the crowbar resistance. As a first limitation, the crowbar resistance ought to be sufficiently high to restrict the short circuit rotor current $I_{r\,max}$. As the second imperative, the crowbar resistance ought to be sufficiently low to maintain a strategic distance from too high voltage in the rotor circuit. In the event that the rotor phase voltage across the crowbar transcends the most extreme converter voltage, high currents will course through the anti-parallel diodes of the convertor. There are approaches restricting the operation time of the crowbar to come back to typical DFIG operation with active and reactive power at the earliest opportunity like in[12] by infusing a demagnetizing current or in[13] utilizing a threshold control.

In the laboratory setup, a passive crowbar circuit is utilized that is activated by a rotor overcurrent. The crowbar can be debilitated manually by the user when safe conditions are restored.

4. Rotor Side Converter (RSC) Control

The RSC gives decoupled control of stator active and reactive power. A cascade vector control structure with inward current control loops is applied. The general control structure is[14]. When adopting Stator-Voltage-Oriented (SVO) control, a decomposition in d and q components is performed ($V_{sq} = 0$).

Where d and q indicates direct axis and quadrature axis components. Where V_{sq} indicates quadrature axis stator voltage. Dismissing the stator resistive voltage drop, the stator output active and reactive forces are expressed as

$$P_s \approx V_{sd} I_{rd} \tag{1}$$

Where P_s is the Stator real power; V_{sd} is the direct axis stator voltage; I_{rd} is the direct axis rotor current.

$$Q_s \approx (L_h I_{rq}) \tag{2}$$

Where Q_s is the Stator reactive power; L_h is the line side inductance; I_{rq} is the quadrature axis rotor current.

Therefore, the stator active and reactive power can be controlled independently, controlling the d and q components of the rotor current. In light of the above equations, the external power control loops are designed.

5. Line Side Converter (LSC) Control

The Line Side Converter controls the DC voltage (Vdc) and gives reactive power support. A voltage-oriented cascade vector control structure with internal current control circles is connected. The line current I_l can be controlled by changing the voltage drop over the line inductance L_l giving the following dynamics:

$$V_s = R_l I_l + L_l \tag{3}$$

Where V_s is the stator voltage; R_l is the line side resistance; I_l is the line side current; L_l is the line side inductance. which is utilized to outline the current controller, while the dc voltage dynamics can be expressed by

$$C_{dc} = I_{dc} - I_{load} \tag{4}$$

where C_{dc} is the dc capacitance and I_{dc} and I_{load} are the dc current and load current towards line side converter and rotor side converter respectively. which is utilized to outline the external dc voltage control loop

6. Conclusion

This paper demonstrates a detailed analysis on the faults which arise due to the voltage sag/dip through various influencing factors and how this fault has been rectified by diverse methods such as Low Voltage Ride Through (LVRT) control of rotor current, crowbar protection, Rotor Side Converter (RSC) control and Line Side Converter (LSC) control. A thorough comprehensive study on the solutions recommended by different researches has been done.

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