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ENHANCEMENT OF LOW VOLTAGE RIDE THROUGH CAPABILITY GRID-CONNECTED PHOTOVOLTAIC POWER PLANTS BY USING VOLTAGE CONTROL METHOD

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Abstract—*A full-scale permanent-magnet synchronous generator (PMSG)-based wind turbine with dc-link voltage control via the machine-side converter has the potential to provide inherent low-voltage ride-through (LVRT) performance without additional hardware components. However, several important performance aspects related to this topology are not addressed in this literature. This paper investigates the impacts of the LVRT control on the stability and risk of resonance, successful operation, and fatigue in a full-scale PMSG-based wind power generation system. An analytical model, considering the double-mass nature of the turbine/generator and typical LVRT requirements, is developed, validated, and used to characterize the dynamic performance of the wind generation system under LVRT control and practical generator characteristics. To enhance the operation and reduce the fatigue under LVRT control, two solutions, based on active damping control and dc-link voltage bandwidth retuning, are proposed, analyzed, and compared. The detailed nonlinear time-domain simulation results validate the accuracy of the developed model and analytical results.*

Keywords— A ging; Fatigue; Low-Voltage Ride-Through; Modeling; Permanent-Magnet Synchronous Generator (PMSG); Stability; Wind Power Generation

1. INTRODUCTION

Wind turbines technology has become very advanced so that wind power is measured as a major green source in modern power systems. Therefore, the saturation level of wind power generation is rising quickly with no signs of slowing down. While the established issues of wind control, for example, removing the mainly severe accessible wind control, have been explained, the expanded entrance level of wind control is create new issues for control frameworks. Joining wind power generators in recurrence control and Low-Voltage Ride Thorough (LVRT) are among these major issues. Recurrence direction has increased noteworthy consideration in the writing as of late, and matrix codes for LVRT have been consistent and actualized in a few countries. Commonly, LVRT guidelines underscore the require to remain a wind control generator related with the network or to advance the voltage profile amid low-voltage homeless people. Reference demonstrates that every one of the generators in a wind cultivate are not essential to give LVRT ability; nonetheless, this reference does not difficulty the need to execute LVRT usage in wind power generators. The execution of a Doubly-Fed Induction Generator (DFIG), as the most well-known sort of wind generator, has been widely examined under LVRT. While the crowbar strategy is broadly used in DFIGs, it is characterize by the loss of control and the misuse of vitality.

As an option, the demagnetizing control strategy has been proposed; be that as it may, it has not been generally embraced because of its difficulty. All these troubles, other than some different issues, such as consistency, misfortunes, and the cost of slip rings and gearboxes, decrease the focal points of DFIGs and result in an expanding trend toward utilizing direct-drive Permanent-Magnet Synchronous Generators(PMSG) with full-downsize to-back converters. However, this topology with ordinary control (i.e., DC-link voltage control by means of the matrix side converter) yields high dc-link voltage amid blame conditions. A few methodologies have been proposed to conquer this trouble. Reference proposes the utilization of a breaking resistor to disseminate inordinate dc-link energy; in any case, this technique builds the misfortunes. The utilization of the turning mass of a twist generator for putting away the extreme generation amid the blame is proposed. The objectives of these investigations were to not just upgrade the dc-link voltage flow amid flaws, additionally to enhance distinctive aspects of the framework voltage even under helter kilter shortcomings. The results of these examinations are promising and show the PMSG as a generator with an inalienable LVRT capacity without the need for any extra segments. Notwithstanding, the twofold mass nature of the turbine-generator mechanical flow and its relatively soft shaft qualities are not considered in these works. The natural reverberation of PMSG-based wind control generators under conventional conditions has been explored completely.

The main contributions of this paper to the field are

1) providing a three-stage small-signal model for a PMSG based wind generator to examine the fault ride-through dynamics by allowing for the double-mass mechanical dynamics and distinctive LVRT characteristics.

2) Investigating the stability, risk of resonance, and successful operation of a PMSG-based wind power generator under LVRT.

3) Studying the impact of the LVRT control on the generator fatigue.
4) Studying and comparing the performance of two possible solutions for performance enhancement and fatigue reduction in a PMSG-based wind generator with LVRT.

2. WIND TURBINES

The wind turbine is the primary and leading part of wind power systems. There are two main types of wind turbines, the horizontal-axis and vertical-axis turbines.

Horizontal-axis Turbines are primarily composed of a tower and a nacelle mounted on top of tower. The generator and gearbox are usually situated in the nacelle. It has an elevated wind energy conversion efficiency, self-starting capability, and admittance to stronger winds due to its rise from the tower. Its disadvantages, on the other hand, include elevated installation cost, the want of a strong tower to hold the nacelle and rotor blade, and longer cables to connect the top of the tower to the ground.

A Vertical axis Turbines' spin axis is perpendicular to the ground (See Figure 2.1). The Wind Turbine is vertically mounted, and its generator and gearbox is situated at its base. Contrasted with even hub turbines, it has decreased establishment cost, and upkeep is less demanding, in light of the ground level apparatus box and generator establishment. Another preferred standpoint of the vertical pivot turbine is that its operation is autonomous of wind course. The cutting edges and its connections in vertical hub turbines are likewise lower in cost and tougher amid operation. Nonetheless, one noteworthy disadvantage of the vertical wind turbine is that it has low wind vitality transformation proficiency and there are restricted choices for speed direction in high winds. Its productivity is around half of the proficiency of even pivot wind turbines. Vertical pivot turbines likewise have high torque changes with every unrest, and are not self-beginning. Basically because of productivity issue, level wind turbines are principally utilized. Thus, the wind turbine considered in this proposal is a flat pivot turbine.

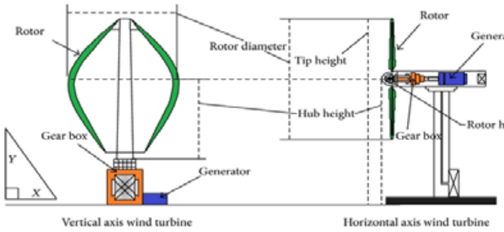


Fig.1 illustration of a horizontal axis and a vertical axis wind turbine

The fundamental assignment of the stator side converters is to control the electromagnetic torque of the turbine. By modifying the electromagnetic torque, the turbine can be compelled to extricate greatest power. The rectifier interfaces the rotor and the utility; it changes over the Alternating Current (AC) from the utility matrix into a Direct Current into the rotor windings. DC current moves through the rotor windings and supplies the generator with the important attractive field for operation. Perpetual Magnet Synchronous Generators (PMSG) are normal in low power, variable speed wind vitality transformation frameworks. The upsides of utilizing PMSGs are its high effectiveness and little size. Nonetheless, the cost of the changeless magnet and the demagnetization of the lasting magnet material ought to be considered.

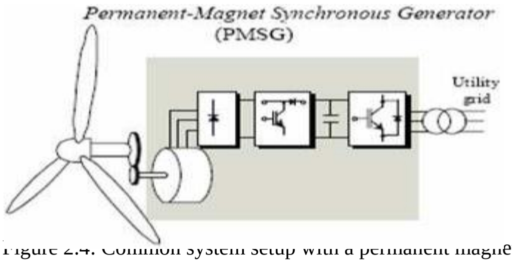


Figure 2.4: Common system setup with a permanent magnet wind turbine (generator is connected to the utility through a diode rectifier, boost converter and an inverter).

The stator windings of the PMSG twist turbine in Figure 3.5 are associated with the matrix through two consecutive PWM control converters. Most extreme power point following calculations are normally actualized in the utility side converter, however can by and large executed in either converter. The PWM tweak utilized as a part of this arrangement decreases the present consonant segment in the information and yield of the framework. By utilizing PWM converters, there is likewise decreased torque throb on the generator and the yield control quality is moved forward.

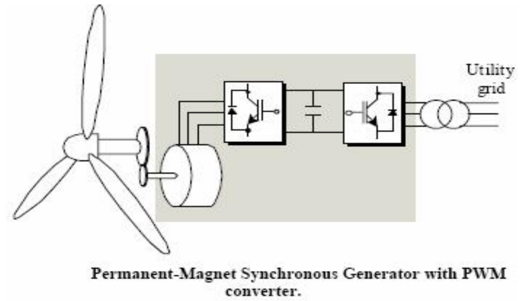


Figure 2.5: Common system setup with a permanent magnet wind turbine (generator is connected to the utility through two back-to-back converters).

Figure 2.4 and 2.5 show two basic network association setups of PMSG wind turbines. In Figure 2.4, the stator windings are associated with the utility framework through a diode rectifier, help converter, and a PWM inverter. The diode rectifier corrects the variable recurrence and extent yield AC voltages from the turbine. The lift converter then again controls the electromagnetic torque of the generator. To support the wind vitality transformation effectiveness of the framework, the lift converter is combined with a greatest power point following calculation. At the matrix side, the power inverter directs the shifting DC interface voltage and controls the yield control figure.

Full Scale Wind Turbines (FSWT) are the state-of-the-art type wind turbines that the generator is completely decoupled from the grid with two back-to-back converters and whole power is transferred through these controlled converters. One converter issued on the generator side and the other one is used on the grid side. FSWTs can employ both induction (asynchronous) and synchronous type generators, where synchronous generators can be separately excited (conventional) or permanent magnet type. Generally multi-pole permanent magnet synchronous generators are employed, which removes the need for a gearbox between wind turbine rotor and generator. Since this type of wind turbines has many advantages like mechanical reliability, better efficiency, reduced risk of possible drive-train oscillations, this thesis will deal with PMSG type FSWTs.

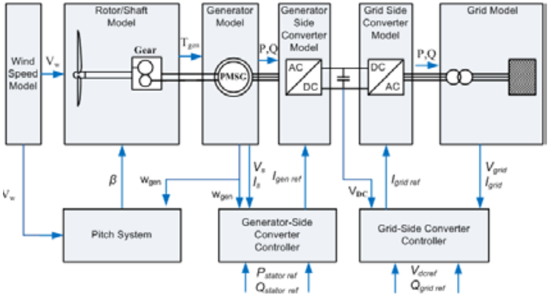


Figure 2.11Block Diagram of PMSG Type Wind Turbine

Figure 2.11 depicts the general block diagram of a Variable Speed Wind Turbine(VSWT) with PMSG. As seen, the model of a VSWT equipped with PMSG is very similar to that of a VSWT with a DFIG. Wind speed model, rotor (aerodynamic) model and pitch model are identical to those in DFIG type wind turbine model.

3. SYSTEM MODELING

Fig. 4.1 shows a PMSG-based wind power generator. Classically, the network side converter (GSC) is used to regulate the dc-interface voltage while the Wind-Generator-Side Converter (WSC) extricates the greatest accessible power. Amid a fault, the GSC loses its capacity to infuse or sink dynamic power, partiallyor totally; in this manner, a voltage infringement may happen in the dc-connect voltage. On the other hand, to use the generator rotating mass for putting away the over the top vitality amid a blame, switching the control elements of the WSC and GSC has been proposed. This exchanging could be either changeless or just briefly amid shortcomings.

In this paper, the performance of an LVRT-capable PMSG-based wind generator in which the control functions of the WSC and GSC are permanently switched is analyzed. It is easy to show that no major difference exists in the behavior of a PMSG-based wind generator under normal operating conditions with the dc-link voltage regulated by either the GSC or the WSC.

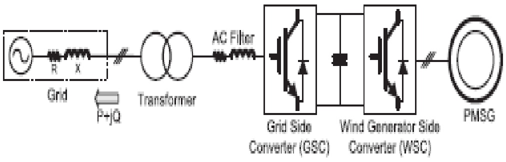


Fig. 4.1.PMSG-based grid-connected wind power generator.

Determining linearized models for a wind control generator is crucial to break down the generator dynamic execution during LVRT and to organize distinctive controllers. Under LVRT, a wind generator will be subjected to various working conditions and tremendous changes; in this manner, using one linearized model does not appear to be sensible. Rather, three models are received in this paper. The primary model describes the wind control generator dynamics in the pre-blame condition. For this situation, the model input is the wind speed. The second model considers the generator dynamics in the "amid blame" period, where the generator output control is managed by the power framework conditions insteadof extricating the greatest accessible wind control.

4. SIMULATION RESULTS

The wind generator converters controllers are depicted in Figs. 4.3 and 4.4. A PMSG is employed in a Distributed Generation unit 1 (DG1). The second unit, DG2, is modeled based. The droop and excitation system models are also included. Typical distribution system lines, with low X/R ratio ($X/R = 2$), are modeled as lumped R–L elements, and the loads are represented by parallel R–L elements. The disturbance used for studying this system is a three phase to-ground fault that occurs. Such a severe fault close to the wind generator allows for observing the worst-case scenario. The Matlab/Simulink package is employed for simulation studies.

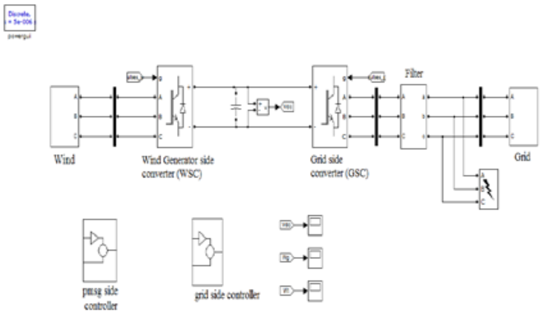


Fig:5.1- Impact of doubly-mass model specifications when a slow recovery occurs after fault.

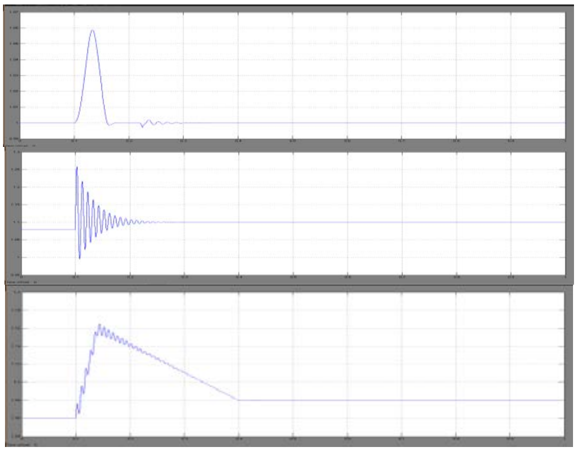


Fig:5.2- Impact of doubly-mass model specifications when a slow recovery occurs after fault: (a) DC-link voltage. (b) Generator rotating speed. (c) Turbine rotating speed.

The shaft stiffness and weight ratio of the rotating masses are changed to examine the analytical results. The slow recovery scenario is adopted here, where the active power injection of the GSC is forced to follow the slow recovery scenario, to examine the worst-case scenario. The results are shown in Fig. 5.2. While these changes do not impact the dc-link voltage, the generator rotating mass can experience a 30% over speed. Meanwhile, the turbine rotating speed does not exceed1.18 per unit. The results, once more, show that the utilization of the single-mass model can lead to misleading results.

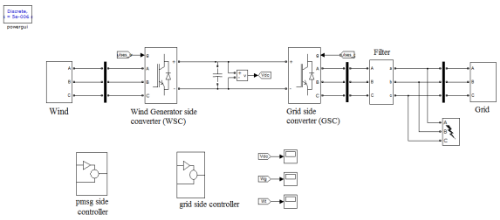


Fig:5.3- Impact of dc-link controller bandwidth when a fast recovery occurs after fault.

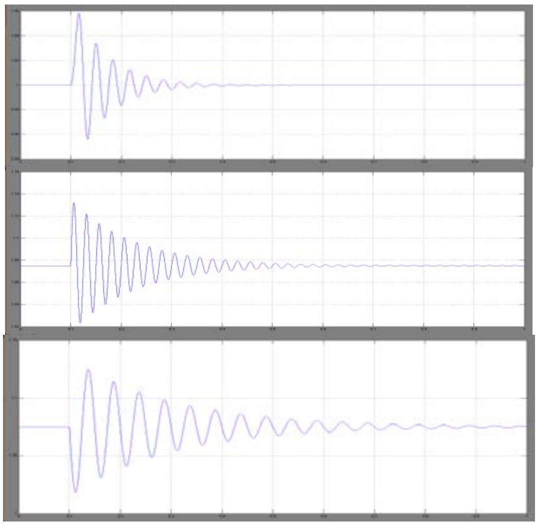


Fig:5.4- Impact of dc-link controller bandwidth when a fast recovery occurs after fault. (a) DC-link voltage. (b) Generator rotating speed. (c) Torque of shaft.

A fast recovery scenario is also tested; the results are shown in Fig 5.4 As predicted by the theoretical analysis, a lower dc-link voltage control bandwidth reduces the amplitude of oscillations on the rotating masses speeds at the cost of larger changes in the dc-link voltage. The figure also depicts the mechanical tensions and how using the dc-link as a buffer can save the generator shaft from higher stresses. Although the stress on the mechanical system of the generator is reduced, the capacitor will wear out faster.

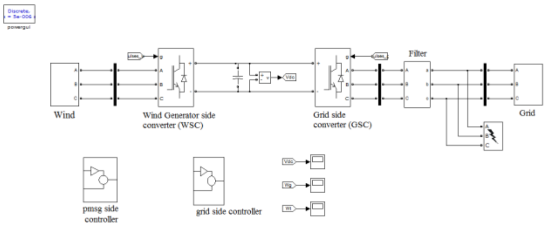
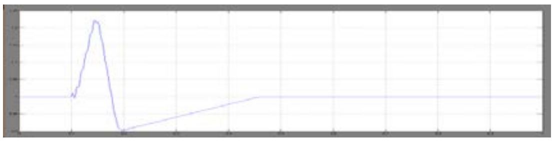


Fig:5.5- Impact of the active damping when a slow recovery happens after fault.



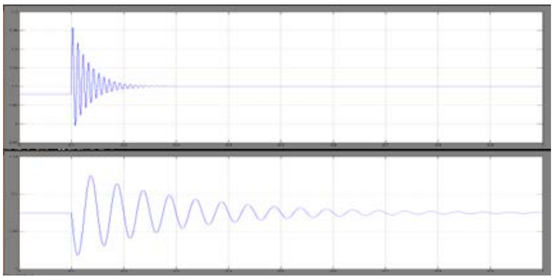


Fig:5.6 Impact of the active damping when a slow recovery happens after fault; (a) DC-link voltage. (b) Generator rotating speed. (c) Torque of shaft.

Fig. 5.6 shows the generator performance when the active damping is applied in the slow voltage recovery case. Again, time-domain simulations confirm the theoretical findings, where the active damping method reduces the fluctuations in the generator rotating mass speed at the cost of higher deviations in the dc-link voltage. Fig. 5.6(b) reveals that at a wind speed of12 m/s, the generator rotating speed can exceed 1.20 p.u., which is close to the over-speed threshold of wind turbines. The active damping method yields a successful LVRT and reduces the mechanical stresses on the turbine shaft, as predicted by the analysis (see Fig. 5.6(c)).

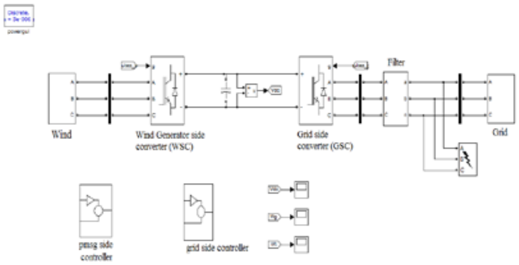


Fig:5.7- Impact of a single-phase fault that occurs at the generator terminal.

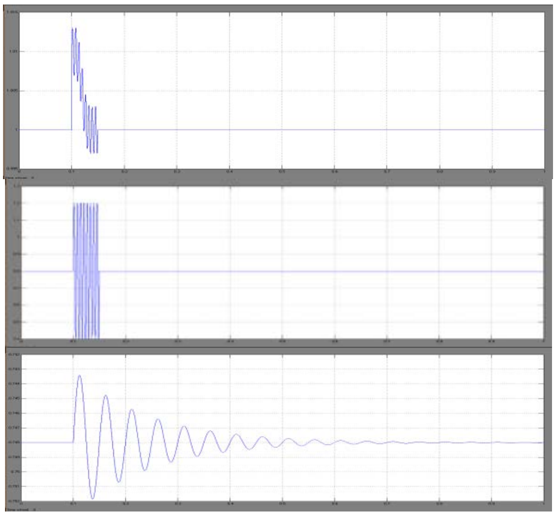


Fig:5.8 Impact of a single-phase fault that occurs at the generator terminal:(a) Output power of wind generator. (b) DC-link voltage. (c) Torque of shaft.

Fig. 5.8 shows the wind power generator performance when a single-phase fault occurs at the generator terminals. Obviously, with a 1.20 p.u. thermal limit of the power converter, the healthy phases are capable of injecting the active power of the faulted phase. In such a case, the average power remains constant, but the second-order harmonic appears on the generator output active power, *Pwind*. However, these oscillations do not yield observable oscillations on the shaft torque and its derivative. Only negligible fluctuations, because of the transients associated with the fault and its clearance, are observed. Instead, the dc-link voltage fluctuates because of the asymmetrical fault.

5. CONCLUSION

The modeling and analysis of a direct-drive PMSG-based wind power generator during fault and post-fault conditions were presented in this paper. An analytical multi-mode model, considering the double-mass nature of the turbine/generator and typical LVRT requirements was developed and validated against the detailed nonlinear time-domain simulation results. The model was successfully used to conduct a detailed analysis to characterize the generator performance under LVRT control, and to tune the control system parameters. The analysis showed the following. 1) Using the rotating masses for storing the excessive energy during the fault can lead to over-speeding the generator. 2) An LVRT-capable PMSG can be subjected to mechanical stresses and, accordingly, faster aging, due to electrical system faults. 3) The use of the active damping method reduces the mechanical tensions at the cost of increasing the electrical stress on the dc-link capacitor. 4) The use of the dc-link voltage control bandwidth retuning reduces the mechanical stresses; however, it yields a higher electrical stress on the dc-link capacitor as compared to the active damping methods. The detailed time-domain simulation results validated the analytical results and discussions.

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