[1]Dr. Nilaykumar A. Patel

[2]Khush N. Patel

[3]Keya N. Patel

Analysis and Mitigation of SSR in a Doubly Fed Induction Generator (DFIG) Based Wind Farm by Employing a STATCOM Controller

Journal of Electrical Systems

Abstract: - The increased integration of transmission networks has given rise to several issues. An obstacle that arises is the requirement for enhanced transmission capacity to facilitate the transfer of a substantial quantity of electricity without compromising the voltage. Series compensation is employed in conjunction with a Doubly-Fed Induction Generator (DFIG) wind turbine when transmitting electricity over long distances. The wind turbine is modeled using MATLAB Simulink, and the generated findings are verified. The wind turbine consists of DFIG is functioning in its typical operational condition. Series compensation causes the occurrence of a phenomenon known as Sub Synchronous Resonance (SSR), which presents a substantial risk to the wind generator. This condition is caused by a change in frequency, which has negative effects on the mechanical components of the generator. If a significant disturbance happens in any part of the study system at any bus bar, the effect of Sub-Synchronous Resonance (SSR) would have a more detrimental impact on the entire performance. There exists a correlation between the compensation percentage employed for series compensation and the influence of Subsynchronous Resonance (SSR). An effective method for mitigating the effects of Subsynchronous Resonance (SSR) involves the utilization of SVC, STATCOM and SSSC. These are called Flexible AC Transmission System (FACTS) devices. In the presented work, the STATCOM is employed due to its exceptional stability margin, minimized switching loss, and adjustable voltage rating. STATCOM is activated in response to a disruption in the transmission line. It accomplishes this by supplying required amount of reactive power and utilizing real power, so enhancing the overall stability of the power system. The controller of STATCOM initiates a pulse that is transmitted to the STATCOM, allowing it to perform its required job, such as absorbing real power or injecting reactive power. Consequently, the Doubly Fed Induction Generator (DFIG) is safeguarded, guaranteeing the stability of the system.

Keywords: Doubly-Fed Induction Generator, Subsynchronous resonance, STATCOM, Induction Generator Effect

1. Introduction

As technology continues to evolve, it is recognized that power has become a crucial necessity for individuals. Frankly speaking, even an ordinary resident requires electricity to operate household devices like the television and the fan. As the electricity demand develops, so does the demand for power supply, which grows in proportion to the rate of production [1]. The non-renewable energy resources encompass coal, oil, nuclear power, thermal power, and other such resources. Due to the devaluation of these assets, they are currently inaccessible to a group of individuals who have not yet arrived. Starting now, we are in the midst of transmitting resources that originate from renewable energy sources, including solar, wind, tidal, geothermal, and biogas. Both olar energy and wind energy are highly cost-effective and efficient sources of power. Due to the plentiful availability of wind, they are very ideal for promoting youthful vitality. India ranks among the top 10 countries globally in terms of wind power generation and it is targeted to reach up to around 145 GW installed capacity with in next six years [2]. India's wind energy sector contributes approximately fourteen percent of the total force segment and contributes of around 41% of total renewable installation [3]. Wind power alone contributes around sixty gigawatts (GW). India has emerged as the fourth-largest wind electricity supplier globally, with a total capacity of 35 gigawatts (GW), signifying the steady growth of its wind energy sector [4]. Wind farms with capacities ranging from 16 to 20 gigawatts (GW) have been built in most of India's states [5]. The coastal states of India have acquired a significant number of wind turbines. The current national total limit has been assessed to be 27,500 megawatts (MW). The administration set a goal of achieving a wind energy capacity of 125 gigawatts (GW) by the year 2025. Out of the entire amount, 60 gigawatts (GW) will be produced by the wind energy sector. The wind turbine has several obstacles, including (a) unpredictable wind force and poor power coefficient, (b) power fluctuations and voltage distortion, and (c) voltage fluctuations and major line accidents. From 10 to 13. These issues have a direct impact

[1] [1-2-3] Dept. of Electrical Engineering, CSPIT-CHARUSAT UNIVERSITY, Changa, Gujarat, India

Email: nilaypatel.ee@charusat.ac.in

patelkp2002@gmail.com

keyap675@gmail.com

on the components of the wind turbine, as well as on the maximum lifespan of the turbine. The wind farms are located on remote places and when they connected with a series compensated transmission lines, a serious oscillations can develop in the rotor of the DFIG [6]. To mitigate the SSR, there are many remedies suggested in the different papers [7-8]. Flexible AC Transmission Systems (FACTS) equipment is used to ensure the stability of the power grid. This is done to safeguard the wind turbine from the aforementioned issues. During the simulation of the project, it is replicating a self-sufficient wind turbine and examining its properties when the voltage across the transmission bar is uneven. In addition, some prospective solutions have been suggested for various issues. However, different methods may necessitate further investigation and advancement to enhance the applicability of wind energy for nomadic purposes [9].

2. Key Arrangement of STATCOM

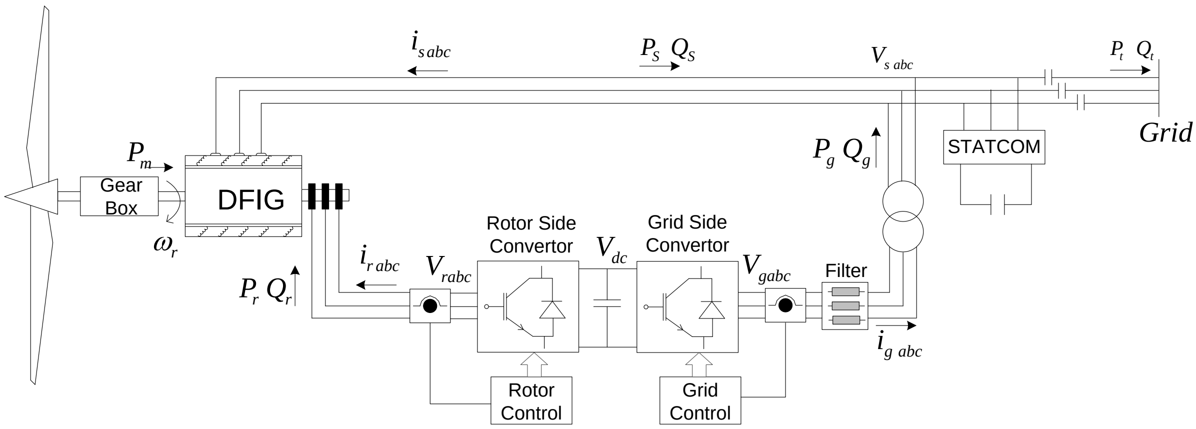

Figure 1. Strategy of STATCOM connected to DFIG

A transformer and a STATCOM controller are linked to the force matrix along with a wind turbine that is equipped with a Doubly Fed Induction Generator (DFIG). If the Doubly Fed Induction Generator (DFIG) experiences any disturbance, the GSC (Grid side Converter) and RSC (Rotor side converter) will come to the action and helps in preserving the stability of the system. When there is enough wind, the turbine will begin to rotate, causing the rotating shaft of the DFIG to turn and generate energy. The energy is transferred to the force lattice that is associated with the Generator, as it is sent there. Constructing the transmission limit is crucial for ensuring a long transmission. Therefore, here arrangement of compensation is done by connecting capacitors in the transmission line. Figure 1 illustrates it.

3. Equivalent circuit

Each of the following particulars is depicted in figure 2. The 'parasitic' components of the stator feature, known as Rs and Ls, are responsible for determining the blockage of the steady segment winding and the spilling inductance of the region twisting separately. Because the spilled inductance is responsible for shaping all of the motion that is produced by ways for current in the stator windings that does not travel through the air-hole of the frames, it is not useful for the assembly of torque. The stator opposition is a home-grown aftereffect that is caused by the windings being constructed from materials that are appropriate conductors but on the other hand, have limited conductance (which is referred to as obstruction). This is similar to the stator circuit, which also contains parasitic components. The rotor opposition, as well as the rotor spillage reactance abbreviated as Lr It is important to note that the stator and rotor windings are linked by a transformer effect whose turns proportion depends on the actual turns proportion between the stator and rotor (1:k), as well as the slip, s, of the model. Additionally, the rotor circuit is responsible for forming the rotor loss factor, which incorporates an additional rotor obstruction factor by the name of Rr(1-s)/s.

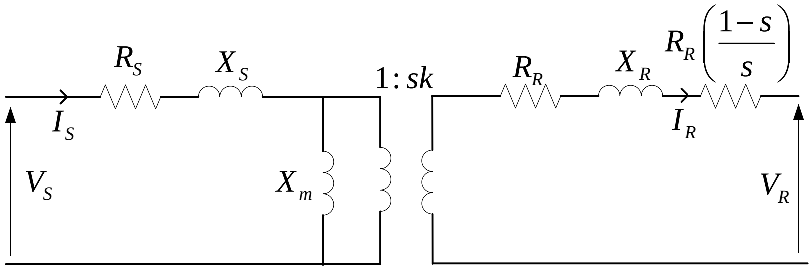

Figure 2. Equivalent circuit

For an induction motor, the slip is given by

$$s = \frac{N_S - N_R}{N_S}$$

Where N_S is the synchronous speed and N_R represents the actual speed of the rotor.

First, we can remember the steps the machine does when it's acting as a regular acceptance engine. When the stator is excited and the rotor is bolted (halted), a voltage, Vr, will be created on the yield terminals of the rotor circuit because the rotor circuit is left open circuit. The scenario's slip being 1, it's plausible that the applied stator recurrence side is where this yield is occurring. The frequency at the rotor's yield terminals will drop as the rotation speed increases rationally in the sub-simultaneous mode. This is because the rotor's speed will approach the coordinated speed more gradually. Coordinated speeds may cause the rotor recurrence to be zero. Once the rotor accelerates beyond simultaneous speed, the recurrence of the rotor voltage starts to grow again. While in sub-coordinated mode the rotor voltage sequence contains a certain portion assortment, in this mode it is not. The rotor voltage recurrence is given by $f_R = sf_e$ if one follows these lines of reasoning.

Since there is no rotor field, there will be no current flowing through the rotor electrical circuit. Consequently, there will be a cessation of power generation. When the rotor is short-circuited, rotor currents may likely circulate, and these currents can occur repeatedly. Due to the presence of mechanical devices, the flow of the rotor creates an attractive transition in the rotor, causing it to rotate at a speed similar to that of the mechanical device. The power is generated by the two active fields. It is crucial to note that the rotor moves in an attractive manner and the stator curls attractively with each rotation at the coordinated speed. Furthermore, the rotor does not rotate at the same time. However, the rotor field rotates at a speed that is similar to the stator curl field due to the same underlying cause. The mechanical torsion generated by the machine can be estimated by calculating the amount of torque absorbed or produced by the rotor resistance component Rr (1–s)/s. In an ideal acceptance machine, the effects of the winding opposition and release inductance of the rotor and stator within the loop area can be ignored. This is the point at which the circuit for each stage becomes straight and identical. The motion generated by the stator curl is closely linked to the rotor current and the resulting rotor motion. This motion is responsible for the development of torsion, especially at low slip values.

4. Control strategy of STATCOM

The design of a STATCOM is primarily focused on efficiently managing and controlling the responsive and dynamic corrections that are applied to the system in various ways. Considering the constant voltage, V_d, each force will be controlled by the d-q components, I_d and I_q, that are injected into the power system. By analyzing the initial terminal conditions, we can see that the flow components rely on the voltage produced by the connected device, the reactance and resistance of the channel, and the decoupling terms.

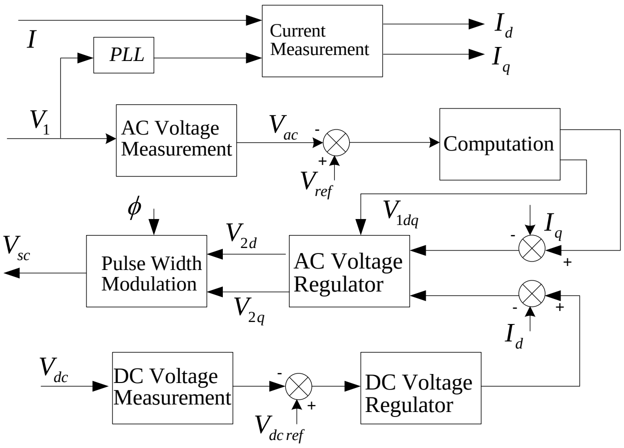

Figure 3. STATCOM Controlling

To determine the fundamental constants that are suitable for the PI controllers, it is of the utmost importance to connect with the management of the matrix relationship through its exchange function. Concerning the most significant time constant, the method that was utilized to ascertain the settings of the inner loop circle controllers is the source of the problem. Presented here is the information in Figure 3. The computational hub contains a single controller that is referred to as PI_q. This controller is a component of the internal circle that is contained within the elective pivot. The creation of the proportional component that will be transmitted to the electrical system is the responsibility of this controller. This component is produced based on the reference percentage that is specified by the force that is received. On the other hand, to avoid the influence of the transient required term at the beginning of the process, the utilization of the controller to create the direct axis reference for the converter necessitates the incorporation of the voltage. Since it possesses the most optimal time constant inside the framework, the time constant for the P-I controller is chosen to serve as the steady-state time of the electrical system instead of any other time constant. Due to the fact that the STATCOM was not intended to receive or absorb this kind of power, the dynamic force that is communicated to the matrix is ineffectual on a constant basis. In light of the circumstances, it is of the utmost importance to make the appropriate modifications to address electric losses to keep a consistent and reliable voltage within the DC transport. Exceptional performances can be achieved through the utilization of a variety of approaches, such as dynamic force separation and specialized consonant compensation, which may result in significant benefits for particular applications. Because of an imbalanced lattice, the zone vector theory continues to be valid; however, it is now necessary to split the electrical voltages into their components of negative and positive value. The method known as Delayed Signal Cancellation (DSC) is frequently utilized to assess an imbalanced three-phase voltage system and disassemble it into its components parts. There is the ability to regulate each succession independently using PI controllers when it has been spoilt. The area vectors in the subsequent dimensions are also added to one another before being integrated into a single support vector machine (SVM).

5. Simulation and Results

The transmission line series compensation level is: $k = {}^{X_c}\!/_{X_{Total}}$, and the value of line reactance as X =0.0031, and 50% compensation the value of X_c will be 0.00155. The analysis of the test system was tested through MATLAB Simulink and by the Eigenvalue analysis. The state space equations will give the Eigenvalues for different wind speed and different compensation levels.

The eigenvalues are presented in table I. It is observed that the stability of the test system with the STATCOM conventional controller, deteriorated when the series capacitor penetration level increased to 55 percent and beyond, while the wind speed varies from 7 to 9 m/s. The choice of line parameters (R and C) is employed to equalize the flow of reactive power in the benchmark model. When the novel controller of STATCOM is employed in the test system, it is observed that all the Eigenvalues real part becomes negative, indicating the stability of the system even when higher wind speed and higher level of compensations are present in the system.

Table I. Eigenvalues for different wind velocity and compensation level

Wind Velocity (m/s)	Series Compensation level	Eigen Values	
		Conventional Controller of STATCOM	Novel Controller of STATCOM
7	50	-1.85±141.80	-1.85±141.85
7	55	**1.21±130.50**	-0.72±134.56
7	60	**4.16±116.95**	-0.54±115.37
7	65	**4.42±110.05**	-0.14±108.72
8	50	-1.75±140.85	-1.72±139.55
8	55	**1.21±128.47**	-1.23±132.12
8	60	**2.25±115.81**	-0.46±117.77
8	65	**6.77±109.09**	-0.04±110.72
9	50	-1.77±139.74	-1.78±139.90
9	55	**1.19±130.5**	-0.59±134.56
9	60	**5.15±117.43**	-0.06±119.83
9	65	**7.02±110.55**	-0.10±109.16

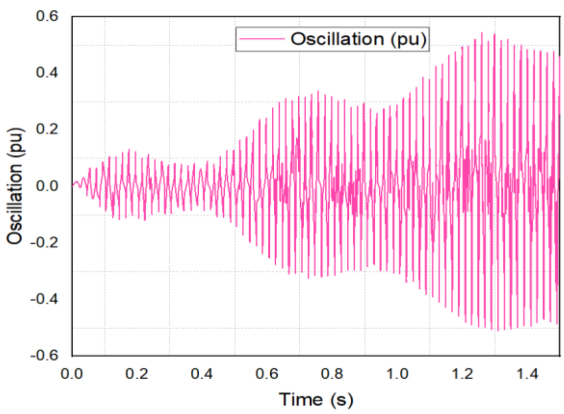

Figure 4 (a). waveform of the torsional interaction for wind speed 8 m/s and 55% compensation with conventional controller of STATCOM

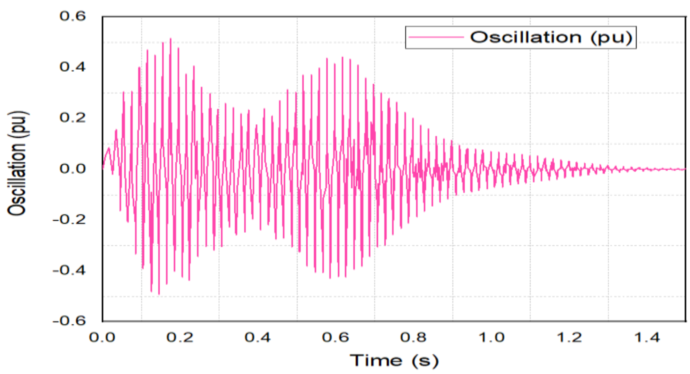

Figure 4 (b). Waveform of the torsional interaction for wind speed 8 m/s and 55% compensation with proposed controller of STATCOM

Figures 4(a) gives the DFIG rotor oscillations for wind speed 8 m/s and 55% compensation with conventional controller of STATCOM. It is demonstrating that the electromagnetic torque also increases when the penetration level of series capacitor increases, resulting in a greater amount of ripple in the waveform. This observation holds true when the wind speed is kept constant. The compensating degree has an upper range of 55% and more. Going above this compensation will cause damage to the turbine due to an excessive electromagnetic torque that exceeds the required amount. This simulation demonstrates that in the presence of the conventional controller of a STATCOM in a system with the series capacitor, the electromagnetic torque (Te) exhibits oscillatory behaviour. When the STATCOM is employed with novel controller scheme, the DFIG rotor oscillations damp out even if system has higher degree of compensation and higher wind speed. Up to 9 m/s wind speed and 65 percent compensation level, the system remain stable.

6. CONCLUSION

This work is looking into the possibility of a Sub-Synchronous Resonance (SSR) problem occurring in wind farms that are built on Doubly Fed Induction Generators (DFIG) and are connected to series compensated transmission lines at the same time. To reduce the effects of Subsynchronous Resonance (SSR), a Static Synchronous Compensator, also known as a STATCOM, is installed at the terminal of the generator with novel control scheme. An additional SSR damping controller is built and included into the core control system of the STATCOM to provide greater performance in terms of motion damping. To validate the results obtain from the Eigenvalue analysis, MATLAB Simulink model also prepared and the results supports the Eigenvalue analysis results. When larger degrees of system adjustment are present, wind farms that are built on DFIG are prone to the possibility of experiencing Sub-Synchronous Resonance (SSR) if conventional controller of STATCOM is present in the system. In addition to this, it has been demonstrated that the STATCOM, when equipped with the novel controller that was suggested, can effectively mitigate the Subsynchronous Resonance (SSR). A low-cost method is utilized in the construction of the STATCOM controller, with the primary emphasis being placed on the shunt compensation capacity. To keep the voltage stable and reduce resonance, the STATCOM controller is applied to manage the reactive power that is present at the generator terminal.

REFERENCES

[1] Li Wang, and Chia-Tien Hsiung MAY. 2011, “Dynamic stability improvement of an integrated grid-connected offshore wind farm and marine-current farm using STATCOM,” IEEE Trans. Power Systems., **vol. 26**, no. 2, pp. 690–698.

[2] Abhishek Kumar, Divyanshi Pal, Sanjay Kumar Kar, Saroj Kumar Mishra, and Rohit Bansal, “ An overview of wind energy development and policy initiatives in India”, Clean Technologies and Environmental Policy. Vol. 24, no. 5, 2022 pp. 1337–1358.

[3] Nitin Kumar and Om Prakash, “ Wind energy potential and its current status in India”, Wind Engineering, Vol. 47, no. 6, 2023, pp. 1067-1095

[4] The Indian Institute of Tropical Meteorology. https://www.tropmet.res.in

[5] L. M. Fernandez, F. Jurado, J. R. Saenz 2008, “Aggregated dynamic model for wind farms with doubly fed induction generator wind turbines, “Renewable Energy, vol. 33, Issue 1, pp. 129-140.

[6] Patel N. A. and Patel K. N., “SSR Mitigation in Power System by LQR Control of nearby DFIG”, Grenze International Journal of Engineering and Technology (GIJET) ISSN Online 2395-5295, Vol. 10 No. 1, 2024, pp. 70-79

[7] Nilaykumar Patel and Praghnesh Bhatt, “Mitigation of Sub-synchronous Resonance with Static Var Compensator”, Journal of Engineering Science and Technology (JESTEC), Vol.14, No. 2, 2019, pp 1101-1117

[8] N. A. Patel and Mihir R Patel, “Mitigation of SSR in Power System through Power Control of Additional DFIG”, International Journal of Grid and Distributed Computing (IJGDC), vol. 13, no.1, 2020, pp. 851-859.

[9] H. A. Mohammadpour and E. Santi April 2015, "SSR Damping Controller Design and Optimal Placement in Rotor-Side and Grid-Side Converters of Series-Compensated DFIG-Based Wind Farm", IEEE Transactions on Sustainable Energy, **vol. 6**, no. 2, pp. 388-399.

Annexure A: DFIG Data

Rating	Voltage	Frequency	Rs and Rr	Reactance
1.5 MW	690	50 Hz	0.01 Ω	18.84 Ω