INDIAN JOURNAL OF SCIENCE AND TECHNOLOGY

RESEARCH ARTICLE

Performance Analysis of Various FACTS Controllers Used for Voltage Stability Improvement in Power System

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OPEN ACCESS

Received: 05-10-2023

Accepted: 25-10-2023

Published: 28-11-2023

Citation: Chavhan V, Amalraj S, Singh SK, Bobade C (2023) Performance Analysis of Various FACTS Controllers Used for Voltage Stability Improvement in Power System. Indian Journal of Science and Technology 16(44): 4098-4107. https://doi.org/10.17485/IJST/v16i44.2524

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Funding: None

Competing Interests: None

Published By Indian Society for Education and Environment (iSee)

ISSN
Print: 0974-6846
Electronic: 0974-5645

Abstract

Background: In order to maintain a reliable and safe electrical grid, voltage stability is considered as a crucial component of power system. The incorporation of Static Compensator (STATCOM) has been a viable approach in recent times to improve voltage stability and alleviate problems related to voltage instability. **Methodology:** An extensive investigation of the effects of FACTS devices is included in this article, including STATCOMs, on voltage stability within power systems. Mathematical modelling and simulated Doubly Fed Induction Generator (DFIG) based wind turbine is integrated with IEEE-9 bus in MATLAB2020. **Finding:** This study employs an advanced modelling and simulation technique to assess the performance of STATCOM in various scenarios, considering different fault conditions and contingencies. Overall work is implemented in MATLAB2020. Simulation results are obtained in the terms of voltage profile, reactive power, wind voltage and active power. The values of the parameters before fault is obtained with a reactive power of -33.44 MVAR and voltage of -0.5586 V. After fault, the reactive power is measured as -85.38 MVAR and Voltage is increased to -0.1766 V. Finally, by using STATCOM, the reactive power is reduced to -30.29 MVAR and Voltage -0.5690 V. Further the obtained results are evaluated and compared with the other approaches. Additionally, the paper investigates the optimal placement of STATCOM at load side to maximise their effectiveness in voltage stability enhancement. **Novelty and Application:** This study contributes a valuable knowledge to power system operators, planners, and researchers, facilitating the informed decisions for the integration and utilisation of STATCOM technologies to ensure the robustness and reliability of modern electrical grids.

Keywords: Doubly Fed Induction Generator (DFIG); Wind Energy; IEEE9 Bus; Static Compensator (STATCOM); Voltage Stability; Reactive Power

1 Introduction

Nowadays, Electric utilities are unable to fulfil the requirement of electricity for modern society due to growing living standards and urbanization. In order to meet load demand and solve power issues, Renewable energy sources have been a viable alternative to conventional energy sources throughout the past 20 years. From technical and economic perspective wind energy is one of the many renewable energy sources that stands out as being especially promising; hence, interest in wind turbine systems must expand on a global scale. The three devices Static Synchronous Compensator (STATCOM), Doubly Fed Induction Generator (DFIG) and IEEE 9 bus systems are used in this study. This study proposes a unique approach to enhance the stability by connecting a flexible alternating current transmission system (FACTS) controller on load side of the system. Number of researchers have connected the FACTS device to a transmission line in the literature; however, these studies have a load side focus. An integration of STATCOM at the appropriate location of the load side is crucial to enhancing voltage stability throughout the system. The system's voltage profile and flexible power flow can both be improved by the STATCOM integrated system. The wind energy system with DFIG-based variables is an advantageous alternative for the current situation of the energy market. The turbine blade and wound rotor induction generator couple through the gearbox of the wind energy system, utilising the DFIG . Both reactive and active powers are autonomously managed here. In order to maintain grid voltages, the generator can also supply reactive power (1,2) .

Voltage stability is one of the system's important priorities and is also one of the most difficult studies. It relates to the capacity on system's ability to keep the voltage on all of its buses within acceptable bounds after being disrupted. In fact, significant occurrences (blackouts) have been brought on by voltage swings throughout the world. Insufficient reactive power is nearly related to the voltage breakdown. As a result, it's imperative to consistently meet the need for reactive energy. Voltage instability can result from a number of factors, including increased load demand, imbalanced load, disturbance, and changing system circumstances. Voltage instability may result from each bus having insufficient reactive power (3–5) . The aim of this study is to assess how well FACTS controller can recover system voltage in load side a metropolitan area by implementing a reactive power compensation approach (6) .

For a variety of reasons, voltage unbalance and collapse have emerged as universal problems. System stability problems are managed with FACTS devices. This study examines the importance and use of STATCOM for improving power system voltage stability on the load side. This study is focused on the investigation of voltage control and reactive power compensation within the framework of the IEEE-9 bus system basically at load side. The research utilises MATLAB2020 software for analysis and simulation purposes . MATLAB 2020 has a smooth integration with Simulink, an excellent instrument for modeling and simulation. From algorithm research to system simulation and implementation, a smooth workflow is made possible by the combination of MATLAB and Simulink (6) . One of the important approaches for reducing line losses is to implement FACTS . Proposed research suggests FACTS controller for decreasing system fault current (7,8) . The voltage of the load bus is enhanced using STATCOM . The outcome performance of STATCOM under various circumstances are examined and contrasted. In current scenario power systems using DFIG, STATCOM is utilised to increase voltage stability. The transient response and overload capacity of STATCOM are better. It has been demonstrated that the STATCOM's position and capacity have a significant influence on enhancing voltage stability (9–11) .

Literature also suggested some method which increases the electrical power system's efficiency while enhancing voltage stability. In this research FACTS controller is connected to the load side of system . Literature observed number of researchers work on transmission line but in this study we focus on load buses. In order to validate the offered option, different occurrences are taken into account in this area including different types of faults (symmetrical and unsymmetrical). To ensure the voltage stability improvement and reactive power consumptions which are experienced across by evaluating the wind speed profiles and faults. The power flow may increase the restrictions in the event of an unexpected fault, leading to a system failure. FACTS Controllers are implemented to overcome all this circumstances obtained the result in normal condition, faulty condition and mitigate by STATCOM and try to improve the voltage profile and reactive power compensation. The simulation results are used for the purpose of testing the 9-bus system shows in Figure 2 , and are demonstrated by adding STATCOM which increases the system's accuracy in terms of voltage stability enhancement (3,4).

2 Methodology

2.1 Voltage of Stability

Voltage Consistency describes a system's capacity to sustain its voltage levels within permissible limits when subjected to disturbances. A single bus or a small group of buses in a specific area may experience voltage stability problems, It may not affect the whole system's functionality.Voltage stability issues exist in power systems when they are loaded or when there is not enough reactive power. The generation, transmission, and reactive power demand can be used to examine voltage stability(12). There are some issues regarding voltage stability which are necessary to consider in this research work.

(1) Voltage instability may result from insufficient reactive power at each bus.

(2) When there is insufficient damping against disturbances, voltage instability may occur, causing the voltage at the receiving end to drop significantly below normal or to oscillate indefinitely.

(3) Voltage collapse is a process that causes the voltage decreases to an inadequate level as a result of a cascade of circumstances that accompany voltage instability.

(4) Limits for controlling voltage and reactive power of the generator, among the most significant impact of voltage collapse is an electric power system's inability to supply enough reactive power due to high reactive power consumption by the loads or the system itself.

2.1.1 Maximum Power Load

The transmission network may result in power system instability over long distances when more power is transferred. Further, while transferring electricity between load centers and preventing voltage instability, more attention is required. A basic circuit that depicts the principles of power transmission in between a load and a generator is represent in Figure 1. For ease of understanding, a real reactive impedance of transmission is X, which is taken into account alongwith the assumption that the synchronous generator (SG) operates similarly to magnitude of a source of static voltage E(13).

Real power equation and Q power flow Bus-1 to Bus-2 is provided by,

$$P = \frac{EV}{X}\sin\delta \quad ,Q = -\frac{V2}{X} + \frac{EV}{X}\cos\delta \tag{1}$$

Where,

The bus- 1 voltage is $E = E < \zeta$, The bus- 2 voltage is $V = V < 0$, Line Impedance $= X$ (neglecting resistance),
Power Angle $= \delta$

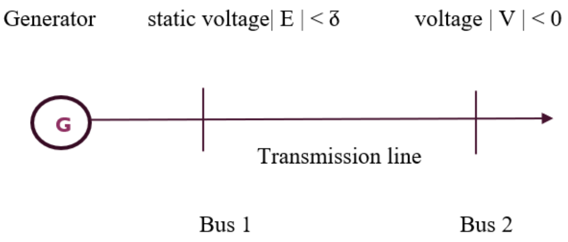

Fig 1. Q-Power from Generator to Load

From the variables in (1) and (2) with
$v = \frac{V}{E}$, $p = \frac{P.X}{E2}$ and $q = \frac{Q.X}{E2}$, one obtains ,

$$\mathrm{p} = \mathrm{v}\cdot\sin\delta, \mathrm{q} = -v_2 + \mathrm{v}\cos\delta \tag{2}$$

Taking the Square of the above two equations and rearranging,

$$v_2\left(\sin_2\bar{\delta} + \cos_2\bar{\delta}\right) = p_2 + (\mathrm{q} + v_2)^2 \tag{3}$$

$$v_4 + v_2(2\mathrm{q} - 1) + (p_2 + q_2) = 0 \tag{4}$$

The preceding equation's positive real solutions for v are provided by

$$v = \sqrt{\frac{1}{2} - q \pm \sqrt{\frac{1}{4} - p2 - q}} \tag{5}$$

2.2 System Modelling

System IEEE 9-Bus(7): There are three different sources which are connected to three separate buses these parameter is considered from Table 1. Out of these three sources, two have been used in the bus, with one being a combination of DFIG based wind turbine system. Bus-5 (125 MW), 6 (90 MW) and 8 (100 MW) has each bus loads connected to it respectively. To design this system Matlab/Simulink software is used. The STATCOM is connected to Bus-8 and MATLAB2020 software is used to obtain the line parameters. By placing the FACTS controller in strategic areas, the system will be more protected. The need level of regulation will be achieved for the short circuit current, power flow, and bus voltage(11). The load side is linked to the FACTS controller (STATCOM) in this article. In Figure 2, the Matlab/Simulink model is shown.

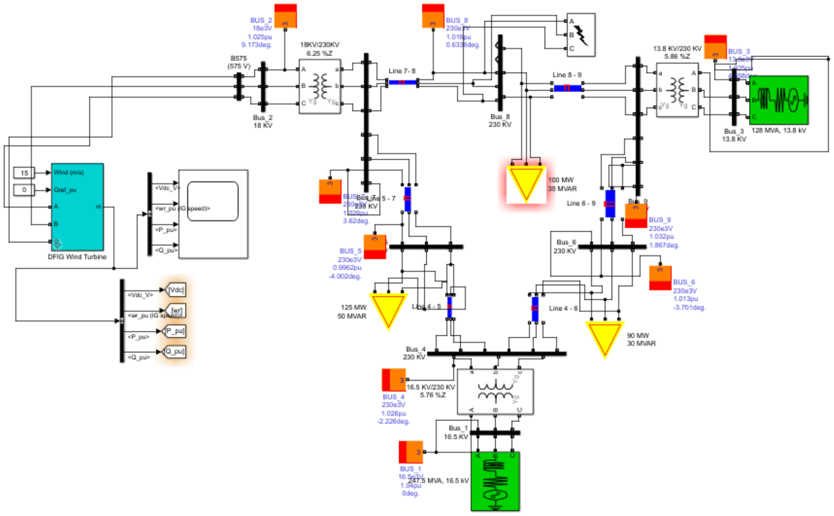

Fig 2. Matlab Model for DFIG-Based Wind Turbine for IEEE 9 Bus System

2.3 DFIG Based Wind Turbine System

Future wind farms will feature DFIGs, which offer many benefits over fixed-speed generators. These benefits, such as speed control, minimum flickering and Active (P) and Reactive (Q) power capabilities in four-quadrants which are mostly achieved through Rotor Side Converter (RSC) control. This is ordinarily rated at somewhere between 30% and 35% of the rating of generator for a certain rotor speed variation range of percentage (%). Figure 3 represent a detail about the system(13).

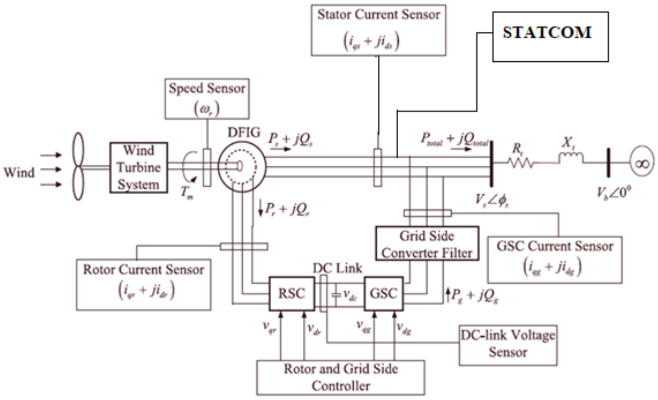

Fig 3. Reference Block Diagram of a DFIG Equipped WT(14)

Wound rotor IG uses DFIG based wind turbines which are coupled in Figure 3 via a gearbox the modelling of DFIG by using the parameter which is shown in Table 1 (13). The rotor and direct grid connected stator of this generator are powered by a two-way power converter. It also has a grid-connected system, RS and GS controllers and converters with DFIG. While the RS of DFIG is connected to the grid via bidirectional converters of power electronic, the stator side is directly connected to the source by transformer. These converter's control capabilities, the DFIG system is more adaptable and stable. It is possible to regulate the current and power transfer through DFIG system. DC link voltage, and the speed of generator is controlled by the two power converters which is RS Controller and GS Controller, as shown in Figure 3. Voltage at the RS and converter voltage at GS are adjusted separately to control the RS and GS controllers. Sensors of many kinds are employed for the proposed control techniques to evaluate the total state variable values and feed those values back in order to minimize deviations in both the situation and the output of the examined system (9,13–16).

Table 1. DFIG Parameter and IEEE 9 Bus system data

Sr no	**DFIG Parameter**		**Values**	
1	Nominal power, L-L voltage, and frequency		(100e6 11.66e3 11e3 50)	
2	Stator side (Rs , Lls)		(0.0231 0.182)	
3	Rotor side (Rr', Llr')		(0.0161 0.162)	
4	Magnetizing inductance of IG Lm (p.u.)		2.91	
5	Inertia constant (k), friction factor of generator, and pairs of poles		(0.685 0.01 3)	
No of Generator	1	2		3
MVA Rating	247.50	192.00		128.01
KVolt	16.50	18.001		13.80

2.4 Modeling Wind Turbine

With the reference of Table 2, the following parameters are obtained. The mechanical power (Pm) of wind turbine (WT) generation:

$$P = 0.5Cp.(\lambda,\beta).\rho.A.v3 \tag{6}$$

Where,

the power coefficient is Cp (λ, β) ,air density ρ is (1.25 kg/m2), wind speed Vw is (ms−1), and swept area A is given the equation $A = \pi R^2$. Now the radius R of blade is (m). .

For aerodynamic model of wind, The kinetic energy is

$$E = \frac{1}{2} \cdot \mathrm{m} \cdot \mathrm{v}^2 \tag{7}$$

The changing air of wind power is equal to

$$Pw = \frac{dE}{dt} = \frac{1}{2} \cdot m \cdot v^2 \tag{8}$$

Where the flow rate of mass is m/sec. The air passes across an area A. From the Equation (9).

$$Pw = \frac{1}{2} \cdot m \cdot A \cdot \rho \cdot v^2 \tag{9}$$

the air density ρ is $\left(\rho = 1.225\ \mathrm{kg/m^2}\right)$

The blades' ability is to draw power from the wind is

$$P\_\text{blade } = Cp(\lambda,\beta) \cdot Pw = Cp(\lambda,\beta) \cdot \frac{1}{2} m \cdot A \cdot \rho \cdot v^3 \tag{10}$$

The λ tip speed is defined as

$\lambda = \frac{wmR}{V}$

The equation of rotor torque given-

$$Tw = \frac{\text{Pblade}}{wm} = (\lambda,\beta)\rho R^2 A v^3/2\omega m \tag{12}$$

The power coefficient is denoted by Cp and is determined as a function of the tip-speed and the angle of the blades.

$$Cp(\lambda,\beta) = c1\,(\mathrm{c2.1}/\gamma - \mathrm{c3}.\beta - \mathrm{c4}.\beta{}^\wedge x - \mathrm{c5})\,e^{\wedge} - c61/\gamma \tag{13}$$

γ defined as

$$\frac{1}{\lambda} = (1/\lambda + 0.08\beta - 0.035/1 + \beta 3) \tag{14}$$

$1 = 0.51, C2.0 = 116.0, C3.0 = 0.40, C4.0 = 0.0, C5 = 5.0, C6 = 22(\mathrm{C4} = 0$ that why x is not used $)$ (14).

Table 2. Parameters of Wind

Parameter	Value
Total No's of Blades of Wind Turbine	3 nos
Air Density of Wind	1.223 (kg.m-3)
Normal Speed of Wind	9.01 (m.s-1)

2.5 DFIG Modeling

The dynamic DFIG model is typically described using the dq ref frame depending on the stator flux or voltage orientation. So the supply side voltages, vds and vqs, and the rotor side voltages, vdr and vqr, are given as below (9,15–17).

$$\mathrm{v_{qs}} = -\mathrm{R_s i_{qs}} + \mathrm{W_s}\lambda_{\mathrm{qs}} + \mathrm{d}\lambda_{\mathrm{qs}}/\mathrm{dt} \tag{15}$$

$$\mathrm{v_{ds}} = -\mathrm{R_s i_{ds}} - \mathrm{W_s}\lambda_{\mathrm{ds}} + \mathrm{d}\lambda_{\mathrm{ds}}/\mathrm{dt} \tag{16}$$

For the rotor side:

$$\mathrm{V_{dr}} = \mathrm{R_r i_{dr}} - \mathrm{sW_s}\lambda_{\mathrm{qr}} + \mathrm{d}\lambda_{\mathrm{dr}}/\mathrm{dt} \tag{17}$$

$$\mathrm{v_{qr}} = \mathrm{R_r i_{qr}} + \mathrm{sW_s}\lambda_{\mathrm{dr}} + \mathrm{d}\lambda_{\mathrm{qr}}/\mathrm{dt} \tag{18}$$

The following are the stator's reactive (Q) and active (p) power

$$Ps = \frac{3}{2}\left(v_{\mathrm{ds}}\mathrm{i_{ds}} + \mathrm{v_{qs}i_{qs}}\right) \text{ and } \mathrm{Qs} = \frac{3}{2}\left(\mathrm{v_{dr}i_{dr}} + \mathrm{v_{qr}i_{qr}}\right) \tag{19}$$

2.6 STATCOM Model

A quick-acting device known as STATCOM can produce or consume reactive current, which controls the voltage at the point of joined to a power grid. A STATCOM's fundamental operation is dependent on two key facts: 1) higher voltage to lower voltage reactive power flows from, and 2) active power (p) flows from the leading toward the lagging point. As a result, STATCOM controls the Q power flow by varying the voltage generated by the VSI in relation to the system voltage.

The reduction of terminal voltage during the fault period is measured by PI controller and this decreases the voltage pass to the SPWM for generating sinusoidal pulse width modulation then the generated pulses pass to the inverter which is used for converting DC to AC then AC pulses given to filter and after filtration it gives back to transformer. The grid and wind farms receive reactive power from STATCOM during the fault period. In order to reduce power system issues and achieve stable grid operation, the STATCOM unit is created to inject Q. Due to the variable components of wind, speed changes continuously so Active (P) and Reactive (Q) powers and terminal voltage fluctuate condition. The active power (P), reactive power (Q), and terminal voltages are obtained as near to nominal value by connecting STATCOM to the grid.

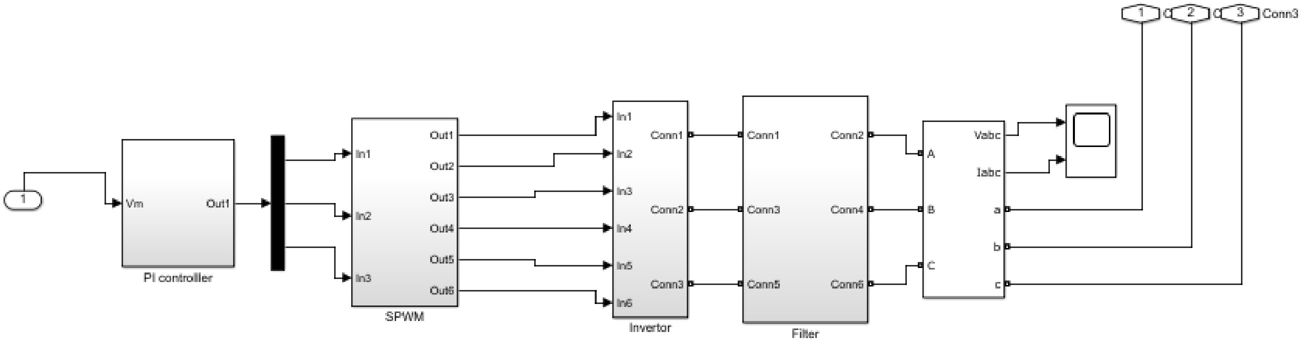

Fig 4. Matlab Simulink Model of STATCOM

3 Results and Discussion

Tabulation result of DFIG based wind generation with standard IEEE - 9 Bus in normal state, faulty and with STATCOM condition. State of the voltage profile is improved by a recently created program known as the pathfinder algorithm (PFA) which encourages to move in groups while hunting, with a leader known as the pathfinder paper(1) state voltage stability is improved by using STATCOM with PI. In this paper, the voltage is recovered when only L-G and L-L fault condition. Compared with this, STATCOM is more convenient controller to use which improves the voltage profile and the reactive power when symmetrical and unsymmetrical fault occur at load bus. A system can be improved by 80–90% based on the comparative results when faults occur at different bus systems shown in the Table 3 below.

Table 3. Representation of IEEE 9 Bus in Fix State condition, Faulty and with STATCOM Condition

Bus	Healthy state		Faulty State at Bus 8		Mitigate by STATCOM	
Terminal voltage	-0.5586		-0.1766		-0.5690	
Bus 8	P = 40.32 Mw	Q= -33.440 Mvar	P = 16.66 Mw	Q = -85.38 Mvar	P = 52.46 Mw	Q = - 30.29 Mvar
Bus 7	P= -0.1248 Mw	Q= -0.04392 Mvar	P=-0.04652 Mw	Q= -0.03130 Mvar	P = -52.46 M w	Q = - 20.55 Mvar
Bus 9	P = -0.08608 Mw	Q = 3.21 e-5 Mvar	P = - 1.1651 Mw	Q = - 0.0027091 Mvar	P = -323.8 Mw	Q = 6.4960 Mvar

3.1 Healthy Condition : Standard IEEE 9 bus system with wind generation

Figure 5 represents healthy condition because it is in stable condition. Here the total generation is in stable condition which is 340 MW of power and also observed the graph of active power (P), reactive power (Q) in healthy condition, voltage and current from wind side and bus system as well. Wind generation consists of a pitch control system, wind turbine model and doubly fed induction generator is connected by two masses and is integrated with IEEE-9 Bus system. Looking at the literature, it seems that some works are not generated as much powered and also don't produce as clear of results when it comes to healthy situation(7).

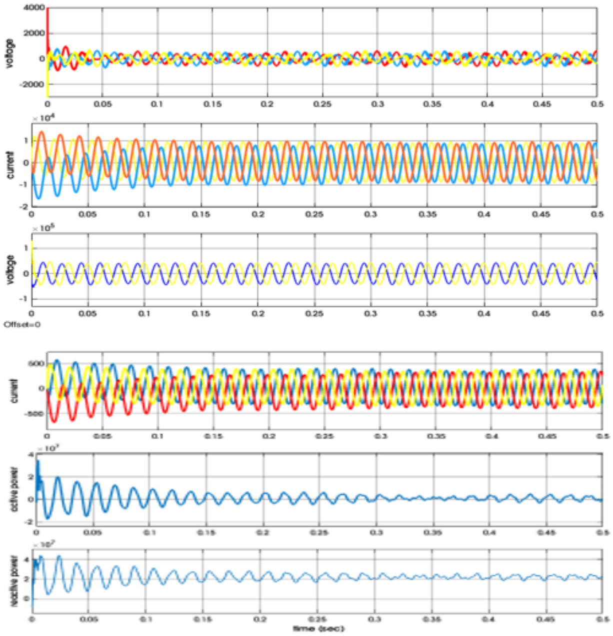

Fig 5. Voltage Current Active and Reactive Power in Healthy Condition

3.2 Faulty Condition : Standard IEEE-9 Bus System with Wind Generation with Fault

Figure 6 represents the disturbance in the system, when fault occours at Bus-8 which is the main bus connected on load 100 MW. The variation occurs due to the 3 phase LLL-G fault at the Bus-8 without STATCOM due to the wind farm terminal voltage, current, generated active power, and absorbed reactive power. When fault occours on Bus-8, it affects on wind generation system then at the time of fault duration and the voltage of the main bus is reduced. The total exported active power (P) at Bus-8 decreases. This may affect the working condition also stability of power system of wind generation. Looking at the literature, it seems that some papers don't reflect after occurring fault and don't produce as clear of results when it comes to faulty situation.

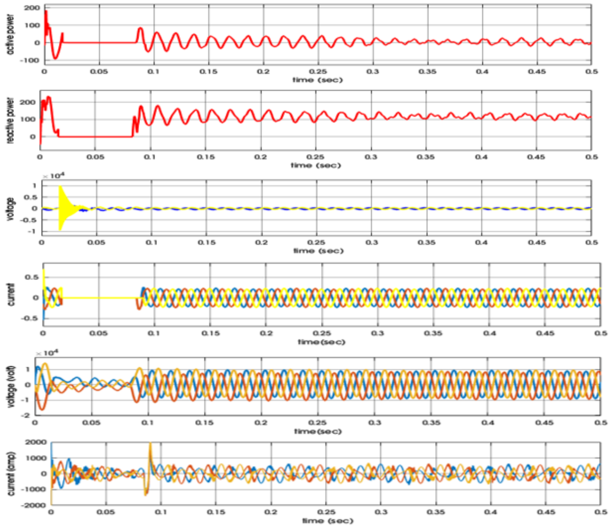

Fig 6. Voltage Current Active and Reactive Power in Faulty Condition

3.3 Metigate Condition: Standard IEEE-9 Bus System with Wind Generation With Fault Using STATCOM

Figure 7 represents the connection of wind generation with standard 9-Bus system with fault and STATCOM. When fault occurs, this fault period voltage is dropped and generated. Active power is decreased and absorb reactive power which increases with STATCOM and also try to maintain the system voltage in steady state condition. The generated active power is decreased by a fault which also increase and absorb reactive power which is decreases. After the issue has been fixed, the generator speed returned to normal, and the mechanical and electromagnetic torques are once again balanced. After the fault clearance, reactive power (Q) is provided by the power system to recover the air-gap flux in case of LLL-G fault. The wind farm has the capapability to stay connected under this faulty situation with and without STATCOM connection either when the fault occurs. After the fault is fixed, the system resumes steady state operation.

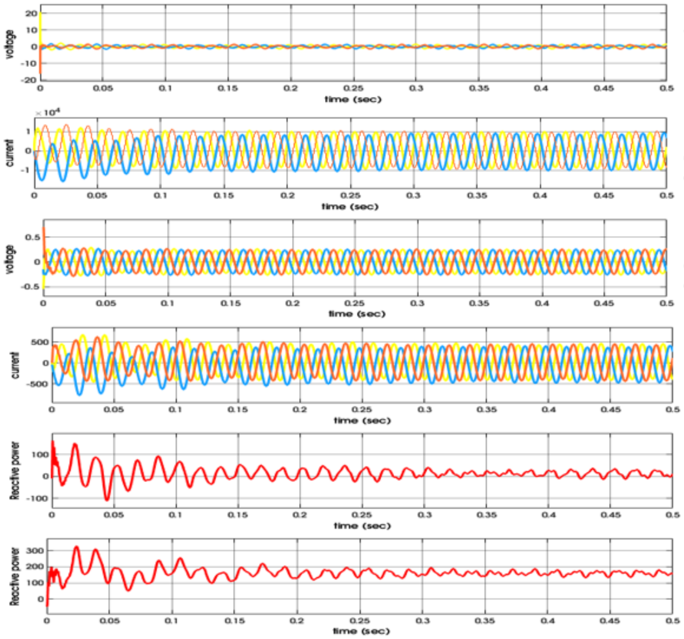

Fig 7. Voltage Current Active and Reactive Power with STATCOM Condition

4 Conclusion

Methods like fault currents and other issues are discussed in details. The proposed method is implemented and obtained with the simulated result in the terms of voltage profile, reactive power, current and active power of at various fault conditions which occur at load bus. The parameters voltage profile, reactive power, system stability are measured on both normal and faulty condition. For the faulty condition, the STATCOM are installed at load bus. The number of simulation results at various fault conditions occured at the load bus are acquired, and the results are compared with the initial state without STATCOM. During fault situations, applications involving huge wind farms have been identified as potentially problematic in terms of reactive power consumption, control, and voltage stability. Prior to implementing STATCOM, the excessive fault current should be taken into account. The influence of STATCOM on the fault current is noteworthy, particularly when the fault arises at the load buses, according to several simulations and analyses. The simulation results in healthy condition are obtained in terms of active and reactive powers which are P = 40.32 MW and Q = -33 MVAR. During faulty condition, the active power get reduced to 16.16 MW and reactive power is increased to -85.38 MVAR. The condition is improved by the FACTS controller by using STATCOM. Load side at the load bus where fault occurs, active power is obtained as 52.46 MW and reactive power 30.29 MVAR. The comparative result shows that the system performance is improved by FACTS controller upto 80–90%. To provide suitable reactive control during faulty situation , the STATCOM is advised and mount to the system at the load side at the load bus. It is also concluded that FACTS Controller are very superior device to maintain the system as transmission side also the load side.

References

1) Abdelsattar M, Hafez WA, Elbaset AA, Kamel S, Alaboudy AHK, Khan B, et al. Voltage stability improvement of an Egyptian power grid-based wind energy system using STATCOM. *Wind Energy*. 2022;25(6):1077–1120. Available from: https://doi.org/10.1002/we.2716.
2) Sarwar M, Arshed M, Hussain B, Rasheed M. Stability Enhancement of Grid-Connected Wind Power Generation System Using PSS, SFCL and STATCOM. 2023. Available from: https://doi.org/10.1109/ACCESS.2023.3262172.
3) Mahmoud MM, Salama HS, Bajaj M, Aly MM, Vokony I, Bukhari SSH, et al. Integration of Wind Systems with SVC and STATCOM during Various Events to Achieve FRT Capability and Voltage Stability Towards the Reliability of Modern Power Systems. *International Journal of Energy Research*. 2023;1(2). Available from: https://doi.org/10.1155/2023/8738460.
4) Meddeb A, Jmii H, Amor N, Chebbi S. Voltage Stability Enhancement Using FACTS Devices. *2020 4th International Conference on Advanced Systems and Emergent Technologies (IC_ASET)*. 2020. Available from: https://doi.org/10.1109/IC_ASET49463.2020.9318220.
5) Adegoke SA, Sun Y. Power system optimization approach to mitigate voltage instability issues: A review. *Cogent Engineering* . 2023;10:2153416. Available from: https://doi.org/10.1080/23311916.2022.2153416.
6) Patil V. Voltage Stability Improvement In Multi-bus System Using Static Synchronous Series Compensator. *International Journal for Research in Applied Science and Engineering Technology*. 2022;10(6):1052–1059. Available from: https://doi.org/10.22214/ijraset.2022.43928.
7) Mehedi IM, Joy JAH, Islam MR, Hasan N, Al-Saggaf UM, Milyani AH, et al. Reducing Fault Current by Using FACTS Devices to Improve Electrical Power Flow. 2021. Available from: https://doi.org/10.1155/2021/8116816.
8) Marouani I, Guesmi T, Alshammari BM, Alqunun K, Alshammari AS, Albadran S, et al. Optimized FACTS Devices for Power System Enhancement: Applications and Solving Methods. MDPI AG. 2023. Available from: https://doi.org/10.3390/su15129348.
9) Mosayyebi SR, Shahalami SH, Mojallali H. Fault ride-through capability improvement in a DFIG-based wind turbine using modified ADRC. 2022. Available from: https://doi.org/10.1186/s41601-022-00272-9.
10) Kholousi M, Tohidi S, Rostami N. Impact of Wind Turbines on Voltage Stability of Power Systems: Assessment and Improvement. *2021 12th Power Electronics, Drive Systems, and Technologies Conference (PEDSTC)*. 2021. Available from: https://doi.org/10.1109/PEDSTC52094.2021.9405960.
11) Sadiq R, Wang Z, Chung CY, Zhou C, Wang C. A review of STATCOM control for stability enhancement of power systems with wind/PV penetration: Existing research and future scope. *International Transactions on Electrical Energy Systems*. 2021;31. Available from: https://doi.org/10.1002/2050-7038.13079.
12) Chakrabarti BS. Notes on Power System Voltage Stability. . Available from: https://home.iitk.ac.in/~saikatc/EE632_files/VS_SC.pdf.
13) Xu L, Wang Y. Dynamic Modeling and Control of DFIG-Based Wind Turbines Under Unbalanced Network Conditions. *IEEE Transactions on Power Systems*. 2007;22(1):314–323. Available from: https://doi.org/10.1109/TPWRS.2006.889113.
14) Radaideh A, Bodoor M, Al-Quraan A. Active and Reactive Power Control for Wind Turbines Based DFIG Using LQR Controller with Optimal Gain-Scheduling. *Journal of Electrical and Computer Engineering*. 2021;2021:1–19. Available from: https://doi.org/10.1155/2021/1218236.
15) Adetokun BB, Muriithi CM. Impact of integrating large-scale DFIG-based wind energy conversion system on the voltage stability of weak national grids: A case study of the Nigerian power grid. 2021. Available from: https://doi.org/10.1016/j.egyr.2021.01.025.
16) Kumar V, Pandey AS, Sinha SK. Stability Improvement of DFIG-Based Wind Farm Integrated Power System Using ANFIS Controlled STATCOM. *Energies*. 2020;13(18):4707. Available from: https://doi.org/10.3390/en13184707.
17) Sun K, Yao W, Fang J, Ai X, Wen J, Cheng S. Impedance Modeling and Stability Analysis of Grid-Connected DFIG-Based Wind Farm With a VSC-HVDC. *IEEE Journal of Emerging and Selected Topics in Power Electronics*. 2020;8(2):1375–1390. Available from: https://doi.org/10.1109/JESTPE.2019.2901747.