[1*]Mahendra Kumar,

[2]Alok Kumar Singh,

[3]Shiv Lal

Power Quality Enhancement in Grid Connected Solar Wind Hybrid System using FACTS Devices

Journal of Electrical Systems

Abstract: Due to the high cost of fossil fuels and the need to care about the environment, there has been a big shift towards renewable energy sources (RES). One of these RES is wind energy which is freely available and which can be used to generate electricity without fuel. It depend on the speed of wind, it can be hard to get good power quality. The presence of this part changes both the power and voltage of the part that is connected to the wind turbine. Controlling the fluctuations and making wind power work better requires a new method and new controls. In order to keep people safe, potential excitation induction generators are also used. Using different energy storage technologies can also help even out the changes that wind power causes. In addition to the reactive power adjustment, use a static compensator for the harmonic current injection. Wind turbines are not only getting better at making power, but they are also getting better at handling problems. A dynamic voltage restorer can help correct the reactive power of a wind turbine. The wind turbine is linked to this thing. Because of this, a Static Compensator, also called a STATCOM, was put in place to fix problems with the quality of the power at the point of common connection. By using PID control, the STATCOM can have a much faster response time. Even though it takes a lot of time and work, making sure the system is stable requires a fast response time, a long settling time, and a good overshoot rate. To successfully control the exchange of active and reactive power between a STATCOM and an AC system, the phase and magnitude of the STATCOM's output voltages must be set in the right way. Because of this, power quality standards in the grid system are kept up by adjusting the output of the STATCOM compensator to match the current control strategy in the control scheme. The power system block set in SIMULINK is used to simulate the wind energy generation system that is connected to the grid. This is done so that the STATCOM-control scheme can be used to improve the power quality.

Keywords: Power Quality Disturbances, Solar-Wind Hybrid System, Statcom, Facts Devices, Renewable Energy.

1. Introduction

The term "renewable energy" refers to power that comes from non-traditional sources of energy. Renewable energy is energy that comes from sources that can be used again and again. Most of the time, this kind of energy is added to the human period. The sun, the wind, the rain, the tides, radio waves, and the heat from geothermal energy are all examples of renewable energy sources (RES); and the RES can be used for various purposes like power generation, heating, cooling, solar refrigeration etc [1]. The solar and wind are mostly integrated for feasible power generation for both off-grid and on-grid systems [2-4]. The way

[1*,2]Department of Electrical Engineering, School of Engineering and Technology, Nirwan University Jaipur, India.
[3]Department of Renewable Energy, Rajasthan Technical University, Kota, India-324010.
Email: msaikota@gmail.com

that electricity is made from wind has changed a lot. The European Commission released the White Paper on "Europe's Future Energy: Renewable Energy" in the second half of 1997. In the past few years, more units for making electricity with wind power than units for making electricity with nuclear power around the world. From a global point of view, it seems like getting electricity from the wind is a great idea. The United States Department of Energy was set a goal (in the year of 1999) of installing 80,000 megawatts (MW) of wind power by the year 2020. The group now goes by the name "American Wind Energy." Bert et al. [5] stated that this ability to use wind power to make electricity makes up about 5% of all electricity made and also say that approximately 20% of Denmark's electricity (costs wise) will be produced by the year 2030. It will be produced from non-traditional sources, especially 4,000 megawatts of onshore wind power. Wind power plant installation is growing in a rapid way. The most recent information from Danish wind turbine manufacturers shows that power production has gotten six times better in the last five years, with a 44% average annual improvement rate.

By November 2024, the world's solar capacity had doubled from the previous two years to almost 2 terawatts (TW). Significant increases in rooftop and utility-scale installations were the main causes of this spike. China was crucial and made a substantial contribution to the world's solar capacity. The nation's large-scale initiatives, like the 'Solar Great Wall' in the Kubuqi Desert, demonstrate its dedication to the growth of solar energy [6]. India's renewable energy sector, especially solar photovoltaic (PV) and wind energy, has grown significantly. With 217.62 GW of non-fossil fuel-based energy capacity as of January 20, 2025, the nation made significant strides toward its 2030 target of 500 GW. A record 24.5 GW of solar capacity was added by India in 2024, more than double the installations from the year before. This comprises roughly 1.48 GW from off-grid installations, 4.59 GW from rooftop installations (a 53% increase from the previous year), and 18.5 GW from utility-scale projects. With 700,000 installations made possible by the PM Surya Ghar: Muft Bijli Yojana, rooftop solar growth was significantly accelerated [7].

With an annual growth rate of 12.6%, the world's wind power capacity was close to 1.1 TW by the middle of 2024. According to projections, the capacity would reach about 1.2 TW by the end of 2024.By the end of 2024, the offshore wind industry had grown significantly, with a global capacity of 80.9 gigawatts (GW)[8]. Due to its significant investments in offshore wind projects, China accounted for over half of this capacity. In the same year, India's wind energy capacity increased by 21%, or 3.4 GW, over 2023. India's dedication to broadening its renewable energy portfolio is shown in this expansion. With 29.98 GW of installed renewable energy capacity, Rajasthan tops the world because to its large land area and abundant solar radiation. Gujarat, which is heavily focused on wind and solar projects, comes in second with 29.52 GW. Karnataka and Tamil Nadu both provide substantial contributions, with respective capabilities of 22.37 GW and 23.70 GW [9-10].

Grigsby [11] Bansal et al. [12] found that German exports of wind turbines have been getting better progress over the past few years. Wind energy is a competitive technology that has been making pollution-free electricity for more than 20 years. Wind power has become the most important source of energy for the future of the world, just like nuclear power has become the most important source of energy for the future of the world. Wind power lets countries get more than 10 percent of their electricity from it. When wind energy is added to the grid, it will cause problems with the circulation network or with the whole grid. Because there is no linear load on the other side of the network, the supply network is mostly used to connect the transmission structure and the generation structure in one region. Because of this, the system is thought to be one that doesn't do anything [13].

When a DFIG is hooked up to the grid and supplying electricity, a lot of problems can happen, and any one of them could stop this generator from working as it should. Problems with the measurements include sudden gusts of wind and irregularities in the grid, such as voltage dips, rises, frequency changes, and so on [14[.

India used to compare the coherence of the wool produced by a connected wind turbine. Will monitor figures such as ear selection, coordination and crest accessories. The conclusion is that the height of the short row on the plate is higher than the level of air force penetration into the box. The control of wind turbines on energy excellence is insignificant [15-17].

By integrating Flexible AC Transmission Systems (FACTS) devices, grid-connected solar-wind hybrid systems can efficiently improve power quality. Due to its intermittent nature and the existence of nonlinear loads, renewable energy systems are prone to power quality problems such voltage sags, swells, and harmonic distortions. These devices are essential in reducing these problems. Dynamic Voltage Restorers (DVRs): These gadgets efficiently handle power quality problems during fault scenarios by enhancing voltage stability and transient response [18]. Unified Power Quality Conditioners (UPQC): These devices manage load demand in hybrid renewable energy systems and drastically lower total harmonic distortion (THD) by combining shunt and series active power filters [19]. Static Var Compensators (SVC) and STATCOM: These tools improve voltage control and reactive power support, which raises the overall quality of power in wind energy systems [20]. The capacity of these FACTS devices to preserve operating efficiency and minimize disruptions has been confirmed by MATLAB/SIMULINK simulations in real-world situations [19-21]. Even while FACTS devices significantly improve power quality, putting them into practice can be expensive and may call for complex control techniques. This calls for a thorough assessment of the technical and financial viability of incorporating these devices into the grid's current architecture.

Using MATLAB Simulink, simulation experiments by Subasri et al. [21] showed how the SVC effectively influences the improvement of the voltage profile during the penetration of wind power in the power grid. They also showed that fuzzy logic controllers produce better results than PI controllers. Liu et al [22] proposed a synchronous compensator static (STATCOM) with hybrid energy storage system (HESS) to mitigate the voltage fluctuation in wind power paralleling in the grid. Low voltage ride through (LVRT) capabilities and the dynamic performance of a VSC-based PV-STATCOM for power quality enhancement in a grid integrated system are explained. According to LVRT standards, real and reactive power injections maintain grid voltage in the event of abnormal grid conditions [23]. Khan et al [24] proposed a D-STATCOM control technique for monitoring the stability of electrical grid and demonstrated the effect of this system on electricity grid on solar PV-Wind integrated microgrid framework and explored an improvement in the system's stable operating limit in the event of implementation of D-StatCOM.

Manohar et al. [25] concentrated on enhancing power quality in electrical networks employing renewable energy sources, particularly through active power filters and synchronous reference frame theory. Instead of concentrating on hybrid systems or FACTS devices, Naick et al [26] focused on a STATCOM-based solution for improving power quality in grid-connected solar PV systems. It was used an ANN-controlled method to solve problems like reactive power compensation and voltage regulation. Manohara et al [27] focuses on enhancing power quality in grid-integrated solar photovoltaic systems using a unified power quality conditioner (UPQC). Al Anbagi and Hamodat [28] focused on enhancing power quality in a hybrid grid using a STATCOM to manage reactive and harmonic currents, thereby improving grid stability and transmission capacity, specifically in a system combining a 100 KW PV plant and traditional power sources.

STATCOM is based on VMC fuel injection (VSC) technology with 50 Hz and 50 MVA amplifiers, which are used to amplify the grid-related turbine-related organization [29-31]. Fuzzy logic controller (FLC) is used as a control method by STATCOM rather than traditional PI control. Wind turbines and improved wind power generation (WPGS) systems were compared to fuzzy manufacturers and PI guards, which included PSCAD / EMTDC [32]. The conclusion is that transferring STATCOM devices to FLC is better than STATCOM with traditional PI Controller. Air pressure improvement and wind power system (WPGS) improvements are compared to a conservative (FLC) bath and FL controller [33]. The work offered is intended for small power systems. It is necessary to study WPGS connected to the main power system with D-STATCOM, and use using the STATCOM controller and its connection with the main power system to solve various problems, such as protection, stability, improved power generation and energy efficiency and quality. The conclusions are the network strength on unresolved border on STATCOM level or cost.

2. Proposed Methodology

The proposed system integrates both solar and wind energy sources to enhance power generation reliability and efficiency while addressing power quality concerns. The system aims to improve power system performance through the utilization of a STATCOM (Static Synchronous Compensator) device and advanced control strategies. Given the variable nature of wind power generation, maintaining power quality becomes a challenge. To tackle this issue, the article suggests employing simulation and analysis techniques to optimize the filtering, rotation, and power enhancement capabilities of synchronous static amplifiers. These amplifiers, coupled with effective control strategies, can mitigate power fluctuations and improve overall system stability. The integration of solar and wind energy into the power system involves multiple steps, including power generation, transmission, and distribution. The main objectives of this work are to ensure the continuous supply of electricity to meet customer needs while maximizing the efficiency of power generation.

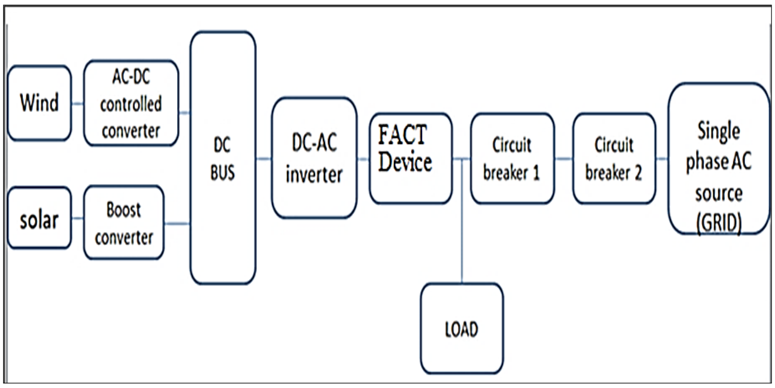

Fig. 1. Proposed Flow Diagrams

After going over the STATCOM's main operating idea, we can now understand how it working for which the proposed flow diagram is presented in figure 1. Source V1 in the diagram above is the voltage coming out of the STATCOM and electrical circuit of STATCOM is shown in figure 2. When the power system's reactive power demand goes up, STATCOM raises its output voltage V1 while keeping the phase difference between V1 and V2 the same (it shall be noted here that there will always exists small phase angle between V1 and V2 to cater for the leakage impedance drop in the interconnecting Transformer). Because V1 is bigger than V2, STATCOM will send reactive power to the power grid. So, STATCOM gives out reactive power and acts as a generator of reactive power.

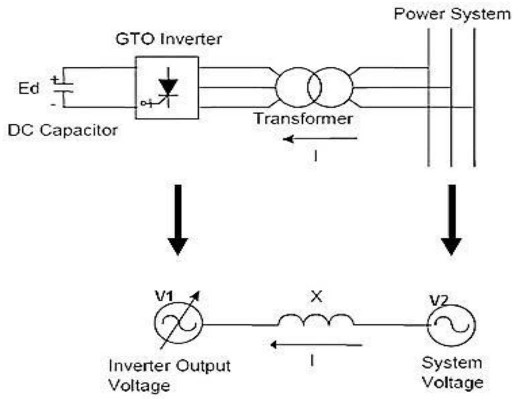

Fig.2. Electrical Circuit of STATCOM

When set to the above settings, STATCOM works in Voltage Control Mode and the control mode is represented in figure 3. Still, like any other piece of equipment, STATCOM must have limits on how much reactive power it can either give off or take in. When the STATCOM is at its limit, the output voltage V1 stays the same, and the device works like a constant current source, giving or taking in reactive power equal to its limiting value at a constant voltage and current. This mode of operation is called "VAR Control Mode" in STATCOM.

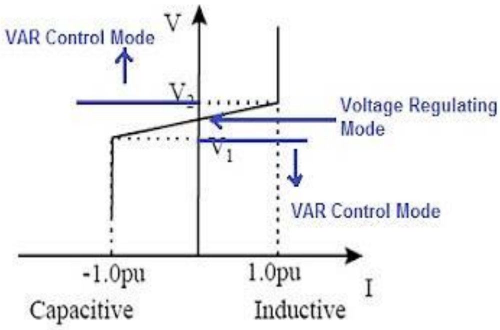

Fig 3. STATCOM Operation Mode

The STATCOM Voltage Current Characteristics are shown in the picture above. As can be seen, STATCOM's voltage regulation goes from V1 (the power system's bottom side) to V2 (the upper side). When the system voltage drops below V1 or goes above V2, STATCOM switches to VAR Control mode. For simplicity, let's just call the voltages discussed above V1 (the voltage used for the STATCOM's output) and V2 (the voltage of the power system) without further explanation.

3. Simulation & Results

To simulate the impact of a STATCOM (Static Synchronous Compensator) on power quality and system stability, you can use software like MATLAB/Simulink as shown in figure 4 (a and b). First, model the power system including wind turbines, solar panels, transmission lines, and loads. Integrate the STATCOM at a strategic point in the network, configuring it to manage reactive power compensation using a control algorithm, as a PI controller. Set initial conditions including wind speed profiles, solar irradiance, then run the simulation to observe the system's behavior under various disturbances. Analyze key metrics like voltage stability, power quality, and reactive power flow to assess the STATCOM's effectiveness, and fine-tune its control parameters for optimal performance.

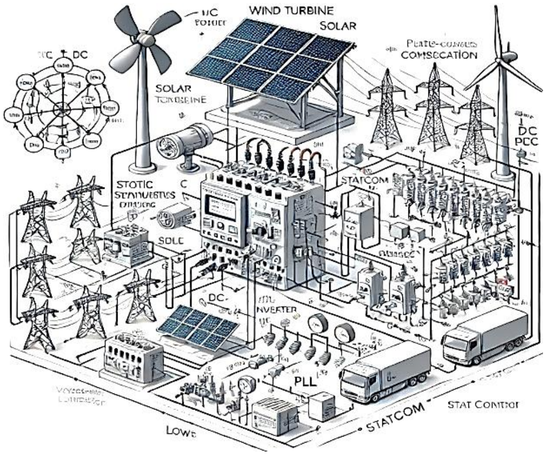

Fig. 4 (A). Block Diagram with STATCOM for Solar and Wind Integration

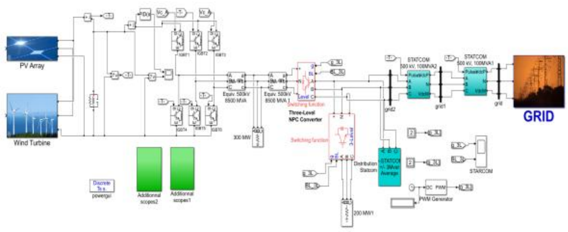

Fig. 4 (b). Simulink Model with STATCOM for Solar and Wind Integration

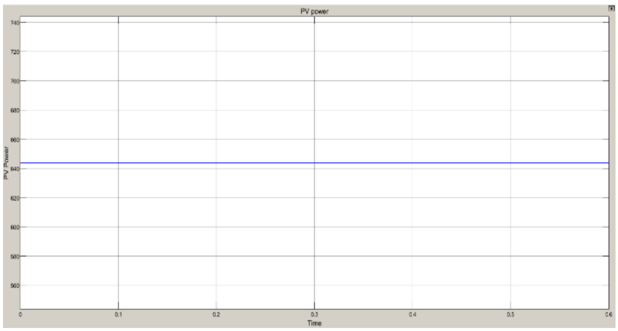

Fig.5. PV Power

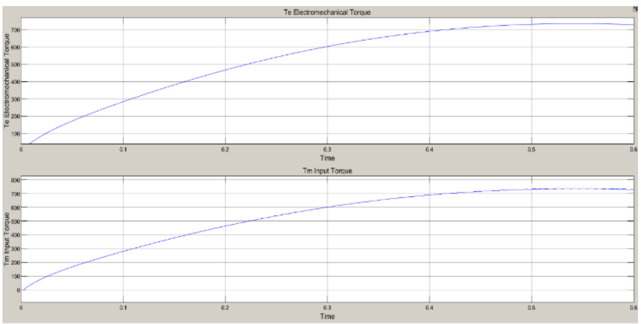

Fig. 6. Electromechanical Torque (Te) and Input Torque (Tm)

The PV power curve is shown in figure 5. Figure 6 illustrates the dynamic behaviour of electromechanical torque (Te) and the mechanical input torque (Tm) in the power system. Electromechanical torque, represented by Te, is generated by the interaction of the stator magnetic field and the rotor in the generator. It reflects how electrical energy is converted into mechanical energy.

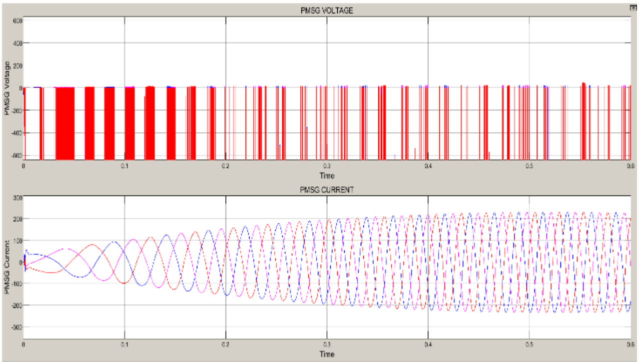

Fig.7. PMSG Current and Voltage

This figure 7 illustrates the current and voltage characteristics of a Permanent Magnet Synchronous Generator (PMSG) within the system

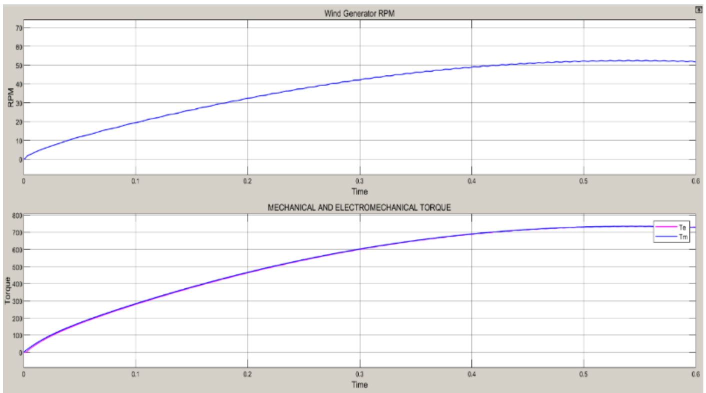

Fig. 8. Wind Generation RPM and Mechanical and Electromechanically Torque

This figure 8 depicts the relationships between wind turbine generation RPM (Revolutions Per Minute), mechanical torque (Tm), and electromechanical torque (Te) within the power generation system.

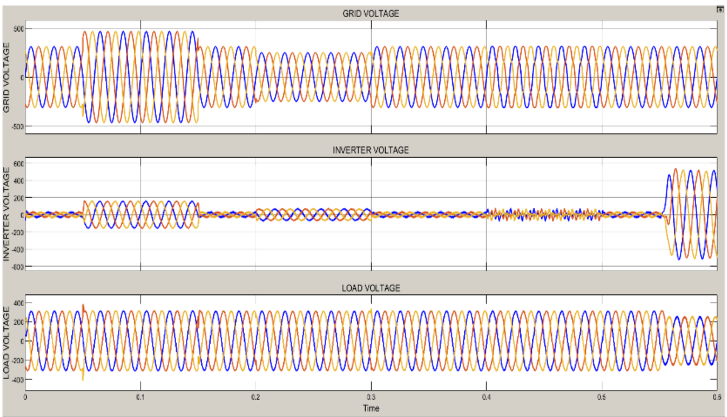

Fig. 9. Grid Voltage, Inverter Voltage, Load Voltage

Analysing the Figure 9 provides insights into the interaction between the grid, inverter, and electrical load in a grid-connected renewable energy system. The inver voltage and inverter current is shown in figure 10.

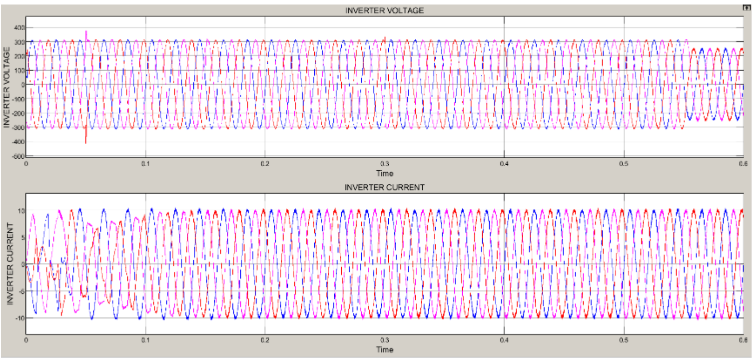

Fig. 10. Inverter Voltage and Inverter Current

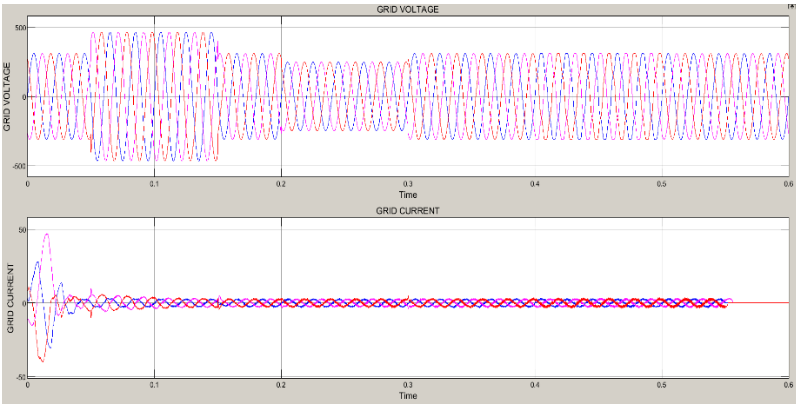

Fig. 11. Grid Current and Grid Voltage

Figure 11 provides insights into the interaction between the grid, system components, and connected loads.

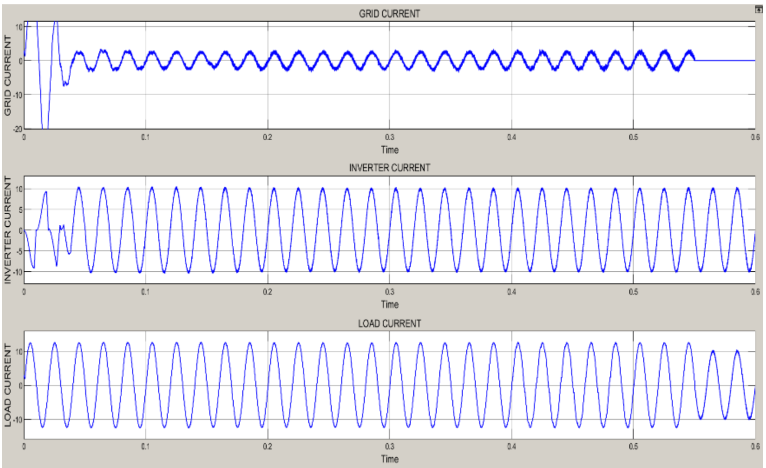

Fig. 12. Grid Current, Inverter Current, Load Current

Figure 12 typically illustrates the current characteristics in a grid-connected power system with an inverter and electrical load. For analysing of these currents provides insights into the dynamics of power flow within the system, including how the inverter manages energy conversion and synchronization with the grid, and how load demands impact overall system operation and efficiency.

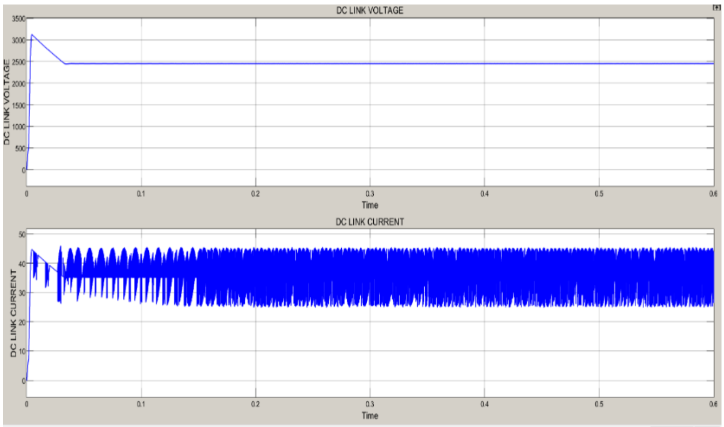

Fig. 13. DC Link Voltage and DC Link Current

Figure 13 typically illustrates the relationship between DC link voltage and DC link current.

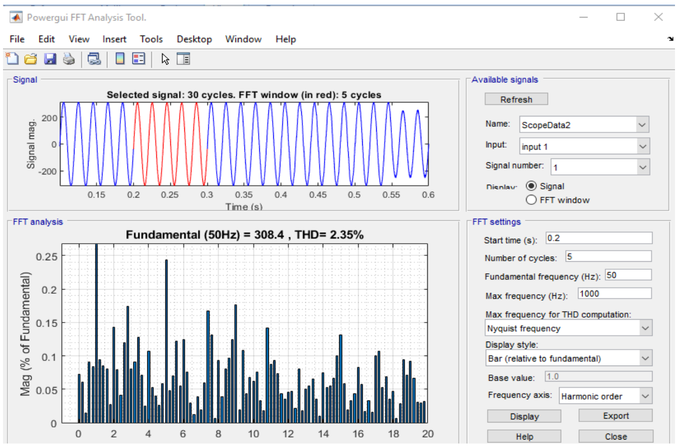

Fig. 14. THD with STATCOM

Table 1 THD Performance of Simulink Model

Type	THD (%)
Without STATCOM	2.59
With STATCOM	2.35

Table 1 presents the Total Harmonic Distortion (THD) performance of a Simulink model, comparing the system's harmonic distortion with and without a STATCOM (Static Synchronous Compensator). The THD value without the STATCOM is 2.59%, indicating a higher level of harmonic distortion in the system's voltage or current waveforms. In contrast, the presence of a STATCOM reduces the THD to 2.35%, demonstrating its effectiveness in improving power quality by mitigating harmonic distortions. This reduction in THD signifies that the STATCOM enhances the overall performance of the electrical system by providing reactive power support and filtering out harmonics, leading to a cleaner and more stable power supply.

4. Conclusion and Future Scope

In this study, the proposed methodology focuses on enhancing power quality and system stability in renewable energy integration, particularly addressing the variability of wind power generation. Through simulation and analysis techniques, the research optimizes the filtering, rotation, and power enhancement capabilities of synchronous static amplifiers, complemented by the strategic deployment of a STATCOM device. Integrated within the MATLAB/Simulink environment, the STATCOM is configured with a PI controller to manage reactive power compensation effectively. Initial conditions such as wind speed profiles and solar irradiance are considered to simulate various operational scenarios, enabling the assessment of key metrics like voltage stability and power quality. This approach aims to improve overall power system performance while ensuring reliable electricity supply to meet customer needs. Central to the methodology is the integration of a STATCOM (Static Synchronous Compensator), a device known for its ability to dynamically control reactive power flow in power systems. In this study, the STATCOM is strategically placed within the network using MATLAB/Simulink modelling. A PI (Proportional-Integral) controller is utilized to govern the operation of the STATCOM, ensuring effective reactive power compensation across varying operational conditions. By simulating scenarios that include different wind speed profiles and solar irradiance levels, the study aims to comprehensively assess the STATCOM's impact on critical metrics such as voltage stability and power quality.

1. These approaches can optimize reactive power compensation more dynamically and adaptively than traditional PI controllers, thereby improving system response to varying renewable energy outputs and grid conditions.
2. Explore comprehensive integration strategies between STATCOMs and energy storage technologies like batteries or supercapacitors.
3. By combining STATCOMs with ESS, the grid gains additional capabilities for storing excess renewable energy during peak production times and releasing it during periods of high demand or low generation, enhancing overall grid stability and reliability.
4. Transition from simulation-based studies to real-time implementation using HIL testing methodologies. This approach allows for the validation and fine-tuning of control strategies and simulation models under realistic operating conditions, ensuring robust performance and reliability of STATCOMs in actual grid environments.

5. References

[1] Veeresh Fuskele, Prashant Baredar, Rishindra Mohan Sarviya, Shiv Lal, Shubham Awasthi. Wind Turbine Nacelle Cooling Systems: A review. WIRE-Energy and Environment Journal (Wiley), 11(6) PP1-13, DOI: 10.1002/wene.456,

[2] Shiv Lal, Verma P., Rajora R. 2013. Performance analysis of photovoltaic based submersible water pump. Pp. 552-560. International journal of engineering and technology, vol. 5, issue 2, pp. 552-560. ISSN: 0975-4024,http://www.enggjournals.com/ijet/.

[3] Shiv Lal, Verma P., Rajora R. 2013. Techno-economic analysis of solar photovoltaic based submersible water pumping system for rural areas of an Indian state Rajasthan. Science journal of energy engineering, vol.1 issue 1, pp. 1-4, DOI: 10.11648/j.sjee.20130101.11.

[4] Shibna Hussain, Santosh Kumar Sharma, Shiv Lal, Feasible Synergy between Hybrid Solar PV and Wind System for Energy Supply of a Green Building in Kota (India): A Case Study using iHOGA, Energy Conversion and Management 315 (2024) 118783, https://doi.org/10.1016/j.enconman.2024.118783

[5] Bert J.M. de Vries, Detlef P. van Vuuren, Monique M. Hoogwijk, (2007) Renewable energy sources: Their global potential for the first-half of the 21st century at a global level: An integrated approach, Energy Policy,35(4):2590-2610, https://doi.org/10.1016/j.enpol.2006.09.002.

[6] Overview, https://www.iea.org/reports/renewables-2024/global-overview, Assessed on 01 December 2024

[7] Energy statistics, https://www.mospi.gov.in/sites/default/files/publication_reports /Energy Statistics_India_publication_2024N.pdf, Assessed on 01 December 2024

[8] Wind and solar year in review 2024, https://globalenergymonitor.org/report/wind-and-solar-year-in-review-2024/, Assessed on 01 December 2024

[9] India's Renewable Energy Capacity Hits New Milestone, https://pib.gov.in/Press ReleaseIframe Page.aspxPRID=2073038, Assessed on 01 December 2024

[10] A.Nagpal , Aravinda K , Haritha M R , A. Harika , P. K. Chandra , M. M. adnan , S. Singh, India Analysis of Scope of Wind-Energy Development in India, E3S Web of Conferences 529, 02012 (2024), ICSMEE'24, DOI:10.1051/e3sconf/202452902012

[11] Grigsby L.L. (2007) Electric Power Generation, Transmission, and Distribution, CRC press, 1st edition https://doi.org/10.1201/9781420009255

[12] R. C. Bansal, Ahmed F. Zobaa, R. K. Saket (20025), Some Issues Related to Power Generation Using Wind Energy Conversion Systems: An Overview, International Journal of Emerging Electric Power Systems, 2(2):1070, DOI: 10.2202/1553-779X.1070

[13] Gajendra Singh Chawda, Abdul Gafoor Shaik, Mahmood Shaik, P. Sanjeevikumar, Jens Bo Holm-Nielsen, Om Prakash Mahela, and K. Palanisamy, "Comprehensive Review on Detection and Classification of Power Quality Disturbances in Utility Grid with Renewable Energy Penetration," in IEEE Access, Volume: 8, pp. 146807 – 146830, 2020.

[14] Rahul Dubey, S. R.Samantaray, B. Chitti Babu and S. Nandha Kumar, "Detection of power quality disturbances in presence of DFIG wind farm using Wavelet Transform based energy function," IEEE International Conference, 2011.

[15] Rajendra Mahla, Baseem Khan, Om Prakash Mahela, and Anup Singh, "Recognition of Complex and Multiple Power Quality Disturbances Using Wavelet Packet Based Fast Kurtogram and Ruled Decision Tree Algorithm," International Journal of Modeling, Simulation, and Scientific Computing, Vol. 12, No. 05, 2150032, 2021.

[16] Ram Narayan Shah, Om Prakash Mahela, Sushma Lohia, "Recognition and Mitigation of Power Quality Disturbances in Renewable Energy Interfaced Hybrid Power Grid," 12th IEEE International Conference on Computational Intelligence and Communication Networks (CICN 2020), September 24-25, 2020, BIAS Bhimtal, Nainital, India.

[17] Atallah Ouai, Lakhdar Mokrani, Mohamed Machmoum, Azeddine Houari, "Control and energy management of a large scale grid-connected PV system for power quality improvement," Solar Energy, Vol. 171, pp. 893–906, 2018.

[18] Patidar, V., & Bhargava, A. (2025). Improving Power Quality and Fault Ride-Through (FRT) in Grid-Connected Hybrid Energy Systems: Design and Optimization of Dynamic Voltage Restorers. Smart Moves Journal Ijoscience, 1–9. https://doi.org/10.24113/ijoscience.v10i8.520

[19] Ranjan, A., & Choudhary, J. (2024). Power Quality Enhancement in Grid-Connected Energy System with UPQC Using Hybrid PSO-GWO Optimization Technique (pp. 23–37). Springer International Publishing. https://doi.org/10.1007/978-981-99-9531-8_3

[20] Adware, R. H., & Chandrakar, V. K. (2023). A Hybrid STATCOM Approach to Enhance the Grid Power Quality associated with a Wind Farm. https://doi.org/10.48084/etasr.6125

[21] Subasri, C. K., Raja, S. C., & Venkatesh, P. (2015). Power Quality Improvement in a Wind Farm Connected to Grid Using FACTS Device (pp. 1203–1212). Springer, New Delhi. https://doi.org/10.1007/978-81-322-2119-7_117

[22] Liu, L., Wang, S., & Tian, G. (2016). Grid power quality improvement with STATCOM/HESS for wind turbine with squirrel-cage induction generator. Conference on Industrial Electronics and Applications, 2552–2557. https://doi.org/10.1109/ICIEA.2016.7604023

[23] Popavath, L. N., & Kaliannan, P. (2018). Photovoltaic-STATCOM with Low Voltage Ride through Strategy and Power Quality Enhancement in a Grid Integrated Wind-PV System. Electronics, 7(4), 51. https://doi.org/10.3390/ELECTRONICS7040051

[24] Khan, Md. M. H., Ullah, A., Siddiquee, S. M. S., Alam, M. S., Biswas, K., & Ali, R. (2022). Power compensation and Voltage flicker control of Solar-wind hybrid microgrid with optimized D-STATCOM using a control Technique. 2022 International Conference on Innovations in Science, Engineering and Technology (ICISET), 1–6. https://doi.org/10.1109/iciset54810.2022.9775864

[25] Manohara, M., Nageswara Prasad, T., Leela Rani, D., Thrinath, B. V. S., Babu, E., Kumar, A. V. R., & Thrinath, A. (2024). Solar grid power quality improvement with synchronous reference frame filters. 395–400. https://doi.org/10.1201/9781003559092-68

[26] Naick, S., Sekhar, C., Prasad, K. V. R. B., & Krishna, H. (2023). Transformerless ANN-Controlled STATCOM-Based Power Quality Improvement for Three Phase DC-AC Boost Inverter in Grid-Connected Solar Photovoltaic Systems. SSRG International Journal of Electrical and Electronics Engineering. https://doi.org/10.14445/23488379/ijeee-v10i11p108

[27] Manohara, M., Muthukaruppasamy, S., Dharmaprakash, R., Sendilkumar, S., Bharadwaj, D. D., & Parimalasundar, E. (2024). Power quality enhancement of grid-integrated solar photovoltaic system with unified power quality conditioner. Electrical Engineering & Electromechanics, 6, 44–48. https://doi.org/10.20998/2074-272x.2024.6.06

[28] Al-Anbagi, M., & Hamodat, Z. (2022). Power Quality Enhancement in Hybrid Grid Using FACTS Device. 98–102. https://doi.org/10.1109/ICPSE56329.2022.9935382

[29] M.M. Mahmoud , H. S. Salama, M. Bajaj ,M.M. Aly, I. Vokony, S. S. H. Bukhari, D.E. M. Wapet , A.M M. A.Rahim, 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, 8738460, pp1-28, https://doi.org/10.1155/2023/8738460

[30] Y. Ni, L. Snider, STATCOM power frequency model with VSC charging dynamics and its application in the power system stability analysis, 1997 Fourth International Conference on Advances in Power System Control, Operation and Management, APSCOM-97, IEEE , 10.1049/cp:19971815

[31] A. Saha, S. Ahmad, A. A. Soma, M. Z. A. Chowdhury, A.A. Hossain, 2017, Modelling and control of STATCOM to ensure stable power system operation, 4th International Conference on Advances in Electrical Engineering (ICAEE), IEEE , DOI: 10.1109/ICAEE.2017.8255318

[32] Juan Shi; Amin Noshadi; Akhtar Kalam; Peng Shi, Fuzzy logic control of DSTATCOM for improving power quality and dynamic performance, 2015 Australasian Universities Power Engineering Conference (AUPEC), IEEE, DOI: 10.1109/AUPEC.2015.7324796

[33] Mohamed Bahgat, Mohamed Ezzat, Mahmoud A. Attia, S. F. Mekhamer ,Nourhan M. Elbehairy , Comparative analysis of PI and fuzzy logic controller for grid connected wind turbine under normal and fault conditions, Scientific report, (2025) 15:1954, https://doi.org/10.1038/s41598-024-85073-w