Power Quality Improvement in a Grid Connected Hybrid Renewable Energy Generation System Using UPFC

Himanshu Verma[1] (M.tech Scholar), Manpreet Singh[2] (Assistant Professor)
Electrical Engineering Department
Baba Banda Singh Bahadur Engineering College,
IKGPTU, Jalandhar, India
(himanshuverma1572000@gmail.com)

Abstract— As a way to lower carbon emissions and improve energy sustainability, the grid's integration of renewable energy sources, such as photovoltaic (PV) and wind power systems, has acquired a lot of popularity recently. Because these renewable energy sources are intermittent and variable, integrating them into the current power infrastructure presents power quality issues. This thesis uses MATLAB/Simulink simulations to implement and analyse Unified Power Quality Conditioner (UPFC) Flexible AC Transmission System (FACT) devices in grid-connected PV-wind integration systems in order to improve power quality. The purpose of the study is to assess how well UPFC FACT devices suppress harmonic distortion and improve power quality parameters.

Keywords— Smart grids , Wind energy, Solar Energy, Unified Power Flow Controller (UPFC), FACTS, Power Quality Improvement, THD, Harmonics

I. INTRODUCTION

To have sustainable growth and social progress, uses of renewable energy sources, such as wind, solar, hydro, cogeneration, etc., are required to supply the demand for energy. Energy efficiency and the utilization of renewable energy sources are the two main aspects of a sustainable energy system. In order to reduce the environmental impact on conventional plants, it is necessary to integrate renewable energy sources like solar and wind power into the power system. Technical challenges with voltage regulation, stability, and power quality issues must be taken into account when integrating renewable energy into the current power system.
Flexible ac transmission systems (FACTS) technology is the ultimate tool for getting the most out of existing equipment via faster control action and new capabilities. The most striking feature is the ability to directly control transmission line flows by structurally changing parameters of the grid and to implement high-gain type controllers based on fast switching. One interesting area of continuing research has been the application of FACTS devices to power system security. The majority of research that have been published have concentrated on how these devices can reduce system oscillations and increase power system security; very few have looked into how these devices affect power system reliability. The possibilities stem from FACTS controllers' capacity to regulate the interdependent parameters that control how transmission systems function, such as current, phase angle, damping oscillations at different frequencies below the rated frequency, and series and shunt impedance. Other than mechanical techniques, these limits cannot be avoided without reducing the usable transmission capacity and preserving the necessary system stability. A line can carry power closer to its thermal rating with the help of the FACTS controller's increased flexibility. Rapid-response power electronics are required for supplementing mechanical switching. Any stability limitations can be overcame with the FACTS technology; in that case, the thermal and dielectric limits would be the absolute limits. Real and reactive power via the transmission line cannot be regulated in the absence of a UPFC. . It is simulated that a control system that allows the UPFC to track changes in reference values such as AC and DC voltages and the angle order of the series voltage source converter exists. The firing pulse for both converters in this control method is produced using a generalized pulse width modulation technique. To evaluate the effectiveness of UPFC, simulations will be run using the MATLAB-Simulink program. The results imply that the transient stability of the simulation model was significantly improved by employing this technique.

The UPFC is recently introduced FACTS controller which has the capability to control all the four transmission parameters. The unified power-flow controller (UPFC) is a member of the FACTS family with very attractive features. This device can independently control many parameter, so it is the combination of the properties of a static synchronous compensator (STATCOM) and static synchronous series compensator (SSSC).

II. POWER QUALITY

A. *Power Quality Issues and Its Consequences*

Power quality issues include voltage imbalance, waveform distortion (including DC offset, harmonics, inter harmonics, notching, and noise), power frequency variations, long-duration voltage variations (including overvoltage, under voltage, and sustained interruptions), and short-duration voltage variations (including interruption, sags (dips), and swells). The majority of these worries are caused by loads attached to electric supply networks.

There are two types of loads, linear and nonlinear. Motors, heaters and incandescent lamps are examples of linear load produce a current proportional to the voltage. The nonlinear load uses high-speed electronic power switching devices to convert the AC supply voltage to a constant DC voltage used by the internal circuits. Power quality issues can be linked to a particular kind of electrical disruption for both its causes and effects. Over 90% of electric motors in most industries are used in applications that are inverter driven. Equipment breakdowns in electronic devices and problems with outlets and transmissions are caused by low power quality. Various power quality issues can be power outages, voltage fluctuations, transients, harmonics etc.

B. Harmonic Distortion

Most of the time, the equipment and installation methods used by the customers cause harmonic issues. The widespread usage of non-linear load devices, such as variable speed drives, computer power supplies, electronic ballasts, compact fluorescent lights, and so on, results in high current flow with harmonic frequency components, which is the source of harmonic distortion. The maximum amount of heat that can be dissipated to prevent bus bars, circuit breakers, neutral conductors, transformer windings, or generator alternators from overheating determines the limiting rating for the majority of electrical circuit elements. Ratio of the square root of the sum of squares of the root mean square value of harmonic component to the Root mean square value of the fundamental components defined as Total Harmonic Distortion (THD)

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III. UNIFIED POWER FLOW CONTROLLER (UPFC)

Essentially, the UPFC consists of two voltage source inverters (VSIs) that are coupled to the power system via coupling transformers and share a common DC storage capacitor. One VSI is connected in series with a series transformer, while the other is connected in shunt with a shunt transformer to the transmission system. To regulate the active and reactive power flows on the transmission line, a symmetrical three-phase voltage system with an adjustable phase angle and magnitude is injected by the series inverter in series with the line. Thus, the line and this inverter will trade active and reactive power. The series inverter electronically supplies the reactive power, while the dc terminals receive the active power.

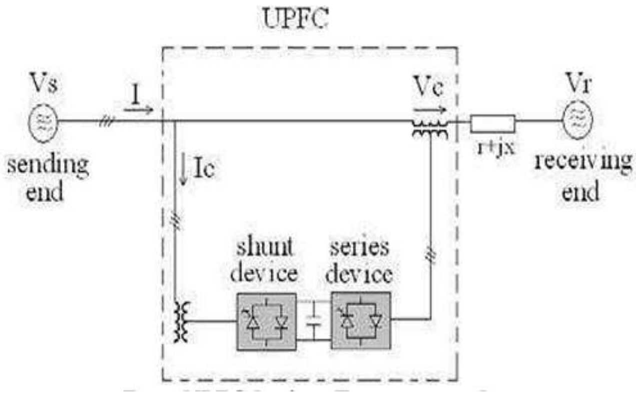

Fig 1 UPFC Link in Transmission Line

The shunt inverter is set up to maintain a constant voltage across the storage capacitor Vdc by taking this dc terminal power, either positive or negative, from the line. As a result, the UPFC's net real power absorption from the line is limited to the inverters' and their transformers' losses. To regulate the voltage at the connection point, the shunt inverter's remaining capacity can be exchanged for reactive power from the line.

A. Characteristics of UPFC

The main problems where the capabilities and use of FACTS are observed include line outages, congestion, cascade line tripping, and power system stability loss. The Unified Power Flow Controller is an example of a FACTS device from the most recent generation (UPFC). The line impedance, voltage, and phase angle—the three parameters that determine the direction of line power flow—can all be controlled concurrently by the UPFC. The Static Synchronous Compensator (STATCOM) and the Static Synchronous Series Compensator (SSSC), two "old" FACTS devices, are combined into one "new" FACTS device. These two devices are actually two Voltage Source Inverters (VSIs), connected to the transmission line in a shunt fashion through a shunt transformer and in a series fashion through a series transformer. They are connected to each other via a common dc link that includes a storage capacitor. At the point of connection, the shunt inverter regulates voltage by introducing a timely reactive power flow into the line and balancing the real power flow that is transferred between the transmission line and the series inverter. By connecting an appropriate voltage with a regulated phase and magnitude in series with the transmission line, the series inverter can be utilized to regulate the actual and reactive power flow of the line.

B. UPFC CONTROL SYSTEM

A common dc connection connects the two voltage source converters that make up the UPFC: a series converter and a shunt converter. Shunt converters, also known as Static Synchronous Compensators, or STATCOMs, are used to supply reactive power to the ac system in addition to providing the dc power needed for both inverters. Series converters, also known as Static Synchronous Series Compensators (SSSC), are used to add controlled voltage magnitude and phase angle in series with the line. Power electronic converters and transformers are found in every branch. There was a common DC capacitor between these two voltage source converters. This DC capacitor typically has a limited ability to store energy. As a result, the active power produced by the series converter and the active power drawn by the shunt converter must match. Greater control over power flow is possible due to the independent selection of reactive power in the shunt or series converter. The device is connected to the system via the coupling transformer. By adding the series voltage, VS, with a certain amplitude, |VS|, and phase shift, ϕ, to V1, power flow can be controlled. A new line voltage V2 with a different magnitude and phase shift will result from this. The phase shift δ between V2 and V3 varies along with the angle ϕ.

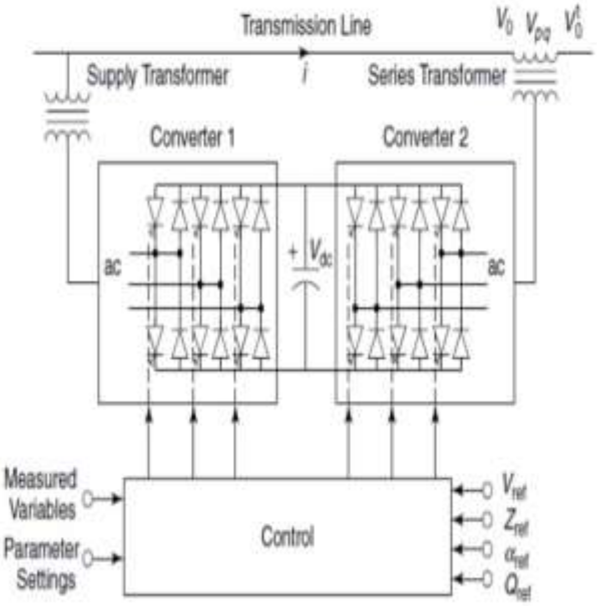

Fig.2 Schematic diagram of three phase UPFC connected to a transmission line

Active power can now be transmitted from the shunt converter to the series converter over the DC bus, giving this FACTS topology far more control over the line active and reactive power than the SSSC. It can now have any angle with regard to line current, unlike the SSSC where the injected voltage Vs is restricted to remain in quadrature with line current I. The locus described by vector V2's end (V2=V1+Vs) is a circle, as indicated by the phasor diagram, if the injected voltage Vs's magnitude is maintained constant and its phase angle with respect to V1 is adjusted between 0 and 360 degrees.

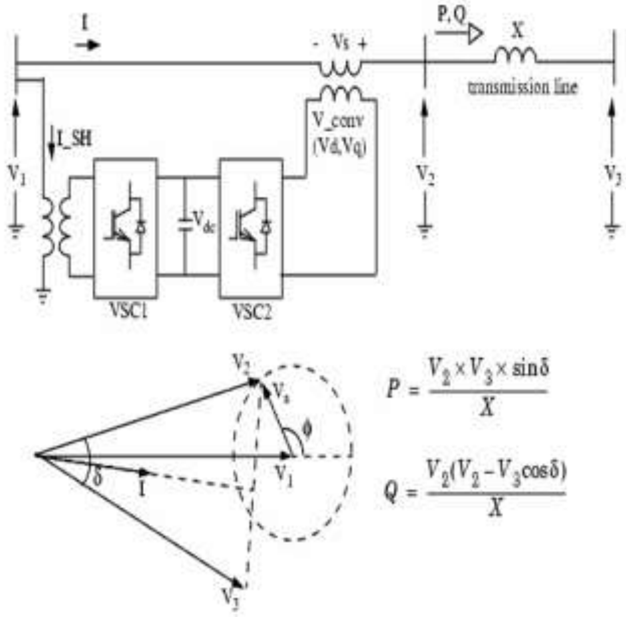

Fig.3 Single line diagram of UPFC and phasor diagram of voltage and current

The phase shift δ between voltages V2 and V3 at the two line ends fluctuates in step with the variation in is. It follows that it is possible to control both the reactive power (Q) and the active power (P) transmitted at one line end. Shunt converters function similarly to STATCOMs. In conclusion, the shunt converter regulates both the DC bus voltage and the AC voltage at its terminals. It makes use of a dual voltage regulation loop, with an outer loop controlling AC and DC voltages and an inner loop controlling current. The series branch is not controlled like the SSSC is. The DC voltage and reactive power in an SSSC are managed by the two degrees of freedom of the series converter. The two degrees of freedom are utilized in a UPFC to regulate the reactive and active powers respectively. Two modes of operation are available for the series converter: manual voltage injection and power flow management (automatic).

IV. MATLAB SIMULATION AND PRESENT WORK

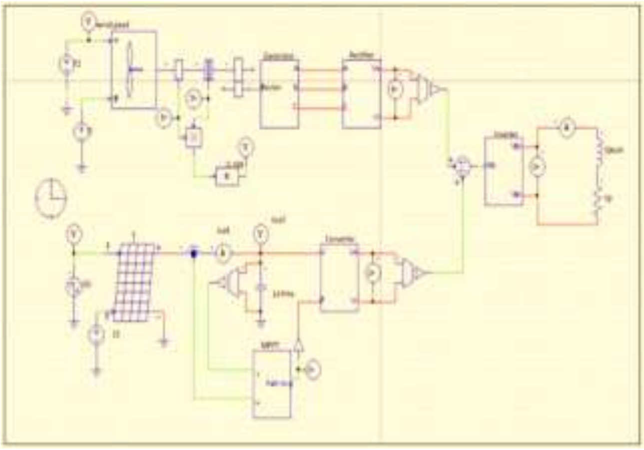

Fig.4 Schematic Diagram of Wind-Solar Hybrid System

Fig. 4&5 shows the schematic diagram of the wind-solar hybrid system, which is composed of two parts. Wind is one and solar energy is the other. The two primary renewable energy systems were connected to create this hybrid system. The system's DC power output was raised and connected to a load by means of an inverter. The vital parts of this energy system are the inverter, DC-DC converter, rectifier, and generator.

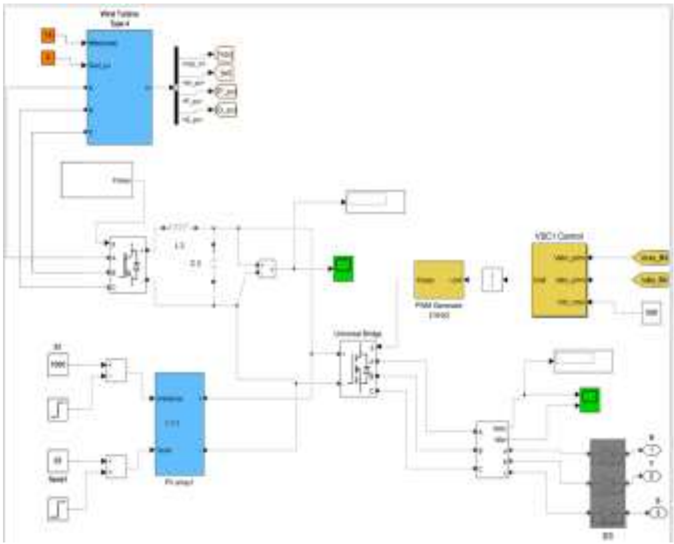

Fig.5 Schematic Model of Wind-Solar Hybrid System using MATLAB

MATLAB/Simulink is used to help the construction and modelling of the solar array and wind turbine system that are coupled to the generator. A hybrid power system consists of a distributed parameters line, a three-phase V-I measurement, a two-winding inductance matrix transformer, and a three-phase breaker.

Table 1 represents the solar array module parameters and their corresponding values or results found during simulation.

Table 1. Solar array module parameters

Parameter	Value
Rated Module output power, P_{MOD}	260 W
Short Circuit Current, I_{SC}	8.99 A
Open Circuit Voltage, V_{OC}	37.8 V
Voltage at Maximum Power, V_{MP}	30.7 V
Current at Maximum Power, I_{MP}	8.48 A
Number of cells in series, N_S	50 Hz
Number of modules in series, N_M	5

Table 2 represents the wind turbine PMSG parameters and their corresponding values or results found during simulation.

Table 2. Wind turbine PMSG parameters

Parameter	Value
Rated Output Power, P_{WIND}	1400 W
Nominal Wind Speed, V_{WIND}	10 m/s
Rated Rotational Speed, ω_{WT}	300 RPM
Damping coefficient, B	0 Nm/s
Inertia coefficient, J_{EQ}	4 kg.m^2
Stator phase resistance, R_S	0.005 ohm
Stator d-axis Inductance, L_d	7.552 Mh
Stator q-axis Inductance, L_q	8.348 mH
Magnets flux Linkage Constant, λ_0	0.34458 Wb

Table 3 presents the power electronics systems parameters. The simulation results were also compared to the performance parameters.

Table 3. Power electronics systems parameters

Parameter	Value
Switching frequency of all converters, F_{SW}	1980 Hz
Line to line RMS Grid Voltage, V_{GRID}	220 V
DS Bus upper limit, $V_{DC(MAX)}$	380 V
DS Bus lower limit, $V_{DC(MIN)}$	330 V
Injected AC current control adjustment, Δi_{ac}	0.05
IBC Inductors, L_1 and L_2	1 mH
DC Bus capacitor, C_{DC}	3 mF
Grid Line frequency, F_{nom}	50 Hz

The output of the wind turbine varies with the variation in wind speed. The output power of the wind turbine varies between 1.4 kw to 1.5 kw at 10 m/s wind speed. For Wind Turbine the value of maximum pitch angle is 27 degree and maximum rate of change of pitch angle is 10 degree/sec. The value of the sample time is 0.1 s. In the proposed model an inverter is used to convert the DC output power of the two-energy system into AC. The DC output power of the wind and solar system is added and supplied to the inverter. And it is connected a limiter at the input of the inverter to limit the amplitude of the input voltage. The upper limit and lower limit of the limiter is 110v and 1005v respectively. the Solar cells are inter connected in certain series /parallel combinations to form modules. These modules are hermetically sealed for protection against corrosion, moisture, pollution and weathering. A combination of suitable modules constitutes an array. A general data for 1m2 of a fixed array kept facing south yields nearly 1.4 kWh of electrical energy on a normal sunny day. If it is required to be used during non-shiny hours a storage system is required. Fig.2 shows the schematic diagram of wind-solar hybrid system using MATLAB. In this proposed model a grid is added with the model so that the unused power can be supplied to the grid. The following Figure shows the grid connected hybrid system which is connected with the grid through a transformer.

Fig.6 shows the schematic diagram of wind-solar hybrid system which is connected to load and in Fig.7 via UPFC.

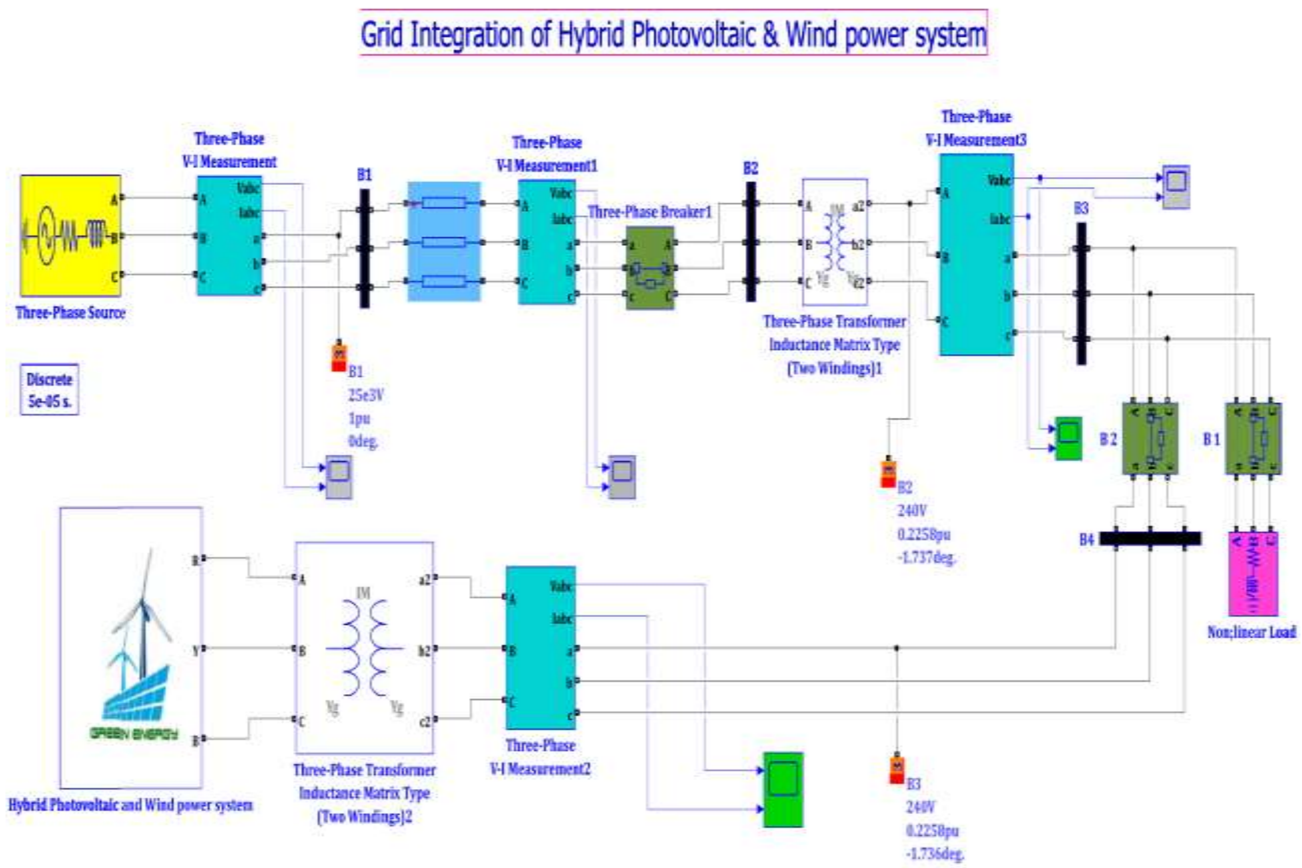

Fig.6 Simulink model of the PV-wind hybrid distributed generation power system

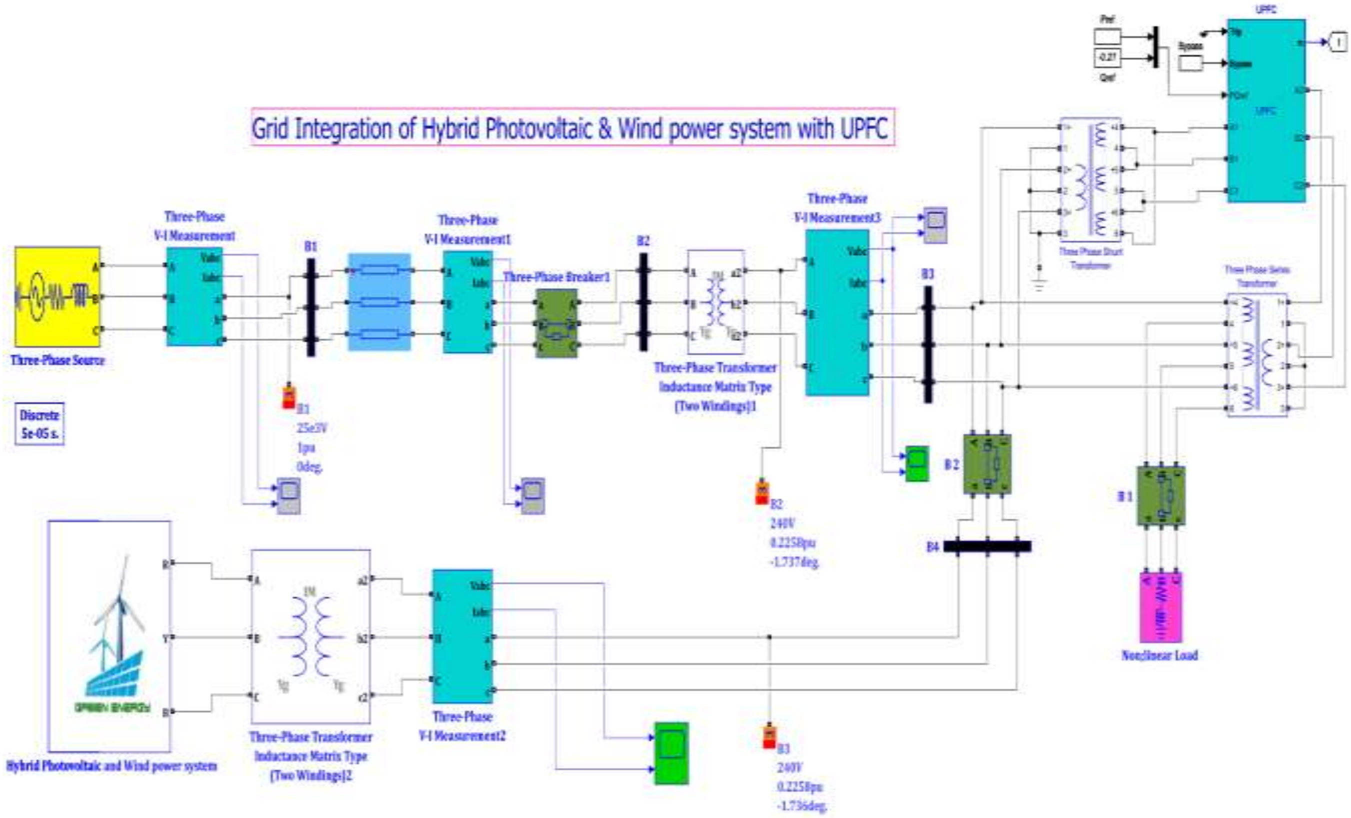

Fig.7 Simulink model of the PV/wind hybrid distributed generation power system with UPFC

The UPFC consists of two three-level, 48-pulse GTO-based converters, one connected in shunt at bus B240 and one connected in series between two buses. The shunt and series converters can exchange power through a DC bus.

V. Simulation Results

The study's findings following the use of the suggested methodology are presented in this section. The proposed method aims to compensate for the issue in a power system that has been identified. This has a power source that feeds into a transformer, which generates two outputs. Then these outputs are used to analyze the two different systems one with UPFC and other is without UPFC. Each system consists of a three-phase dynamic load.

The graphs with and without the UPFC-based power system model are displayed in Figure 8&9. The graphs show that there are less voltage variations when UPFC is present, whereas there are more variations when UPFC is not there.

When the two converters are operated in UPFC mode, the shunt converter operates as a STATCOM. It controls the bus B 220 voltage by controlling the absorbed or generated reactive power while also allowing active power transfer to the series converter through the DC bus. The reactive power variation is obtained by varying the DC bus voltage. The power quality analysis in DFIG based wind energy conversion system is done by using the FFT tool of the powergui; you will find that decrease in the THD of the current injected in the system.

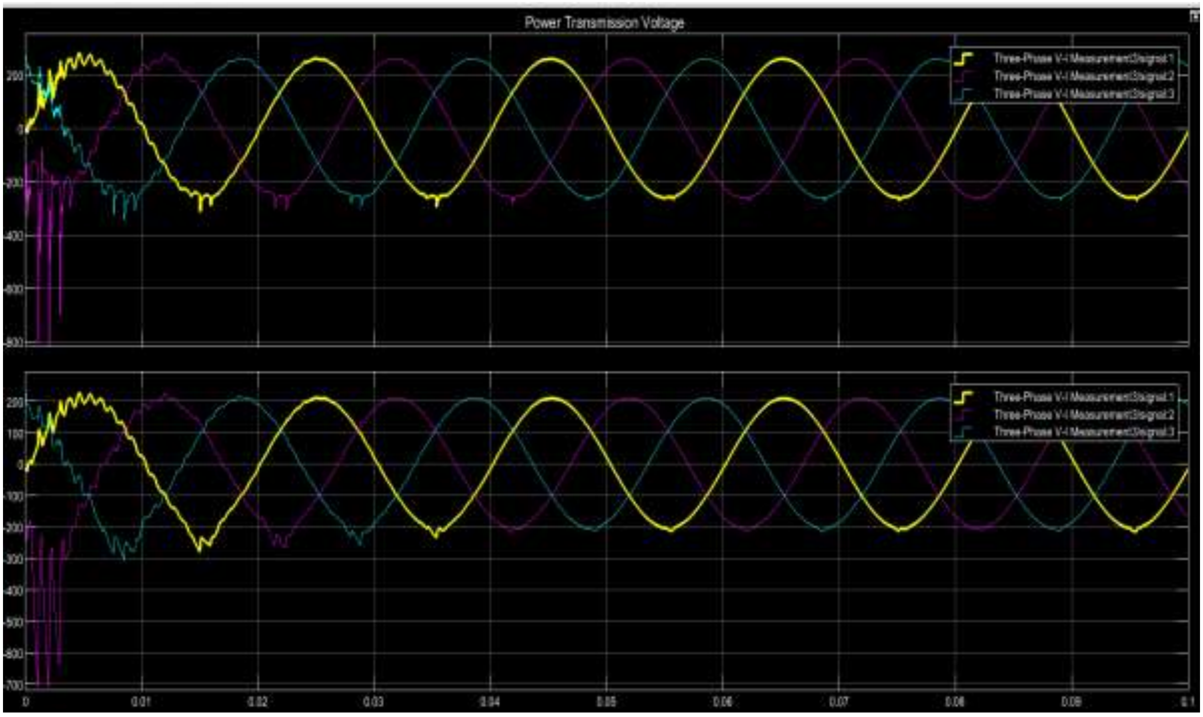

Fig.8 The output power transmission voltage of the system model without UPFC

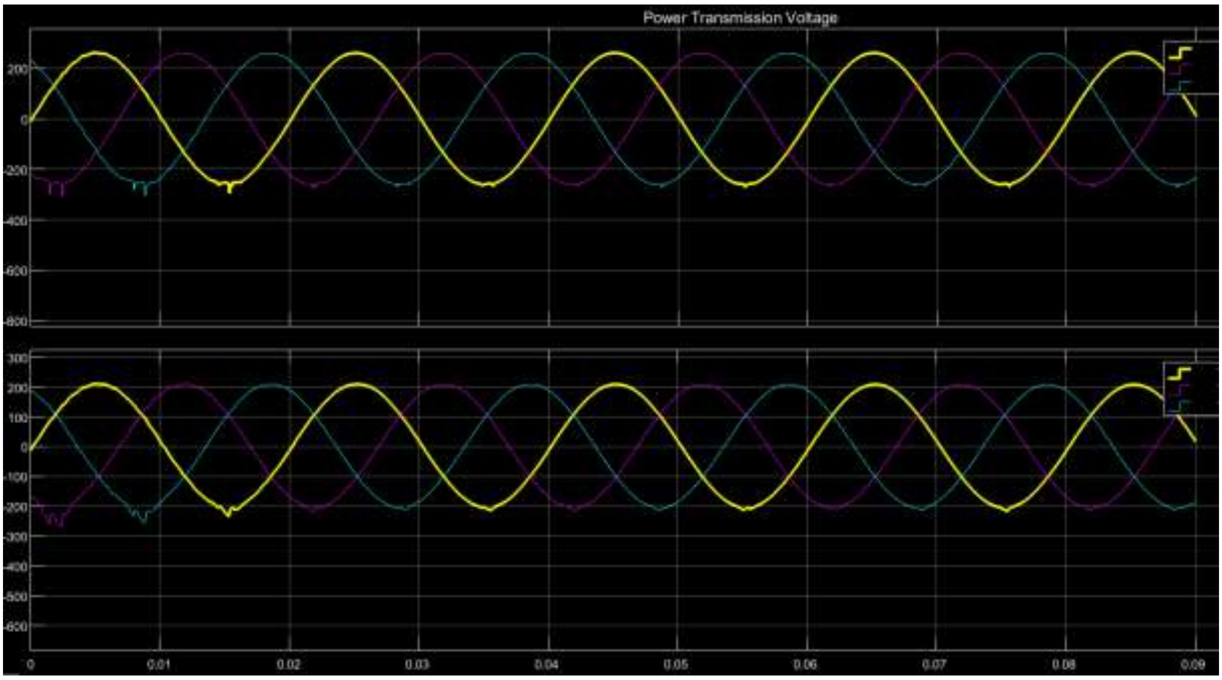

Fig.9 The output power transmission voltage of the system model with UPFC

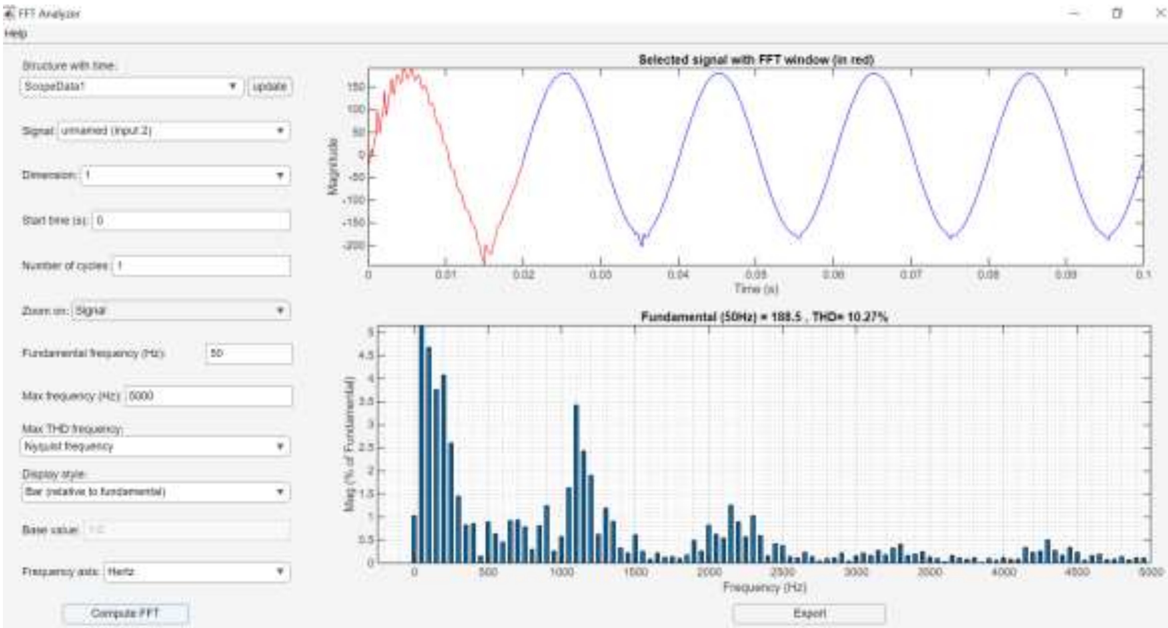

Fig.10 the output power transmission voltage of the system model with UPFC

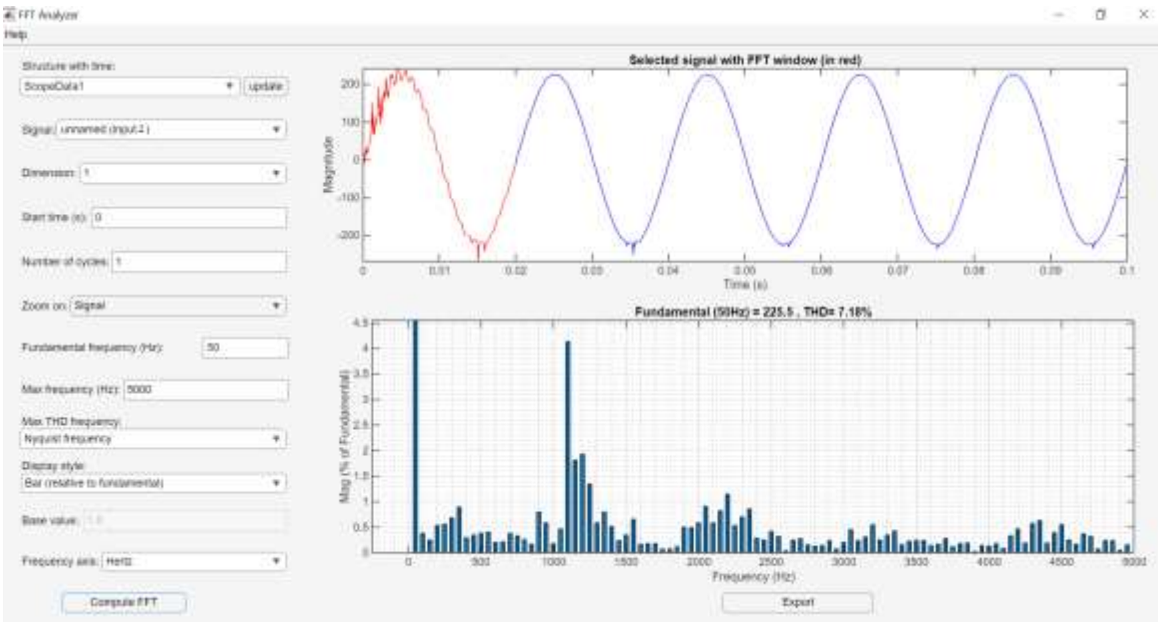

Fig.11 the output power transmission voltage of the system model with UPFC

The THD graphs with compensation and without compensation are given in fig.10&11. The total harmonic distortion without compensation is 10.27 %, which is reduced to 7.18 % where UPFC is connected.

TABLE 4: THD WITHOUT AND WITH UPFC

Time Interval (sec)	THD without UPFC (%)	THD with UPFC (%)
0 – 0.02	10.27	7.18
0.02 – 0.04	2.69	1.52
0.04 – 0.06	1.02	0.58
0.06 – 0.08	0.93	0.51
0.08 – 0.1	1.14	0.54

The THD wave shape of feeder which connect with UPFC show clearly elimination of total harmonic distortion , on other hand feeder without UPFC has a large amount of total harmonic distortion as shown in fig.10&11.

VI. CONCLUSION

This study confirms that using UPFC to enhance power quality in a grid-connected hybrid wind-solar system can enhance power quality. The simulations conducted using MATLAB/Simulink verify that UPFC is an efficient way to lower THD and improve voltage stability. Future research will concentrate on exploring practical implementation issues and refining UPFC control mechanisms.

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REFERENCES

[1] Joanne Hui, Alireza Bakhshai, Praveen K. Jain “A Hybrid Wind-Solar Energy System: A New Rectifier Stage Topology” Applied Power Electronics Conference and Exposition (APEC), 2010 Twenty-Fifth Annual IEEE.)

[2] H. Yang, Z. Wei, and L. Chengzhi, “Optimal design and technoeconomic analysis of a hybrid solar-wind power generation Applied Energy, vol. 86, no. 2, pp. 163-169, February 2009, doi: 10.1016/j.apenergy.2008.03.008.

[3] Manpreet Singh, Lakhwinder Singh: A Comprehensive Study of Power Quality Improvement Techniques in Smart Grids with Renewable Energy Systems Conference paper, First Online: 28 January 2024

[4] N. Hatziargyriou, H. Asano, R. Iravani, and C. Marnay, “Microgrids,” IEEE Power Energy Mag., vol. 5, no. 4, pp. 78–94, Jul./Aug. 2007..

[5] S. W. Mohod and M. V. Aware,” Power quality issues & its mitigation technique in wind energy conversion,” in Proc. of IEEE Int. Conf. Quality Power & Harmonic, Wollongong, Australia, 2008.

[6] N. G. Hingorani and L. Gyugyi, Understanding FACTS: Concepts and Technology of Flexible AC Transmission Systems, New York: IEEE, 2000.

[7] Gyugyi, L. “Unified power flow controller concept for flexible AC Transmission system”, IEE Proceedings-C vol-139, no.4,pp 323-331 July 1992.

[8] Hingorani, N.G.: „High power electronics and flexible AC transmission system‟, IEEE Power Eng. Reo., July 1988.

[9] GhorbanianM.J. Goodarzvand F. Poudaryaei A. Mahadi W.N.L. (2014). Power quality improvement of grid connected doubly fed induction generator using STATCOM and BESS “proc. Of IEEE-International Conference on Engineering Technology and Technopreneuship (ICE2T)”Kuala Lumpur, Malaysia,110 - 115.

[10] Dr. Rakesh Saxena, Sonali Barod, “Analysis of power Quality in power Supplies”, International Journal of Scientific & Engineering Research Volume 3, Issue 8, August-2012

[11] Preeti Ranjan Sahu;Prakash Kumar Hota;Sidhartha PandaComparison of Grasshopper and Whale Optimization Algorithm for Design of FACTS Controller with Power System Stabilizer 2018 Fifth International Conference on Parallel, Distributed and Grid Computing (PDGC) Year: 2018.

Author Profile

Himanshu Verma
Master’s Degree in Power System Engineering from
I,K, Gujral Punjab Technical University, Jalandhar, India.