Hybrid Wind-Solar System with UPQC

Abhishek Saxena[1], *Rajesh* Gundlapalle[2*], *Manish* Gupta[3], *Ediga* Poornima[4], *Harjeet* Singh[5], *Ali* Albawi[6], *K* Arunkumar[7]

[1]Department of Mechanical Engineering, ABES Engineering College, Ghaziabad - 201009, UP, India.
[2]Department of Electronics and Communication Engineering, New Horizon College of Engineering, Bangalore, India
[3]Lovely Professional University, Phagwara, India.
[4]Department of AI&ML, GRIET, Bachupally, Hyderabad, Telangana, India.
[5]Lloyd Institute of Engineering & Technology, Knowledge Park II, Greater Noida, Uttar Pradesh, India.
[6]Radiology Techniques Department, College of Medical Technology, The Islamic University, Najaf
[7]Department of Aeronautical Engineering, MLR Institute of Technology, Hyderabad, Telangana, India-500081

Abstract. The hybrid wind-solar system is a combination of renewable energy sources, specifically wind and solar, that is utilized for power generation. While wind power has historically been used for various purposes such as sails, windmills, and wind pumps, it is now predominantly used for electricity generation. This system incorporates solar panels and small wind turbine generators to produce electricity. The advantage of hybrid systems is that they can generate electricity as needed, taking into account the varying peak working hours of solar and wind systems throughout the year. To ensure a stable power system, UPQC (Unified Power Quality Conditioner) is employed. This multipurpose power conditioner serves multiple functions, including preventing harmonic load current from entering the power system, rectifying voltage fluctuations, and compensating for voltage disturbances from different power sources. It is specifically designed to minimize interference with sensitive or critical loads. With its series and shunt compensation capabilities, UPQC effectively manages power flow, reactive power, harmonics, and voltage disturbances. In this paper, the work addresses the issue of electricity quality that arises from the installation of wind turbines in the grid. To get over this issue, the suggested course of action demonstrates how to install a BESS and a unified power quality conditioner (UPQC) at the connection point. Even though wind power fluctuates, the use of battery energy storage technology helps to provide a constant power supply. With the power system block established in MATLAB/SIMULINK, one can simulate the UPQC control method of a grid-connected wind energy generating plant. As a result, the power's quality will increase. When the recommended approach lowers the load's and the induction generator's reactive power requirements, it is successful.

* Corresponding author: gundlapallerajesh@gmail.com

Furthermore, the plan for raising the grid's power quality criteria and developing the grid coordination rule are also provided.

Keyword-: -: Power Quality, Generator, Solar PV, Unified Power Quality Conditioner, Wind Energy.

1 Introduction

Since the demand for power is increasing at a very rapid rate, connecting to the distribution network necessitates the utilization of alternative energy sources. The primary drawbacks of alternative energy sources are their seasonal and erratic power production [1] [2]. Numerous alternative sources are connected in order to address these issues. A diode rectifier that supplies RL loads (non-linear-load) is employed to investigate the concept of compensation, different techniques of control, and overall performance of the UPQC. The theory, methodology, and application of a single power quality conditioner are documented in paper [4]. Effective participation in a remote island microgrid that makes use of solar-powered turbines requires combining the control of the battery storage with the management of the maximum power point of the tracking (MPPT). In order to maximize power generation, this integrated approach combines battery storage control with MPPT approaches, such as the perturb and observe method developed by the paper's author [6]. “The UPQC, as described in article [7], incorporates active power filters (APFs) in both series and shunt configurations to mitigate harmonics in the supply voltage and load power. Although a proportional-integral (PI) controller is included into the shunt APF control scheme, it is used in the series APF control scheme to relieve harmonic currents induced by nonlinear loads.” By comparing and contrasting two UPQC models, the writers in [8] were able to determine which interface dramatically improved power quality. This paper's authors have come up with a number of different approaches to shunt active power filters that are used in three-phase systems [9]. The control methods for parallel active power filters that correct for current harmonics and voltage source inequality were thoroughly described by the authors of paper [10]. “In paper [11], authors have devised an effective voltage sag detection approach for an active voltage restorer. The experimental configuration and modeling of a shunt active power filter, which attempts to account for reactive power as well as harmonics, have been disclosed by the authors in paper [12].”The method described above has the advantage of maintaining a steady DC connection voltage. Wind energy could be able to provide the UPQC with the necessary power to run when sunlight isn't present. The main flaw with UPQC is that it cannot adjust for voltage interruptions; however, the recommended method can perform all of UPQC's duties and compensate for voltage interruptions.

2 Related Work

According to authors of study [12], the 21st century demands energy since renewable energy sources are widely used, easily accessible, and inexpensive. However, the volatility, round-the-clock accessibility, and other drawbacks of these fuels in their pure form can be mitigated by hybrid energy sources. They are essentially composed of numerous combinations of energy from renewable sources. They provide efficient responses to power issues, harmonic evaluations, voltage, and frequency fluctuations in stand-alone systems. Hybrid electrical systems retain the lowest possible unit cost, minimize energy variations brought on by DPSP (deficient power supply probability), and decrease complications with the help of appropriate design, increased quick reaction, good optimization, and control feasibility. This paper provides a brief description of hybrid wind and solar energy systems. The utilization of the model served two purposes: firstly, to assess the technological viability of PV-wind hybrid systems within a defined load requirement range, and secondly, to conduct a cost-effective analysis for standalone PV, standalone wind, and PV-wind hybrid systems**.**

In order to aid decision-makers in their examination of the various elements involved in the creation of a hybrid solar-wind power system (HSWPS) for grid-connected applications, authors devised a decision support method. These elements primarily encompass advancements in social, political, and technical aspects, as well as improvements in economic and technological factors. The Analytic Hierarchy Process (AHP) is employed to assess the numerous disparities in beliefs, actions, and events that contribute to uncertainty and confusion during the development of HSWPS. More than one plan is made through the trade-off risk technique used to consider future 16 scenarios which lastly involve the development of respective curves of the trade-off. The current model was applied for two applications: one, for the technological feasibility evaluation of a PV-wind hybrid system within the span of a given specific load size; and two, for the cost-effective analysis for the stand-alone PV, the stand-alone wind, and the hybrid system of PV-wind [6].

Authors developed a decision support method to assist the decision-makers in analyzing the following of different factors associated with the development of an HSWPS for grid connected applications. Factors are primarily associated with social and political advancements, technical improvements, economic, and technological factors. In this regard, a number of discrepancies in beliefs are viewed as inducing uncertainty and confusion into the development of HSWPS, for which the application of the Analytic Hierarchy Process is employed [8]. Through the utilization of the trade-off risk technique, multiple plans are generated to account for 16 potential future scenarios, resulting in the creation of corresponding trade-off curves. Authors in this paper explored various methods of communication that can be employed to incorporate renewable energy sources into the power grid. Since renewable energy sources are often sporadic, it is crucial to integrate a substantial portion of them into the framework of a power grid. Currently, power is transmitted from centralized facilities to consumers through a single pathway. While a conventional power plant may have a greater capacity compared to a renewable energy facility, it is essential to recognize the potential of renewable energy as an emerging resource [9].

According to a study conducted by authors in paper [12], there is a projected rise in the adoption of renewable energy systems in the coming years. This shift is driven by the negative environmental consequences associated with conventional energy sources, as well as the escalating expenses of electricity [13-16]. Solar and wind energy power are complimentary; hence some strain on the energy grid can be alleviated. It has a note, however, that independently verified responses are on their own unpredictable and not, therefore, very reliable [17]. However, studies showed that a PV/WT hybrid energy system with autarkic features is comparably feasible and cost-effective to deliver electricity to remote customers worldwide. The work at hand provides a comprehensive introduction towards system setup, modeling, and renewable energy generation, optimum sizing estimation, hybrid system optimization criteria, and control techniques. A similar comparative study conducted concerning the Barwani, India, case states that the PV-Wind-Battery-DG hybrid system is the most cost-effective and environmentally friendly option compared with other freestanding hybrid combinations for application in remote areas. As an expansion of the discussion, the paper highlights some developments that will potentially further help in increasing the financial attractiveness and customer support of these approaches in the future [18-21].

3 Control Strategies of the UPQC System

To determine the UPQC reference voltage and current, a number of control mechanisms are possible.

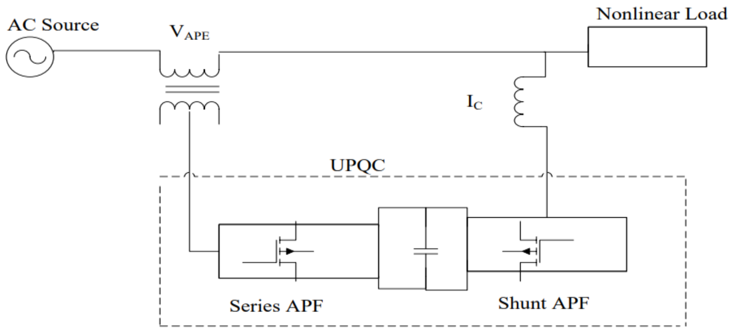

Fig. 1: Block Diagram of UPQC.

The block diagram for the control mechanism of the UPQC system is displayed in Figure 1. In the context of compensation and dependability, FACTS (Flexible AC Transmission System) equipment is essential to the power system. “Similar to the Unified Power Flow Controller, the Unified Power Quality Conditioner (UPQC) is intended for the electric power the system's distribution side. Shunt filters and series filters are both of them categories of active filters [22].

Shunt active power filters can help reduce harmonics caused by load current, while series active power filters can compensate for voltage disturbances such as voltage spikes and voltage sags. Energy exchange by connecting DC link capacitors to shunt and series active power filters in a back-to-back configuration.

3.1 Series/ Voltage Source Converter

It reduces voltage variations by connecting the voltage source converter in series with the AC line. As a result of nonlinear loads, parallel branches are formed to absorb harmonic currents so that voltage fluctuations will be avoided. The series converter voltage is often regulated using sinusoidal pulse width modulation (SPWM) [24-27]. An evaluation of a high frequency triangular signal and a voltage reference input is required to generate the gate pulses necessary for the converter to operate.

3.2 Shunt Converter

In order to control the reactive current of the load, correct for current distortion, and lower the power factor, this parallel source of voltage converters may also be utilized as an energy source [28]. Additionally, it controls the DC bus voltage, which considerably lowers the DC capacitors' power. A shunt converter's output current can be adjusted using a dynamic hysteresis range that stays in a predetermined hysteresis band and conforms with the reference signal by changing the state of the semiconductor switches [29-32].

3.3 DC Capacitor Bank Connected to Ground at the Midpoint

It is split into two series-connected groupings. The secondary transformer's neutral conductor is directly linked to the middle of the intermediate circuit [33]. The primary winding of the series transformer in a three-phase transformer connected in Y/Yo receives zero voltage to make up for the supply network's zero voltage. On either transformer's main side, there is no residual current flowing [34]. This guarantees that even when there are voltage fluctuations, the system current stays balanced.

3.4 Low-pass Filter

Low-pass filters pass signals below cutoff frequencies through while they attenuate sounds above cutoff frequencies [35]. Filters respond to frequencies differently depending on their structure. In electrical circuits, low-pass filters are used to filter audio hiss, improve acoustics, blur images, smooth data sets, and condition signals prior to analog-to-digital conversion [36]. In sectors such as banking, moving averages are used as low-pass filters. The investigation of this filter can also be done using signal processing techniques that are also available for investigating other low-pass filters. In order to smooth out a signal, low-pass filters can be used, which can eliminate short-term fluctuations while preserving a longer-term trend, so the signal can be provided with a rounded appearance. There is a possibility of using it to reduce the high-frequency elements at the output of a series converter that are caused by high-frequency switching [37-41].

3.5 High-pass Filter

When applied to electrical signals, high-pass filters (HPFs) allow those frequencies beyond a certain cutoff while reducing the volume of those frequencies below it. The design of the filter dictates the amount of attenuation that each frequency receives. A linear time-invariant system is often used to mimic a high-pass filter. It goes by a several names in the world of audio engineering, including low-cut and bass-cut filters. High-pass filters are useful for several things, one of which is shielding devices from non-zero average DC voltages, such as electronics or radio frequency equipment. They are versatile enough to be used in the construction of both low-pass and band-pass filters. Positioned near the shunt converter's output, it dampens ripples caused by current switching.

4 Result Analysis

MATLAB simulation of UPQC models in the field of wind/solar energy, including series AF, shunt AF, solar PV, wind energy, and boost converters is illustrated in Figure 1.

4.1 Equivalent Circuit

A UPQC consists of two voltage source converters, which can be arranged in a single-phase, three-phase, or four-phase configuration, as shown in Figure 2. All of these converters are interconnected by a DC intermediate circuit. A voltage link inverter is connected between the source and the load at the point of common coupling (PCC).

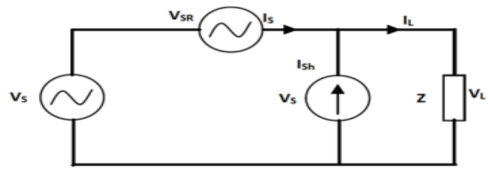

Fig. 2. Equivalent circuit for UPQC.

V_S : Voltage at power supply

V_{SR} : Voltage compensation by Series Active Power Filter (APF),

V_L : Load voltage and

I_{Sh} : Current compensation and VSR compensation by Shunt Active Power Filter (APF)

The voltage distortions may result in harmonic as well as negative phase sequence components in the structure of the system.

The source voltage in Figure 2 may often be written as:

$$V_s+V_{SR}=V_L \quad (1)$$

To obtain a constant amplitude sinusoidal load voltage, V, the voltages that are output of the series-APF have to be supplied by:

$$V_{SR}=(V-V_{lp})\sin(\omega t+\theta_{1P})-V_{Ln}(t)-\sum_{z=2}^{R} V_k(t) \quad (2)$$

Where, V_{lp} : Fundamental frequency of positive sequence voltage amplitude.

θ_{1p} : Initial phase angle of the positive sequence voltage.

V_{Ln} : Negativesequence component

A parallel APF functioning as a regulated current source must generate harmonic, reactive, and negative sequencing elements in its output in order to balance these numbers inside a load current. This is accomplished by matching the load component (as indicated by the following equation) with the output current of the parallel APF (Ish):

$$\begin{aligned} I_L &= I_{1p}\cos(\omega t+\theta_{IP})\sin\varphi_{1P}+I_{Ln}+\sum_{q=2}^{K} \\ \phi_{1P} &= \varphi_{1P}-\theta_{1P} \end{aligned} \quad (3)$$

Where, φ_{1P}: Initial phase of current for positive sequence.

The above equation shows that the power supply does not receive any harmonics, reactive power, or negative sequence currents.” Therefore, the phase voltage at the load connection and the terminal source current have the same phase angle and are harmonic-free sinusoids-

(I_S&=I_L-I_Sh@&=I_1p sin⁡(ωt-θ_1P)cos⁡φ_1 p) (4)

4.2 Implementation and Discussions

A BESS, or battery energy storage system, is the energy storage element used in voltage regulation. STATCOM works well with BESS because of its reactive power injection and absorption capabilities, which help to stabilize the grid system and naturally keep the DC capacitor voltage constant. Additionally, it provides extremely fast control options for power transmission and distribution networks. With BESS, power fluctuations in the system can be compensated by operating during charging and discharging phases.

The DC capacitors and battery of STATCOM are linked in parallel. With capacitors on its DC terminals, the STATCOM is a three-phase voltage source inverter connected at a common coupling point. The STATCOM provides a compensation current with programmable frequencies and amplitudes elements at the standard coupling point.

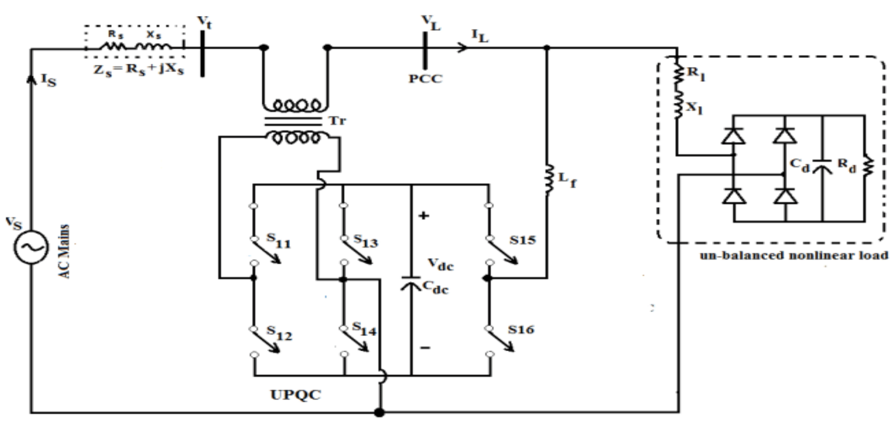

Fig. 3: System Operational Scheme in UPQC

The block diagram for the control mechanism of the UPQC system is displayed in Figure 1. In the context of compensation and dependability, FACTS (Flexible AC Transmission System) equipment is essential to the power system. The Unified Power Quality Conditioner (UPQC) is designed for the distribution side of the electric power system and functions similarly to the Unified Power Flow Controller. One kind of active filter is the shunt filter, while another is the series filter.

4.3 Simulation Model

Pitch controls, induction generators and wind turbines are used to generate wind power. Due to its simplicity and cost-effectiveness, induction generators are preferred over other types of machines in this case. The pitch angle of the turbine blades is adjusted by a pitch angle controller to maintain a constant rotational speed regardless of wind speed. Additionally, the IM acts as a generator, receiving reactive power from the parallel capacitor bank.

Each time a sampling interval is completed, record the rms values of the resulting voltage and current, calculate the power, and trace the waveforms with an oscilloscope. In the figure, the timer is used to assign the wind speed to three different states, which are linearized after multiple loop operations.

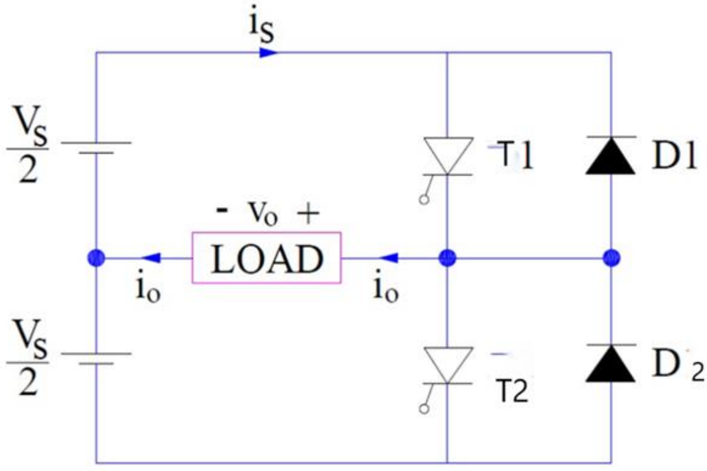

Fig. 4: Voltage Source Inverter with Battery

A voltage source inverter (VSI), which changes DC voltage into AC voltage, is shown in Figure 4. Another name for this gadget is a voltage-fed inverter, or VFI. A DC power source, switching transistors (such as IGBTs, MOSFETs, and thyristors), and a DC link capacitor—which reduces fluctuations and serves as a filter—make up the VSI. The VSI utilizes a voltage sensing interface (VSI) to maintain a consistent voltage throughout its operation.

Table 1: Different parameters and their ratings to carry out the simulation work.

Equipment/Specification	**Specification Value**
Voltage of Grid	315 V
Frequency of Operation	50 Hz
Specifications of Induction Generator	3.35 KVA, 415 V, 60 Hz
Rotational Speed	1240 rpm
Resistance - Rotor (Rr)	0.01 Ω
Resistance - Stator (Rs)	0.015 Ω
Inductance (Ls and Lr)	0.06 H
Voltage - DC Link (Inverter)	700 V
Capacitance - DC Link	100 µF
Frequency of Switching	2 kHz
Load (Non-linear)	15 KW

 https://doi.org/10.1051/e3sconf/202455201127

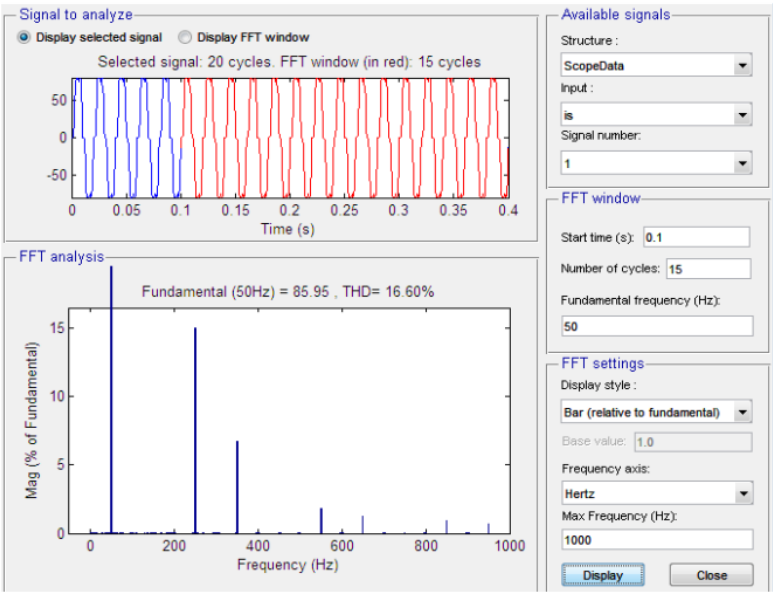

Fig. 5: Harmonics analysis without shunt APF.

The above figure 5 shows that harmonic analysis involves examining the harmonic content of voltage and current wave forms within a power system. Problems like better losses, equipment over heating, and interference with sensitive equipment can arise from harmonics produced by non-linear hundreds like rectifiers, electricity electronics, and variable velocity drives if a shunt APF isn't always used. Engineers may measure the effects of these harmonic distortions on the gadget's performance using harmonic evaluation.

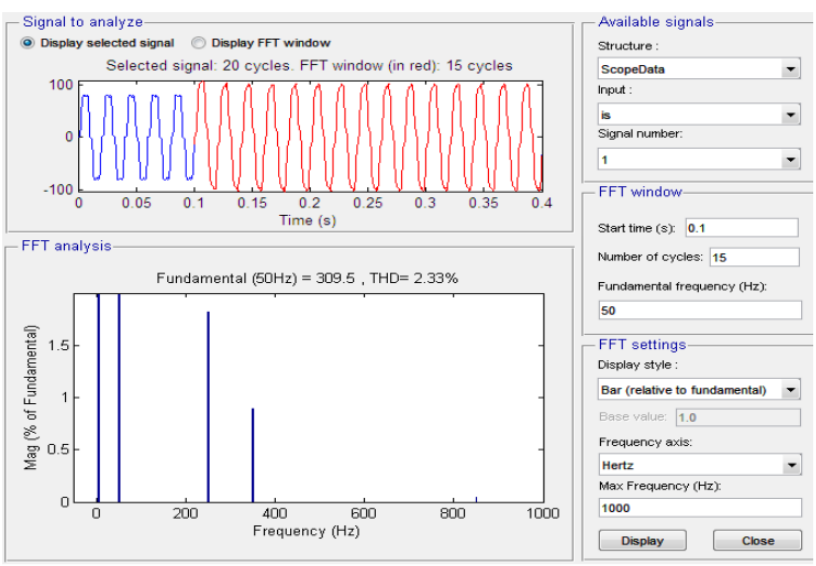

Fig. 6: Harmonics analysis with shunt APF.

As shown in figure 6, engineers can evaluate the effectiveness of an active electricity filter out (APF) in compensating for harmonic distortions through combining harmonic evaluation with a shunt APF. In order to reap the desired stage of harmonic mitigation, this method enables the optimization of APF manage settings and modifications.

Engineers can also achieve access to system performance blessings through integrating harmonic evaluation with shunt APFs. Improvements in strength first-class, stability, and total harmonic distortion (THD) discount need to be assessed. Also, it is beneficial for finding any harmonic issues that would necessitate further mitigating measures.

5 Conclusion

This paper proposes a FACTS- primarily based manage method for grid-connected wind generators operating underneath non-linear loads and with stepped forward power excellent (UPQC). The paper delves into electricity exceptional problems and the way they effect each utilities and customers. Power pleasant should be maintained by using modeling the UPQC control system in MATLAB/SIMULINK. it filters out the harmonics inside the load current.The opportunity to increase the transmission line load issue arises whilst the supply voltage and contemporary remain in section, the reactive power requirements of the wind generators are satisfied, and the demand at the PCC inside the grid gadget is met. Consequently, the performance of installing FACTS with BESS and wind power to preserve the specified voltage distribution is notable. Consequently, the proposed grid-linked device answer keeps the grid voltage free of distortion and harmonic seven as meeting Energy high-quality standards

References

1. Ashish S. Ingole*, Prof. Bhushan S. Rakhonde, “Hybrid Power Generation System Using Wind Energy and Solar Energy” International Journal of Scientific and Research Publications, Volume 5, Issue 3, March 2015.
2. Karim Mousa1, Hamzah AlZu’bi2, Ali Diabat3, “Design of a Hybrid Solar-Wind Power Plant Using Optimization”
3. Medugu, D. W. & Michael, E., “Integrated Solar – Wind Hybrid Power Generating System for Residential Application”, Global Journal of Researches in Engineering: F Electrical and Electronics Engineering , Volume 14 Issue 4 Version 1.0 Year 2014.
4. Rashid Al Badwawi, Mohammad Abusara & Tapas Mallick, “A Review of Hybrid Solar PV and Wind Energy System”, Smart Science Vol. 3, No. 3, pp. 127-138(2015).
5. Rashid Al Badwawi1,*, Mohammad Abusara1 and Tapas Mallick1, “A Review of Hybrid Solar PV and Wind Energy System”, Smart Science Vol. 3, No. 3, pp. 127-138(2015).
6. R. Chedid, “A Decision Support Technique For The Design Of Hybrid Solar-Wind Power System”, IEEE Transactions on Energy Conversion, Vol. 13, No. 1, March 1998.
7. Sandeep Kumar1, Vijay Kumar Garg2, “A Hybrid Model Of Solar-Wind Power Generation System”, International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering, Vol. 2, Issue 8, August 2013.
8. Vaibhav J. Babrekar, Shraddha D. Bandawar, Ashwini R. Behade, “Review Paper on Hybrid Solar-Wind Power Generator”, International Journal of Computer Applications (0975 – 8887) Volume 165 – No.5, May 2017

9. Chandragupta Mauryan.K.S, Nivethitha.T, Yazhini.B, Preethi.B, “Study on Integration of Wind and Solar Energy to Power Grid”, Nivethitha.T et al Int. Journal of Engineering Research and Application,Vol. 4, Issue 5(Version 1), May 2014.
10. V. K. Gajbhiye1, Prof. A. A. Kanaskar2, Prof. S. S. Jawre, “Solar Wind Hybrid System-A Review”, International Journal of Research in Advent Technology, Vol.5, No.5, May 2017.
11. J. Barros, M. de Apraiz, and R. I. Diego, “Measurement of Subharmonics In Power Voltages”, Power Tech, IEEE Lausanne, Page(s): 1736 – 1740, 2007.
12. Mahesh Singh and Vaibhav Tiwari, “Modeling analysis and solution of Power Quality Problems”,
13. Chellali Benachaiba and Brahim Ferdi, “Voltage Quality Improvement Using DVR”, Electrical Power Quality and Utilisation, Journal Vol. XIV, No. 1, 2008.
14. R.N.Bhargavi, “Power Quality Improvement Using Interline Unified Power Quality Conditioner”, 10th International Conference on Environment and Electrical Engineering (EEEIC), Page(s): 1 - 5, 2011.
15. K. Palanisamy, J Sukumar Mishra, I. Jacob Raglend and D. P. Kothari, “Instantaneous Power Theory Based Unified Power Quality Conditioner (UPQC)”, 25th Annual IEEE Conference on Applied Power Electronics Conference and Exposition (APEC), Page(s): 374 – 379, 2010.
16. G. Siva Kumar, P. Harsha Vardhana and B. Kalyan Kumar, “Minimization of VA Loading of Unified Power Quality Conditioner (UPQC)”, Conference on POWERENG 2009 Lisbon, Portugal, Page(s): 552 - 557, 2009.
17. V. Khadkikar , A. Chandra, A.O. Barry and T.D Nguyen, “Conceptual Study of Unified Power Quality Conditioner (UPQC),” IEEE International Symposium on Industrial Electronics, Vol. 2, Page(s): 1088 –1093, 2006.
18. V. Khadkikar , A. Chandra, A.O. Barry and T.D. Nguyen, “Power quality enhancement utilising single-phase unified power quality conditioner: digital signal processor-based experimental validation” Conference on Power Electronics, Vol. 4, Page(s): 323 –331, 2011.
19. V. Khadkikar , A. Chandra, A.O. Barry and T.D.Nguyen, "Application of UPQC to Protect a Sensitive Load on a Polluted Distribution Network", IEEE PES General Meeting, 2006.
20. Ahmed M. A. Haidar, Chellali Benachaiba, Faisal A. F. Ibrahim and Kamarul Hawari, “Parameters Evaluation of Unified Power Quality Conditioner”, IEEE International Conference on Electro/Information Technology (EIT), page(s):1 - 6, 2011.
21. M. Tarafdar Haque, and S.H. Hosseini, "A Novel Strategy for Unified Power Quality Conditioner (UPQC)", Conference on Proceedings of Power Electronics Specialists, Vol. 1, Page(s): 94 - 98, June 2002.