Novel UPQC Control Method for DFIG - Based Wind System Under Different Loads

IJIMSR, Vol. 2, No. 1, (2024) 24.2.1.011

Dr.G.Pandu Ranga Reddy
Electrical and Electronics Engineering
G.Pullaiah College of Engineering and Technology
Kurnool, 518002, India

Dr.B. Madhusudhana Reddy
Electronics and Communication Engineering
Ravindra College of Engineering for women
Kurnool,518002, India

Syed Inayatullah
Electrical and Electronics Engineering
G.Pullaiah College of Engineering and Technology
Kurnool, 518002, India

Gaddam Jasuva
Electrical and Electronics Engineering
G.Pullaiah College of Engineering and Technology
Kurnool, 518002, India

M.Arun
Electrical and Electronics Engineering
G.Pullaiah College of Engineering and Technology
Kurnool, 518002, India

Mallela Naveen Reddy
Electrical and Electronics Engineering
G.Pullaiah College of Engineering and Technology
Kurnool, 518002, India

***Dr. G. Pandu Ranga Reddy**
Electrical and Electronics Engineering
G.Pullaiah College of Engineering and Technology
Kurnool, 518002, India
Email : pandurangaeee@gpcet.ac.in

***Corresponding author**

Received 13th January 2024; Accepted 15th April 2024

KEYWORDS: Harmonics, Power Quality, Phase Locked Loop, Unified Power Quality Conditioner (UPQC) and Doubly Fed Induction Generator(DFIG)

Novel UPQC Control Method for DFIG - Based Wind System Under Different Loads

Dr.G.Pandu Ranga Reddy
Electrical and Electronics Engineering,
G.Pullaiah College of Engineering and Technology,
Kurnool, 518002, India

Dr.B. Madhusudhana Reddy
Electronics and Communication Engineering
Ravindra College of Engineering for women,
Kurnool,518002, India

Syed Inayatullah
Electrical and Electronics Engineering
G.Pullaiah College of Engineering and Technology,
Kurnool, 518002, India

Gaddam Jasuva
Electrical and Electronics Engineering
G.Pullaiah College of Engineering and Technology,
Kurnool, 518002, India

M.Arun
Electrical and Electronics Engineering
G.Pullaiah College of Engineering and Technology
Kurnool, 518002, India

Mallela Naveen Reddy
Electrical and Electronics Engineering
G.Pullaiah College of Engineering and Technology, Kurnool, 518002, India

Dr. G. Pandu Ranga Reddy
Electrical and Electronics Engineering
G.Pullaiah College of Engineering and Technology, Kurnool, 518002, India
Email : pandurangaeee@gpcet.ac.in

ABSTRACT

The incorporation of renewable energy sources into the electrical grid presents difficulties, particularly with the variable nature of wind energy systems due to wind fluctuations. Voltage instability in power networks can cause sag, swell, harmonics, and flicker, among other problems. To address these issues, the introduction of Flexible AC Transmission System (FACTS) devices is required, with the Unified Power Quality Conditioner (UPQC) emerging as a reliable option. This research critically explores the use of UPQC in a wind system based on a Doubly Fed Induction Generator (DFIG), notably under unbalanced and distorted load situations. The analysis focuses on this situation in order to improve knowledge and offer appropriate methods to ensure the stability and dependability of power networks, particularly in the context of renewable energy integration. The UPQC is designed using a revolutionary synchronous reference frame control mechanism. The model is built using the MATLAB/SIMULINK platform, and the results show that the suggested strategy is effective in decreasing power quality concerns.

KEYWORDS: Harmonics, Power Quality, Phase Locked Loop, Unified Power Quality Conditioner (UPQC) and Doubly Fed Induction Generator(DFIG)

1. INTRODUCTION

To enhance power quality in electrical distribution networks, experts conducted a detailed examination of UPQC systems. For large-capacity loads that are susceptible to perturbations in supply voltage balance, the UPQC is predicted to provide a powerful remedy [1]. This extensive research indicates a developing understanding of UPQC's ability to greatly reduce problems related to supply-voltage-imbalance distortions in systems, indicating that it is a promising path towards enhancing overall power quality in the electrical distribution domain. The UPQC, which consists of 2 converters with a common DC link [2], effectively alleviates different power quality disturbances. Additionally, it demonstrates the ability to regulate the flow of power and improve the stability of voltage. In addition, by combining a series and shunt APF, the UPQC may efficiently mitigate voltage disruptions, as long as there is an storage energy component or battery included into the DC- link [3].

When loads are connected in parallel to the shun APF , it can efficiently handle a number of current-related problems, including DC-link voltage control, compensation of reactive power, enhancement of power factor, compensation of neutral current, current harmonic suppression, and imbalance load compensation. In contrast, a series transformer (ST) connects the series APF in line and acts as a regulated voltage source. The device's effectiveness in managing different electrical irregularities is evidenced by its ability to mitigate a variety of voltage-related issues, including voltage harmonics, sag, swell, and flicker [4].

This work presents an enhanced control method for UPQC device in DFIG based wind systems, utilizing an optimized Synchronous-Reference-Frame (SRF) approach [7]. Significantly, the optimization reduces the necessity of measuring transformer voltage, load, and filter current, hence reducing the quantity of current measurements needed. This strategy improves system efficiency. The proposed control approach entails utilizing Matlab/Simulink software to measure, assess, and test load voltage, source voltage and current in the occurrence of imbalanced and distorted load situations. This investigation enhances the effectiveness of UPQC control in DFIG-based wind systems by emphasizing important parameters and implementing an effective control method. The study showcases possible enhancements in performance and measurement efficiency [12].

2. System Configuration

2.1 Wind Turbine dynamic model:

The eq.1 gives the power generated from wind turbine [5]

$$P_m = \frac{1}{2} \rho C_p(\lambda, \theta) A_r V_w^3 \quad (1)$$

Cp denotes the power coefficient. The following equation can be used to compute it.

$$C_p(\lambda,\beta) = 0.73\left(\frac{151}{\lambda_i} - 0.58\beta - 0.002\beta^{2.14} - 13.2\right) e^{\frac{-18.4}{\lambda_i}} \quad (2)$$

Where

$$\lambda_i = \frac{1}{\frac{1}{\lambda - 0.02\beta} - \frac{0.003}{\beta^3 + 1}} \quad (3)$$

and

$$(\lambda) = \frac{\omega_r R_r}{V_w} \quad (4)$$

2.2 Modelling of DFIG Machine

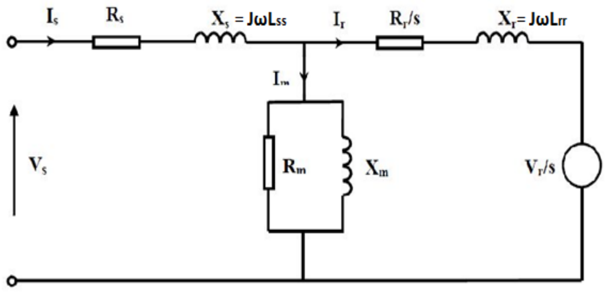

Figure.1 DFIG Equivalent circuit

Figure 1 depicts the DFIG's identical circuit. The following equations are used for DFIG design [3]

$$V_{ds} = R_s i_{ds} + \frac{d\psi_{ds}}{dt} - \omega_s \psi_{qs} \quad (5)$$

$$V_{qs} = R_s i_{qs} + \frac{d\psi_{qs}}{dt} + \omega_s \psi_{ds} \quad (6)$$

$$V_{dr} = R_s i_{dr} + \frac{d\psi_{dr}}{dt} - (\omega_s - \omega_r)\psi_{qr} \quad (7)$$

$$V_{qr} = R_s i_{qr} + \frac{d\psi_{qr}}{dt} + (\omega_s - \omega_r)\psi_{dr} \quad (8)$$

2.3 UPQC Device

Fig. 2 depicts a simple UPQC system with series & shunt Active Power Filters (APF). In addition to regulating voltage and compensating for harmonics at the utility-consumer Point of Common Coupling (PCC), it may also fix voltage problems. The shunt APF also absorbs current harmonics [6][8].

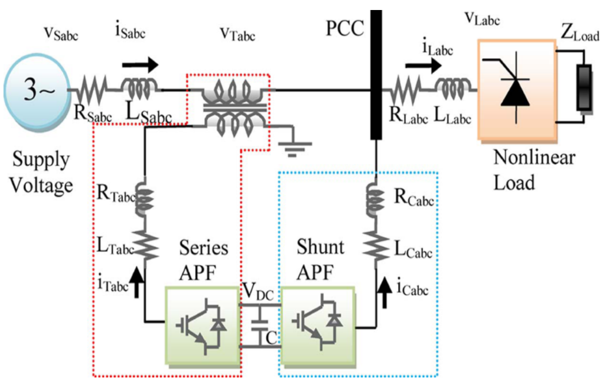

Figure.2 UPQC Basic Model

3. PROPOSED CONTROL METHOD

The SRF-based control strategy is regarded as both classic and effective among the various APF control strategies addressed in the sources. The standard Synchronous Reference Frame (SRF) approach is successful in isolating harmonics in supply voltages or currents. To address the issue of current harmonics, it is necessary to convert the distorted currents into 2-phase stationary coordinates using a transformation method that is similar to the pq theory. Next, the sine and cosine functions that were acquired from the PLL are employed. These fixed frame variables are turned into synchronous rotating frames. This methodical technique simplifies the process of extracting and analysing harmonics, allowing for the implementation of specific compensatory schemes to develop the quality and stability of the electrical system being studied [9].

The sine and cosine functions are crucial for maintaining synchronization between the system and the provided voltage and current. Analogous to the p–q theory, the application of filters enables the direct segregation of fundamental components and harmonics, these signals can be translated to the a-b-c frame and used as filter source signals. Its principal aim has been to enhance the operational efficiency of the compensator[10].

In 3-phase, 4-wire systems, APF applications that employ the SRF method convert the source signals to the standard rotating. frame. The angular orientation of the reference frame is indicated by the transformation angle (ωt), which is used in the SRF technique. This reference frame spins in perfect coordination with the 3-phase AC voltage, maintaining a constant speed. In situations involving nonlinear loads, PLL algorithms play a crucial role in the identification of reactive currents and harmonics within the load. Following this, currents that have reverse phases and identical magnitudes are produced and introduced into the power system in order to adequately offset the effects of reactive power fluctuations, harmonics, and neutral current. In the SRF, the coordinates of α–β–0 exhibit constancy, while the coordinates d–q–0 undergo synchronized rotation with the supply voltages present in the SRF.

In the 3-phase, 4wire systems, the "d" coordinate of the current is coordinated with the voltage and represents the +ve - sequence current. -ve sequence reactive current is denoted by the iq element of the current in the "q" coordinate, which is vertical to the id element of the current. The component representing the'0' sequence of the current is i0, which is perpendicular to both id and iq. A negative value for the imaginary component of the current signifies the presence of inductive reactive power in the load. A affirmative result indicates the presence of capacitive reactive power in the load. The proposed SRF control methodology utilizes transformation equations that convert the abc coordinate system to the dq0 coordinate system, incorporates filters, and implements an enhanced Phase-locked loop (PLL) algorithm.

3.1 Modified PLL

The conventional PLL circuit operates satisfactorily when exposed to unbalanced and distorted system voltages. In the presence of extremely distorted and unbalanced conditions, however, its efficacy degrades considerably. This article presents a revised PLL circuit, illustrated in Fig.3, that has been purposefully engineered to improve the identification of positive sequence components in system voltage signals. The primary objective of the modification is to enhance the functionality of the UPQC filtering in situations characterized by significantly distorted and unbalanced voltage, which are areas where the conventional PLL falls short. The purpose of this modification is to enhance the efficacy of the circuit in demanding electrical conditions.

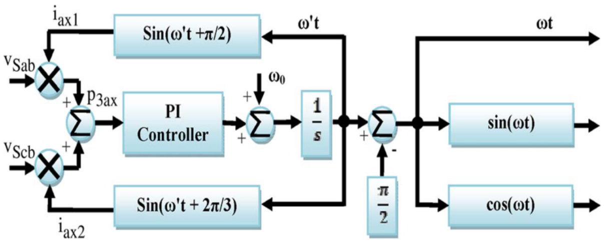

Figure. 3. Diagram of the altered PLL circuit

This altered PLL circuit utilizes instantaneous source line voltages to compute three-phase auxiliary total power. It determines the system supply voltage's transformation angle (t). The aforementioned angle, which is vital in power systems, represents the rotation and phase relationship of the voltage waveform. The function of the PLL is to assess and synchronize the power components of the system. The updated PLL circuit takes the observed three phase line voltages as inputs and outputs the ωt angle. The line voltages are strengthened by auxiliary feedback currents of the same magnitude (iax1 and iax2), one of which is 120 degrees out of phase with the other. This procedure is conducted to compute the instantaneous active power of the three-phase auxiliary system.

Using the reference fundamental angular frequency improves the output stability of the proportional-integral controller. Putting this calculation together yields the secondary transformation angle (t). However, the discovered t is 90 degrees off from the system's core frequency [11].

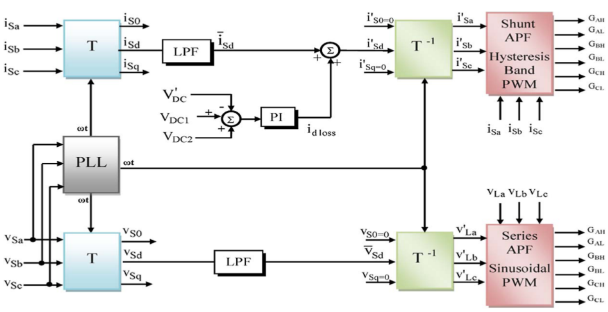

Figure.4: Proposed control block diagram for SRF-based UPQC

To improve system stability, the proportional-integral controller incorporates the reference fundamental angular frequency into its output. This computation is integrated to get the auxiliary transformation angle (ωt). However, it has been discovered that the resulting t is 90 degrees below the system's fundamental frequency. As a result, the integrator's output is changed by adding -/2 to match the fundamental frequency of the system.

When the instantaneous active power of the three-phase auxiliary decreases to zero or oscillates at a low frequency, the PLL circuit enters a stable working condition. In addition, the output of the redesigned PLL circuit is referred to as the transformation angle (ωt). This angle captures the line voltages' fundamental positive-sequence components.

3.2 Reference Voltage Signal Generation for Series APF

The suggested control technique based on SRF (Synchronous Reference Frame) can effectively address the PQ problems associated with harmonics in the source voltage, imbalanced voltages, and voltage fluctuations such as sag and swell. This control algorithm is specifically designed for series Active Power Filters (APFs). The proposed method entails utilizing an APF controller to ascertain the source value that will be introduced by the STs. Fig.4 displays the algorithm for producing the reference-voltage signal in the APF series.

$$T = \sqrt{\frac{2}{3}}\begin{bmatrix} 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \\ \sin(\omega t) & \sin(\omega t - 2\pi/3) & \sin(\omega t + 2\pi/3) \\ \cos(\omega t) & \cos(\omega t - 2\pi/3) & \cos(\omega t + 2\pi/3) \end{bmatrix} \quad (9)$$

$$\begin{bmatrix} V_{s0} \\ V_{sd} \\ V_{sq} \end{bmatrix} = T \begin{bmatrix} V_{sa} \\ V_{sb} \\ V_{sc} \end{bmatrix} \quad (10)$$

When the source voltage is imbalanced and contains harmonics, the momentary source voltages consist of both oscillating and averaging components. The distorted load generates oscillating elements, namely harmonics and -ve sequence components, which stem from the reference voltages. The positive-sequence components of the voltages are included in the average component. Eq.(11) provides the average and oscillating components of the reference voltage in the d-axis.

$$V_{sd} = \bar{V}_{sd} + \tilde{V}_{sd} \quad (11)$$

3.3 Reference current Signal Generation for Shunt APF

The study introduces a shunt APF that aims to mitigate current harmonics resulting from nonlinear loads and regulate reactive power. The suggested algorithm for producing the reference signal for the shunt APF reliessolely on the measurements of source signals & DC-link voltages [7].

$$\begin{bmatrix} i_{So} \\ i_{Sd} \\ i_{Sq} \end{bmatrix} = T \begin{bmatrix} i_{Sa} \\ i_{Sb} \\ i_{Sc} \end{bmatrix} \quad (12)$$

4. SIMULATION RESULTS

4.1 DFIG Based Wind System Without UPQC:

Figure 5 illustrates the Simulink model of the proposed system without the UPQC device. This technique involves the parallel connection of two transmission

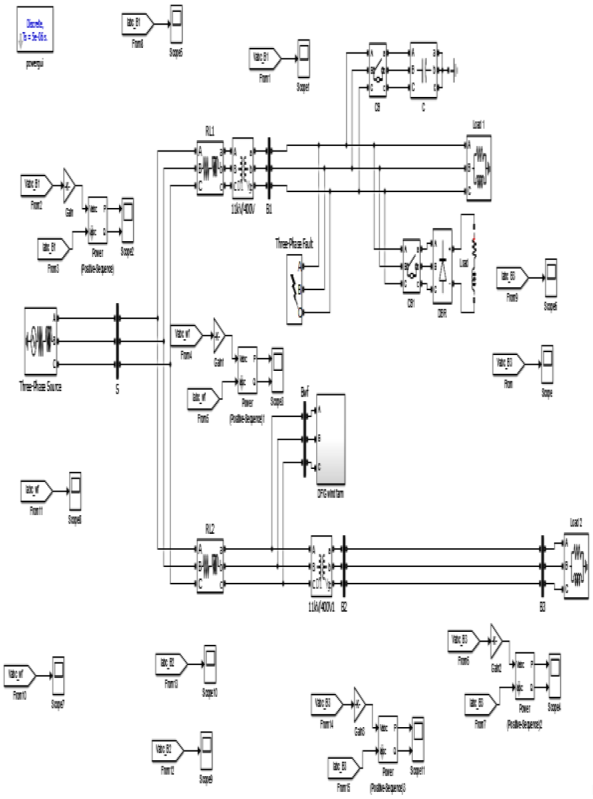

Figure.5 Proposed System Without UPQC device

A three-phase fault is introduced, causing a voltage sag in the first transmission line commencing t=0.3sec to t=0.5 sec. Capacitive reactance is used to cause voltage swells between t=0.7 sec and t=0.9 sec. Harmonics are produced at a time of 1.1 seconds by connecting a non-linear load to the power line. Power quality issues in the first transmission line have an impact on the second transmission line, as depicted in Figure 6. Figures 6 and 7 depict the voltage and current waveforms at load point (B3). Figures 8, 9, and 10 display the total harmonic distortion (THD) of the voltage level (VL) at specific time points: t = 0.3 seconds, t = 0.7 seconds, and t = 1.1 seconds, respectively. The total harmonic distortion (THD) is 9.94% at a time of 0.3 seconds, 13.37% at a time of 0.7 seconds, and 6.42% at a time of 1.1 seconds.

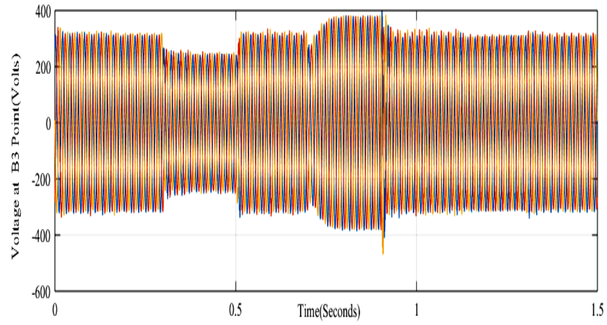

Figure.6 Waveform of voltage taken at point B3

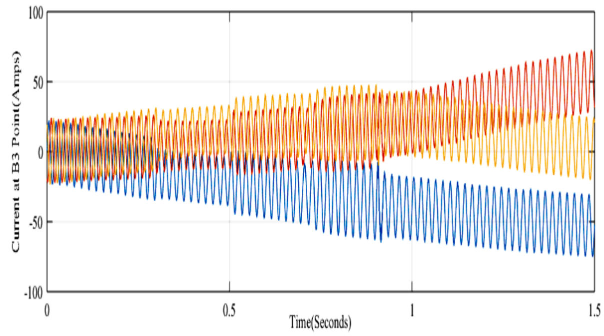

Figure.7 Waveform of current taken at point B3

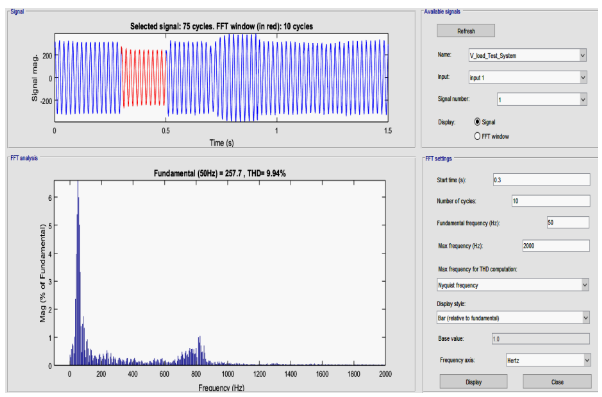

Figure.8 %THD of VL at t = 0.3sec (voltage sag)

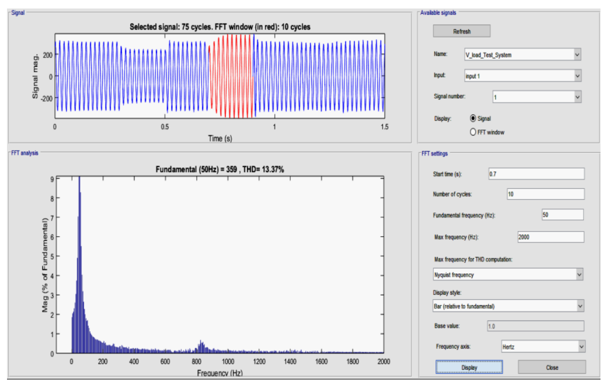

Figure.9 %THD of VL at t = 0.7sec (Swell)

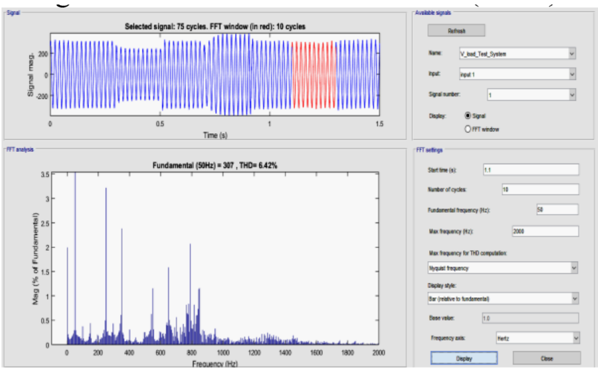

Figure.10 %THD of VL at t = 1.1sec (Non – linear load)

4.2 DFIG Based Wind System With UPQC:

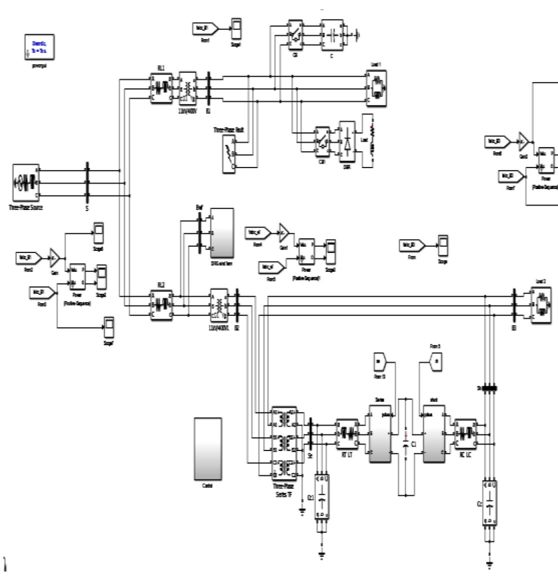

Figure.11 Proposed System with UPQC device

Simulink diagram of proposed system with UPQC as depicted in Fig.11. It connects to second transmission line at PCC. The voltage and current waveforms at load point B3 after attaching UPQC are presented in Fig.12 and Fig.13. Figs.14,15, and16 illustrate the %THD values of VL at t = 0.3 sec t = 0.7 sec, and t = 1.1 sec, respectively. The %THD is 6.38% at t=0.3 sec, 6.56% at t=0.7 sec, and 6.07% at t=1.1 secs. Fig.17 shows the comparative analysis of %THD of VL at different time instants.

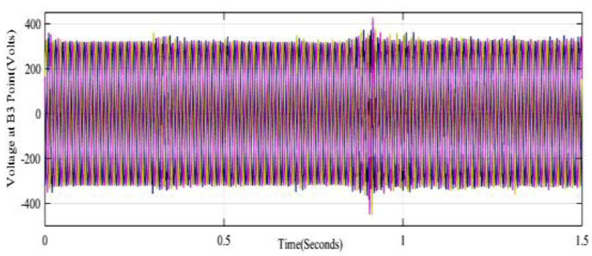

Figure.12 Waveform of voltage taken at point B3

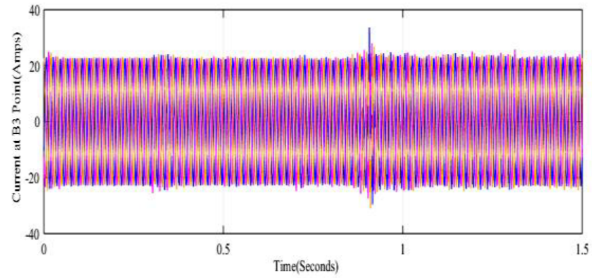

Figure.13 Waveform of current taken at point B3

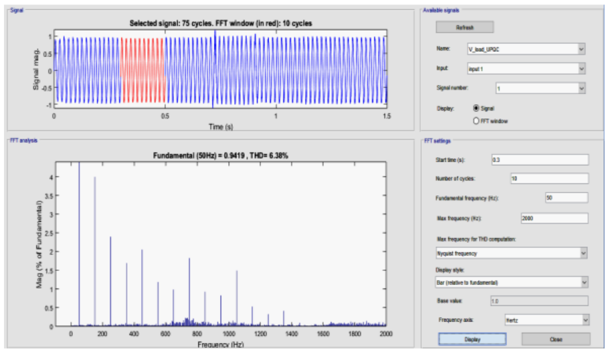

Figure.14 %THD of VL at t = 0.3sec (voltage sag)

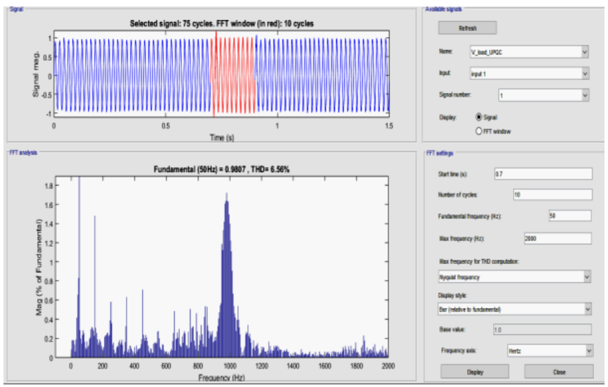

Figure.15 %THD of VL at t = 0.7sec (Swell)

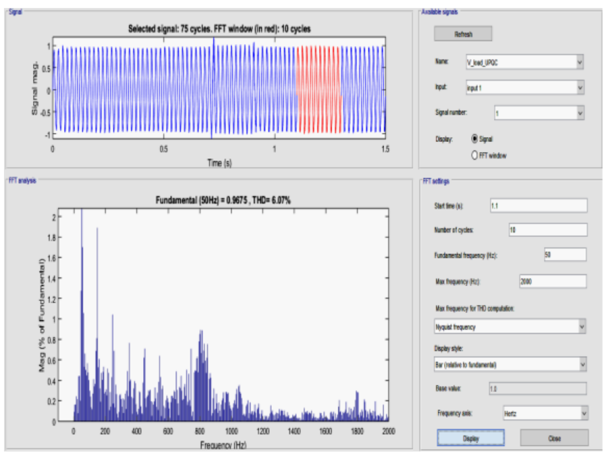

Figure.16 %THD of VL at t = 1.1sec (Non – linear load)

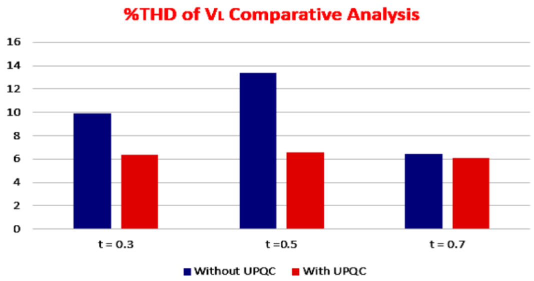

Figure.17 %THD of VL Comparative Analysis

5. CONCLUSION

This paper explores the implementation of a SRF based control method for UPQC device in DFIG based wind systems. The study involves a comparison of %THD values between the proposed system without UPQC and the one with UPQC. Utilizing MATLAB/SIMULINK, models are developed and analyzed to assess performance. Results indicate that the proposed system with UPQC effectively mitigates voltage sags, swells, and harmonics. Additionally, the research extends to incorporate UPQC with intelligent controllers, enhancing the potential for further advancements in power quality enhancement.

REFERENCES

[1] V.Sowmya Sree, G. Panduranga Reddy,C.Srinivasa Rao (2021), Mitigation of Power Quality Issues in Hybrid Solar-Wind Energy System using Distributed Power Flow Controller", 2021 IEEE International Women in Engineering (WIE) Conference on Electrical and Computer Engineering (WIECON-ECE).

[2] Raghu Thumu, Kadapa Harinadha Reddy, Chilakala Rami Reddy (2020), Unified power flow controller in grid-connected hybrid renewable energy system for power flow control using an elitist control strategy", Transactions of the Institute of Measurement and Control.

[3] P Dr. M.Ramasekhar Reddy, Dr.G.Pandu Ranga Reddy,(2020) Power Quality Improvement In DFIG Based WECS Connected to the Grid Using UPQC Controlled By Fractional Order PID And ANFIS Controllers in Journal of Mechanics Of Continua And Mathematical Sciences, Issue, No.-5, January (2020) pp 1-13.

[4] Pandu Ranga Reddy Gongati, Ramasekhara Reddy Marala, Vijaya Kumar Malupu. (2020) Mitigation of Certain Power Quality Issues in Wind Energy Conversion System Using UPQC and IUPQC Devices in European Journal of Electrical Engineering

[5] S. S. Sathri, M. Manohara, (2017) Power quality improvement in grid connected wind energy conversion systems by using custom power device, International Research Journal of Engineering and Technology (IRJET), Vol.: 04, Issue: 06, pp: 3254 – 3259.

[6] K. Neha ; K. Hemalata, (2016) An improved Interline Unified Power Quality Conditioner with FLC for compensation of voltage and current distortions in adjacent feeders, International Conference on Electrical Power and Energy Systems (ICEPES)

[7] Metin Kesler and Engin Ozdemir, Senior Member, IEEE (2011) Synchronous-Reference-Frame-Based Control Method for UPQC Under Unbalanced and Distorted Load Conditions in IEEE Transactions On Industrial Electronics, Vol. 58, No. 9, 3967 -3975.

[8] R.Bhavani, Dr.N.Rathina Prabha, C.Kanmani,(2015) Fuzzy Controlled UPQC for Power Quality Enhancement in a DFIG based Grid Connected Wind Power System", International Conference on Circuit, Power and Computing Technologies.978-1-4799-7075-9/15/$31.00 ©2015 IEEE

[9] Sergiu Ivanov, Marian Ciontu, Dumitru Sacerdotianu, Alexandru Radu (2017), Simple control strategy of the series filter within a unified power quality conditioner, International Conference on Electromechanical and Power Systems (SIELMEN).

[10] Kota, Venkata Reddy, and Sudheer Vinnakoti(2015), SRF-based control of unified power quality conditioner for power quality enhancement, International Conference on Electrical Electronics Signals Communication and Optimization (EESCO).

[11] Dr. R. Karpagam, J. Lydia, Dr.S. Leones Sherwin Vimalraj, Suganthi. S, K. Shanthi(2019), Synchronized Control of Voltage and Current Harmonics in Distributed Generation System using Fuzzy Controller, International Journal of Innovative Technology and Exploring Engineering.

[12] A. Jeraldine Viji, T. Aruldoss Albert Victoire (2014), Enhanced PLL based SRF control method for UPQC with fault protection under unbalanced load conditions in International Journal of Electrical Power & Energy Systems.