Application of UPQC on Grid Interfaced WECS

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***Abstract*— Custom power devices—such as DVR, D-STATCOM, and UPQC—play an important role in enhancing the power quality of distribution networks. Depending on the nature of the disturbance or the specific requirement at the load or grid side, an appropriate device and compensation method can be selected. Among these solutions, the Unified Power Quality Conditioner (UPQC) combines both series and shunt active filters, enabling it to address issues related to supply-side voltage disturbances as well as load-side current distortions. In the proposed work, UPQC is treated as a versatile power-conditioning unit capable of mitigating voltage anomalies, compensating for fluctuations, and suppressing harmonic distortion. This study focuses on integrating UPQC with a wind energy conversion system, and the designed system is tested through MATLAB/Simulink simulations to verify its performance and the effectiveness of the compensation strategy*Index Terms*— WECS, CSIR, NAL, MNRE,PMSG, CPC,RL, ANN,PQ, etc**

I. INTRODUCTION

In the last recent year, the deployment of wind farms and other renewable generation units has grown substantially. Despite this rapid expansion, wind energy is often viewed as challenging from a power-quality standpoint due to its variable and uncertain nature. The quality of electricity in a grid that incorporates wind turbines is strongly affected by how these turbines interact with the network. Their integration can introduce several issues such as voltage fluctuations, harmonic distortion, flicker, and transient peaks. These disturbances arise from both technical characteristics of the turbine and environmental conditions. Factors such as turbulent wind flow, tower-shadow effects, continuous power variation with rotor rotation, performance of electrical components, aerodynamic behavior, transformers, and mechanical dynamics all contribute to power-quality deviations.

Additionally, the annual energy output of a wind farm cannot simply be estimated by multiplying the rated capacity by the total hours in a year, because wind speed is not constant. The capacity factor—the ratio of actual annual energy production to the theoretical maximum output—reflects this variability. At well-situated wind farm locations, typical capacity factors range between 20% and 40%Variation of the wind on site and the generator size affect the capacity factor by several parameters.

A smaller generator would be cheaper and have a higher capacity factor, but would generate fewer (and therefore less) power in high winds. In contrast, large generators would cost more but produce little extra power and could break out at low wind speed. The optimum capacity factor of the wind farm would therefore be approximately 20–35 %.

Apart from stressing its increasing importance as a major source of renewable energy, this technical review papers discuss the wind power in India and elsewhere. In the next section here discuss the different approach uses in the wind energy conversion system.

Wind-powered electricity can vary highly at various timescales: hourly, daily, or seasonally. However, the wind is always supplied somewhere, making it a reliable energy source, as it will never expire or extinguish. There is also annual variability, but it is not so significant. Wind energy must be prepared, as must other sources of electricity. Wind power forecasting methods are used, but for short-term activity the predictability of wind plant performance is still poor. Since immediate generation and consumption of energy must remain in order to preserve grid stability, the introduction of large amounts of wind power into a system can pose considerable problems.

Intermediation and non-disconnected existence of wind power production that lead to higher regulatory costs, increased operating reserves, and (at high penetration), increased energy demand management, load shedding, storage solutions and system interconnection with HVDC wires that are already present. At low wind penetration, load and failure allowances in large generating systems require a reserve capacity that can also offset wind generation variability. There is therefore a unique challenge to the power system in integrating significant amounts of wind energy, demanding more flexibility and at the same time reducing the capacities of conventional production units.

In this paper discuss the various literature based on the wind energy conversion system. Also discuss the FACT device which is used for the improving the power quality issue based on the grid interfacing of the wind energy conversion system. A MATLAB based simulation id also discussed in this paper for validating the result of the proposed system.

II. REVIEW BASED ON WECS

In [1] we examine the simulation of, optimization of, and existing tools for simulating and designing autonomous hybrid electricity systems. In order to describe the different types, signatures and diagnostic systems of defects [2]

When a wind energy conversion system (WECS) — especially variable-speed or DFIG/PMSG-based systems is connected to the grid, its variable power output and power-electronics interface often introduce **power quality (PQ) issues**:

Recent research has highlighted the growing importance of power-quality enhancement in wind-based generation systems, and several studies have demonstrated the suitability of UPQC for this purpose.

The operational and maintenance costs of Wind Energy Conversion Systems (WECSs) are constantly reduced. If the state of these systems was constantly controlled, this cost reduction would be most successful. It enables early detection, facilitates proactive reactions, minimizes downtimes and maximizes productivity. Wind generators cannot also be accessed, as they are situated at very high towers normally 20 m or higher. In [3] a mathematical modeling and control strategy for small PMG grid-connected wind turbine systems is presented. A new dc link voltage-based algorithm is given in [4]. In addition, with a dc connection voltage, the output a tension of the inverter can be maintained continuously regardless of the varying speed and load of the wind. A strong inverter control technology based on the PWM (pulse width modulation) scheme is being built to regulate line voltages in common pairs (CPCs). The wind power system (PMSG) is a low voltage ride-through system for a synchronous magnet permanent generator at grid voltage pitch [5].A straightforward power control strategy, based on rapid torque control and the traditionally controlled pitch- angles, is discussed in [6]. This strategy increases the MPPT- feature of modern WECSs. A wind energy conversion system based on a high performance synchronous magnet synchronizing generator is described in[7]. In this paper the power converters are used with a diode correction, a three-level boost (TLB) converter and an inverter for a positive clamping point (NPC).An Algorithm for Permanent-Magnet Synchronous Generator (PMSG) based variable-speed wind energy conversion systems (WESSs), is available in the [8] Artificial Neural Network (ANN) based reinforcement learning (RL). A variable-speed direct-driven wind power converter (WECS) system based on sliding mode control (SMC) is equipped with a permanent magnet synchronous generator connected to the grid in [9]. This paper uses a diode rectifier, boost converter; positive spike inverter and L filter for the wind turbine and the grid interface.

A survey on important electrical engineering aspects for PMSG-based megawatt-level wind energy conversion systems (WECSs) is discussed in [11]. A comprehensive analysis on power converter topologies for wind turbines (WTs), grid integration of wind farms, digital control schemes, fault-ride-through compliance methods, and future trends is presented. The updated market share, technology trends, WT products information, in-depth technical analysis, and promising research works highlighted in this study will help the reader to understand the state-of-the-art and emerging technologies for PMSG-based WECS. Frequency response strategies for the PMSG-based WECS are explored, and an enhanced frequency response strategy is investigated to regulate the RAPS system frequency jointly with the integrated ultra capacitors is presented in [11]. The proposed short-term frequency response strategy utilizes a virtual inertial technique along with the supplementary droop control. Suboptimal power-point-tracking is also implemented at the PMSG to improve the active power reserve. The enhanced frequency response strategy can regulate the RAPS system frequency while alleviating high rate-of-change-of-power, and thus stresses on both the conventional generator and PMSG under frequency disturbances. Proposed control strategies are validated by both simulations and experiments.

A setup which includes wind turbine based on DFIG and SST is proposed in [12].Presented a detailed study on integrating a Unified Power Quality Conditioner (UPQC) with a wind energy conversion system to address the major power-quality disturbances that arise during grid connection. Their work highlights how variable wind speed and converter-based interfacing often introduce issues such as voltage fluctuations, harmonic distortion, and unbalanced currents at the point of common coupling (PCC). To mitigate these problems, the authors designed a UPQC configuration consisting of coordinated series and shunt active filters [13]. presented a detailed analysis of a wind-energy conversion system integrated with a UPQC, emphasizing how the combined series–shunt configuration can effectively reduce voltage disturbances, harmonic distortion, and other PQ issues at the grid interface. Their work established a baseline model showing that the UPQC significantly improves system stability under varying wind conditions. Building on this foundation [14]. Maximum power tracking point control with the fluid logic is used for the photovoltaic generator with a varying solar radiation. An attempt to adjust the controls of the wind energy conversion system (WECS) based induction generator (DFIG) is proposed in. The procedure is optimized to enhance WECS performance in both normal and temporary operating conditions. The external control loop, i.e., the speed controller, affects the quality and amount of output power under normal operating conditions. A new Static Switched Filter Compensation (SSFC) scheme by FACTS device is proposed in . This FACTS SSFC system is an effective tool to mitigate power quality, stabilize voltage, reduce energy losses, and enhance wind energy for wind systems interfacing with intelligent grid distribution nets.

III. UNIFIED POWER QUALITY CONDITIONER

A UPQC is a relatively new member of the family of custom power devices. The shunt and series compensators were integrated simultaneously in UPQC. The concept of UPQC is firstly introduced in 1996 so it is speculated that can address almost any power quality (PQ) problems. PQ problems generally occur either because of a distortion in voltage of supply or due to the absence of loads current.

Because UPQC has both series and shunt compensation technique hence it once mounted at the point of common coupling (PCC), it can handle supply voltage and load current issues at the same time. It can protect sensitive loads against events of power quality, which increase on the utility side and simultaneously prevent disturbances on the load side of the device.

The UPQC is a compensator based on power electronics and operates on the effective filtering concept. It is a mixture of Shunt (SHUC) and Series (SERC) compensator in cascaded through a DC link condenser. There are two types of UPQC configurations are possible depending on the position of the SHUC and the SERC. Figure 1 and Figure 2 show schematic diagrams of both configurations.

All UPQC components consist of an IGBT-based bridge inverter which depending on the control scheme and it can operate in a Voltage or Current Controlled Mode.

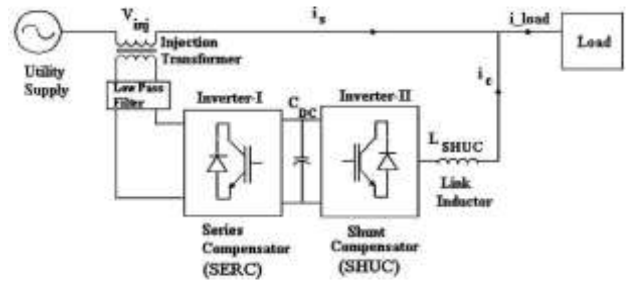

Fig.1: Basic Structure of Left Shunt UPQC

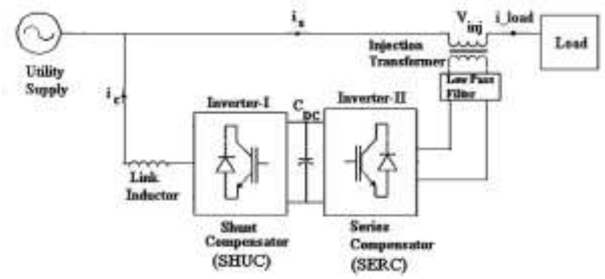

Fig.2: Basic Structure of Right Shunt UPQC

The Inverter I (Series compensator (SERC)) is connected with a low-level LC filter and a transformer at the supply voltage side. The Inverter II (Shunt Compensator (SHUC)) is connected to the load side with a smoothing inductor parallel to the load. The SERC acts as a controlled voltage source and offsets all voltage disruptions in the grid. The SHUC works as a controlled current source and offsets reactive power or harmonic from the load side. This serves as a real power path for maintain the DC link voltage at a constant value with constantly charging the DC link condenser.

The reactive power compensation is provided by SHUC and also current harmonic compensation in the load side. The position of the SHUC and SERC for the left shunt configuration (Figure 2) will be changed as per the concern type of utilization. The many work record recorded on the UPQC was the use of the right shunt UPQC, because of its characteristics are more conducive to the use of load reactive energy and harmonics than those from the left shunt UPQC for the normal use and the voltage disturbance on the spring side has to be compensated by SERC, When UPQC application for a distribution system is considered. The left shunt configuration of UPQC shall be preferred when UPQC catered for two different loads, one being voltage-sensitive and the other generating harmonics.

IV. SYSTEM MODELING

The approach of the system modeling is based on the implementation of UPQC in the wind energy conversion system.

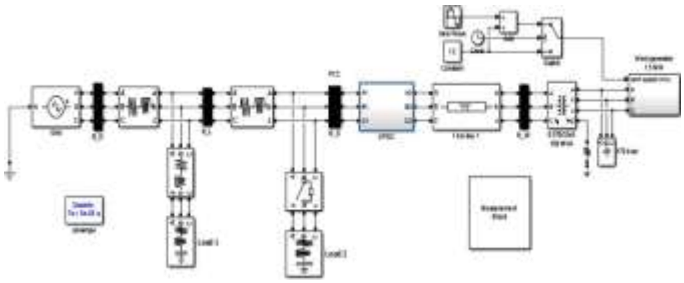

Fig.3: SIMULINK model of Proposed System

Figure 3 shows the implemented model of the proposed system. Here in this model the 1.5 MW wind farm is connected with the grid with the help of the UPQC. The UPQC here work as a bridge between the wind farm and the grid. A variable load is implemented for checking the performance of the applied system. Table 1 show the basic parameter which is used in this simulation. The whole simulation is run in the MATLAB 8.2 with ode23tb solver.

Table 1: System Parameter

Parameter	Value
Wind Energy Conversion Parameter	
Output Power of Wind Turbine	1.5 MW
Induction Generator Rating	7.5 kW, 400 V, 50 Hz, 1440 RPM
Pitch Angle	0 Degree
Load at Wind Side	10 kW, 50 Hz, 1000V
Transmission Line Parameter	
Length of Line	1 km
Line Parameter	r = 0.115Ω/km, L= 1.05mH/km
Grid Voltage	33 kV, 50Hz
UPQC Parameter	
Series Controller PI parameter	k_p=100, k_i=10
Carrier Wave Frequency	1080 Hz
Shunt Controller PI Parameter	k_p= 200,k_i=10
DC Link Capacitor	300µF
Switch	IGBT
Series Filter Choke	L=1 mH, r =1Ω
Shunt Filter Choke	L= 1mH, r=1Ω

Figure 4 shows the active and reactive power of the proposed system. As we know that the induction generator produces the reactive power to the grid. But due to presence of the UPQC it is compensated and makes it constant as shown in the result.

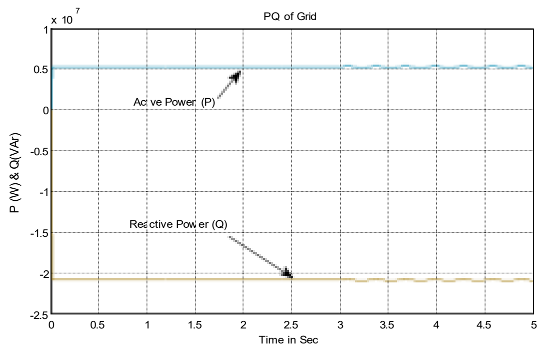

Fig. 4: Active and Reactive Power of the grid of the Proposed System

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Figure 5 shows the grid voltage of the proposed system for entire simulation. Here it is clearly seen that the overall voltage of the system is always in sinusoidal in nature. So due to presence of the variable output wind generation integration doesn't affect the system. Similarly in the current of the grid is also a show the same result. Figure 6 shows the current performance of the proposed system.

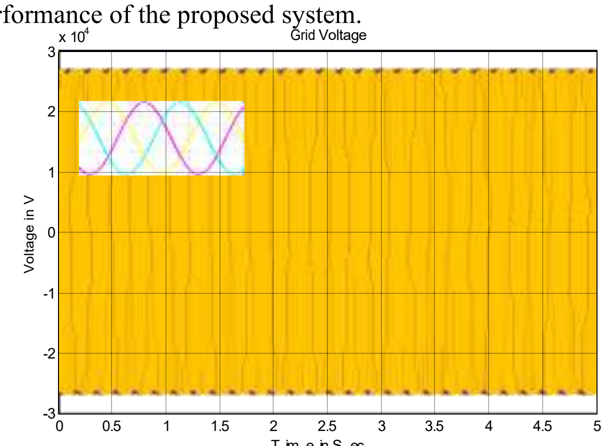

Fig. 5: Grid Voltage of the Proposed System

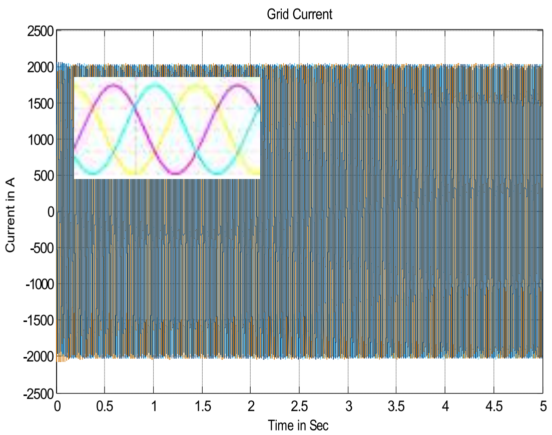

Fig. 6: Grid Current of the proposed System with UPQC

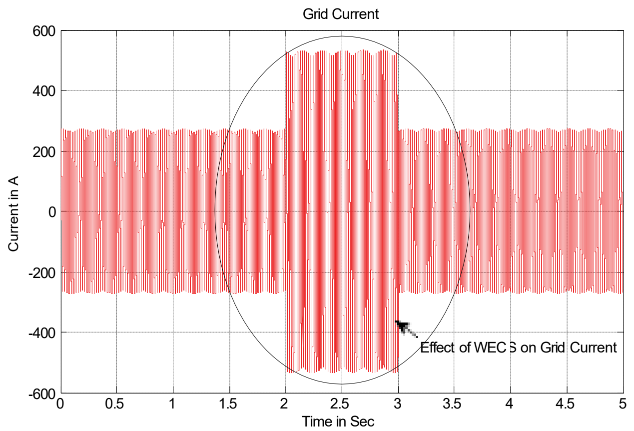

Fig. 7: Grid Voltage without UPQC in the proposed system

Figure 7 shows the proposed model without implementation of UPQC in the system. Here it is clearly seen that the effect of UPQC in the grid. Without UPQC the level of the current get decrease and also when the load is sudden applied the level increase. This makes system failure at ant time and retard the power quality of the system.

V. CONCLUSION

In this paper the application of UPQC is used for the compensation of the current variation in the grid interfaced wind energy system. For completing of this thesis firstly studied the several literature based on the wind energy conversion system. Also study the basic power quality issue in the WECS. Then discuss about the gird interfacing of the WECS. For compensating the current issue due to sudden change of current here in this thesis proposed UPQC in between the grid and WECS. A simple control technique based on the generation of unit vector templates is discussed in this thesis. In MATLAB, the proposed model was simulated. The simulation results show that the proposed control strategy can effectively compensate for the current due to sudden change in the load to the grid with wind generation integration.

REFERENCES

[1] José L.,Bernal-Agustín, RodolfoDufo-López, "Simulation and optimization of stand-alone hybrid renewable energy systems", Renewable and Sustainable Energy Reviews Volume 13, Issue 8, October 2009, Pages 2111-2118

[2] Y.Amirat, M.E.H.Benbouzid, E.Al-Ahmar, B.Bensaker, S.Turri, "A brief status on condition monitoring and fault diagnosis in wind energy conversion systems", Renewable and Sustainable Energy Reviews Volume 13, Issue 9, December 2009, Pages 2629-2636

[3] Md. Arifujjaman, "Modeling, simulation and control of grid connected Permanent Magnet Generator (PMG)-based small wind energy conversion system",IEEE Electrical Power & Energy Conference, 2010

[4] C. N. Bhende ; S. Mishra ; Siva Ganesh Malla, "Permanent Magnet Synchronous Generator-Based Standalone Wind Energy Supply System", IEEE Transactions on Sustainable Energy, Volume: 2 , Issue: 4 , Oct. 2011

[5] Ki-Hong Kim ; Yoon-CheulJeung ; Dong-Choon Lee ; Heung-Geun Kim, "LVRT Scheme of PMSG Wind Power Systems Based on Feedback Linearization",IEEE Transactions on Power Electronics , Volume: 27 , Issue: 5 , May 2012

[6] OmidAlizadeh ; AmirnaserYazdani, "A Strategy for Real Power Control in a Direct-Drive PMSG-Based Wind Energy Conversion System",IEEE Transactions on Power Delivery, Volume: 28 , Issue: 3 , July 2013

[7] VenkataYaramasu ; Bin Wu, "Predictive Control of a Three-Level Boost Converter and an NPC Inverter for High-Power PMSG-Based Medium Voltage Wind Energy Conversion Systems", EEE Transactions on Power Electronics, Volume: 29 , Issue: 10 , Oct. 2014

[8] Chun Wei ;Zhe Zhang ; Wei Qiao ; LiyanQu."An Adaptive Network-Based Reinforcement Learning Method for MPPT Control of PMSG Wind Energy Conversion Systems", IEEE

Transactions on Power Electronics, Volume: 31, Issue: 11, Nov. 2016

[9] Seyed Mehdi Mozayan ; MaaroufSaad ; Hani Vahedi ; Handy Fortin-Blanchette ; Mohsen Soltani , "Sliding Mode Control of PMSG Wind Turbine Based on Enhanced Exponential Reaching Law", IEEE Transactions on Industrial Electronics,
Volume: 63 , Issue: 10 , Oct. 2016

[10] VenkataYaramasu; ApparaoDekka; Mario J. Durán; Samir Kouro; Bin Wu, "PMSG-based wind energy conversion systems: survey on power converters and controls", IET Electric Power Applications , Volume 11, Issue 6, , p. 956 – 968, July 2017

[11] Yingjie Tan ; Kashem M. Muttaqi ; Phil Ciufo ; LasanthaMeegahapola, "Enhanced Frequency Response Strategy for a PMSG-Based Wind Energy Conversion System Using Ultracapacitor in Remote Area Power Supply Systems", IEEE Transactions on Industry Applications,
Volume: 53 , Issue: 1 , Jan.-Feb. 2017

[12] NeevatikaVerma ;Navdeep Singh ; ShekharYadav ; Sandeep Gupta. "Reactive Power Compensation of Solid State Transformer for WECS", 2018 2nd International Conference on Electronics, Materials Engineering & Nano-Technology (IEMENTech)

[13] WIND ENERGY CONVERSION SYSTEM WITH UPQC — Vijay Kant Singh, Neeraj K. Sharma, *IJCSPUB*, 2022

[14] WIND ENERGY CONVERSION SYSTEM WITH UPQC — Vijay Kant Singh, Neeraj K. Sharma, *IJCSPUB*, 2022Cost-effective optimization of unified power quality conditioner in wind energy conversion systems using a hybrid EnHBA-GWO algorithm — Shaziya Sultana & Umme Salma, *IJPEDS*, 2025