A Review on Power Quality in Grid Connected Renewable Energy System

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***Abstract*— This paper presents a review on power quality problems associated with the integration of renewable energy systems in to grid and it shows how power electronic devices and Flexible AC Transmission Systems play a role to mitigate the power quality problems. Photo Voltaic (PV) and Wind energy systems integration issues and associated power quality problems are discussed. Classification of various Power Quality Issues used by different researchers has been done and put for reference. Application of various techniques as applied to mitigate the different Power Quality problems is also presented for consideration.**

***Index Terms* — Power Quality, grid connected PV, grid connected wind, Distributed Generation, FACTS Devices, Renewable Energy.**

Abbreviations:

GCSPV	: Grid Connected Solar Photo Voltaic
GCWT	: Grid Connected Wind Turbine
PQ	: Power Quality
PE	: Power Electronics
CPD	: Custom Power Devices
AII	: Anti-Islanding Issues
FACTS	: Flexible AC Transmission Systems
1Ø	: Single Phase
UPQC	: Unified Power Quality Conditioner
STATCOM	: Static Compensator
D-STATCOM	: Distributed Static Compensator

I. INTRODUCTION TO THE PQ ISSUES

It is necessary to meet the energy demand by utilizing the renewable energy sources like Wind, Solar, Hydro, Biomass, Cogeneration etc., to have sustainable growth and social progress .In sustainable energy system, energy conservation and the use of renewable sources is important. The need to integrate the power sources from renewable sources like wind and solar into power system is to make it possible to minimize the environmental impact of conventional plant reported in [1]. The integration of wind and solar energy into existing power system presents technical challenges such as voltage regulation, flicker, harmonic distortion, stability etc., these power quality issues are to be confined to IEC and IEEE standards. A review of many papers reveals that these power quality issues can occur at the generation, transmission and distribution. The issue of power quality is of great importance to the Solar (PV) and Wind turbine, as sources. A major issue related to interconnection of distributed resources into the power grid is the quality of power provided to customers connected to the grid.

In order to investigate the power quality problems and it's mitigation techniques a review of many papers published during the last ten years has been presented. Issue has been discussed in [28-32],[11],[12],[13] presents about the voltage regulation problems. Papers [33],[34],[14] presents about the voltage sags and swells and it' s mitigation methods are reported. In [13] flicker issues and it's related mitigation techniques are discussed. Researches [7],[35-38] discussed about the harmonics and it's mitigation techniques. In[39-44],[25],[15],[16] authors discussed about the real and reactive power problems and its compensation techniques. In [40], [45], [29-32], [46], [17], [20], [21] authors presents about the different power quality issues and it's mitigation techniques in general.

This paper is organized as follows: In section II Integration issues of Renewable energy systems such as GCSV Systems and particularly GCWT Systems are discussed. Section III discusses the Power Electronic solutions for Power Quality improvement with applications, presented by different authors with their respective models. In section IV Application of FACTS devices are presented and finally section V concludes the review with a summary.

II. INTEGRATION OF RENEWABLE ENERGY SYSTEMS

Here most promising and prominent technologies of GCSPV and GCWT are only considered for discussion.

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A. Solar Photovoltaic Systems:

When the PV cell receives photon energy (=hµ) as a function of time, power electronic converters are to be employed to meet the load specifications [1],[2], focusing on PQ issues and Anti-Islanding Issues (AII) regarding PV systems connected to low and medium voltage levels of the network. The overall performance of SPV system including PV module, inverter, filter controlling mechanism etc., is to be optimized [3] such that the voltage variations and complex power of the line are controlled, limited to the guidelines. Based on the type of grid, the systems are designed for single-phase or three-phase. Also, when multiple PV arrays are connected, the harmonics developed are observed to have higher bandwidths of frequencies from sub-harmonic to multiple order harmonics.

Custom Power Devices (CPD) plays a vital role in many of the GCSPV connection topologies. These CPDs, connected to non-linear loads, introduce harmonics to the grid. Therefore, this needs to be considered in the controller design for the CPDs [4],[5] to make the output stabilized at the Point of Common Couplings (CPP). The applications of these are briefly discussed in [6]. Experimental outcome of a single-phase laboratory setup (2 kVA inverter) is illustrated in [7] to explain phase-synchronized grid voltage with the help of kalman filters. Recently Multifunctional PV Inverters for micro grid applications are coming up to introduce the reliability as an additional objective [8].

B. Wind Energy System:

The causes for reduced PQ in GCWT, violating the regulatory frameworks were extensively discussed in [9] considering the voltage deviation and frequency variations defined by IEC 61400-12,-13, and -21. Fluctuations, flickering and harmonics were found by simulations and experiments to explain the pressing need for CPDs in improving the PQ [6]. Each GCWT influences the overall outcome and hence a centralized approach was not found fruitful, but decentralized mitigation of PQ problems has to be done whatever connection topology is used [10].

III. CPDs FOR PQ IMPROVEMENT

PQ events may be seen from the utility perspective (Including generation, transmission and distribution) and the load perspective. Popularly known solution for these problems is to install line conditioning systems excited by flywheels, super capacitors, and other energy storage devices which smoothens the power system disturbances. Mainly power electronic devices and FACTS devices are used.

Due to innovations in the field of PE, the cost per installed kW of GCSPV and GCWT systems are coming down encouraging the bulk usage. The capacity-weighted average installed price between 2004-2008 was \$6.2/W, while in 2009-10 was \$3.9/W and in 2011 was \$3.4/W. [9] The inverters became more efficient and reached efficiencies more than 98%, since 60% of the energy being consumed is converted, while commercial solar modules reached efficiencies of almost 33.5%. In this paper the recent trends of power electronic topologies used in such systems are presented. Typical hybrid architecture of a grid-connected renewable energy sources is shown in fig.1.

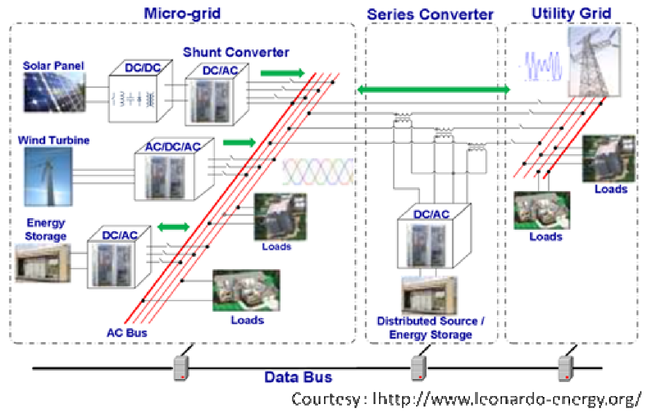

Figure 1: Architecture of Grid connected renewable energy sources

In [11-19] steady and dynamic state study is presented as a STATCOM based control scheme for grid integrated micro generators. [20], [21] authors discussed about UPQC based control scheme to mitigate the PQ problems. These methods proved through simulation and experimental results that the injected voltage gets minimized and a circulating power under all operating conditions of grid connected systems.

A. Power Electronics for GCSPV Applications:

Papers [22-25] highlight the power electronic solutions for GCSPV applications. PV module is connected to the inverter which is directly fed to the grid, so without using batteries it will supply the energy during day-time, reducing the cost of the system and maintenance. Feedback systems are mostly required to continuously monitor the grid voltage and frequency. Broad literature is available for PWM modulation techniques to fire up with switching frequencies of 2 to 20 KHz [26]. Extensive VSI based inverter designs are presented in [25], summarizing interconnection standards of PV systems. The inverter technology here is broadly classified as a) centralized

b) String technology and

c) Multi-string technology.

The topologies can be further classified based on

a) Number of power processing stages

b) Location of power decoupling capacitors

c) Types of grid interface.

References to ac-module-inverters are given in {[25]–[35]} of [25]. All these three topologies can be found in [25] where a cascaded multilevel inverter to integrate Segmented Energy Storages (SES) for a 1Ø GCSPV system to mitigate the overvoltage at PCC, while compensating reactive power flows. A new Online Overvoltage Prevention (OOP) control

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strategy maintains PV terminal voltages within specified range while maximizing the PV energy [24].

B. Power Electronics for Wind Turbine (WT) Applications:

Papers [28 -48], highlight the CPDs for GCWT applications. Several issues like voltage fluctuations, sags/swells, and harmonics with real and reactive power compensations are addressed through CPDs. They are briefly addressed in this paper.

a. Voltage Regulation:

The droop characteristics are used, particularly for DFIGs to control the voltage magnitude and frequency [31]. This can be extended to GCWT systems by doing a voltage sensitivity analysis to achieve voltage regulation at PCC. The high DC bus ripple is a result of the voltage-drive mode to provide the best AC power quality [28] and concludes that the bidirectional power flow and the bottom-up decentralized control methods make DG systems are well controlled and organized. To overcome this problem in [29] author focuses on the grid-interfacing architecture, with fuzzy logic controllers to improve voltage quality. For wind generators, there are three frames of references that one can work on. In [30] a control method based on stationary-frame is used for an islanded micro grid. Here, the complex power droop control systems use a virtual impedance loop, to compensate the unbalances.

b. Voltage Sags/Swells:

The operation of Sensitive loads connected to the grid is influenced by the voltage dips. To overcome this disadvantage author presented power electronic converter, in [33] using a series compensator, which requires considerably less active power and is able to restore the voltage at the load side. Distributed Generation is one way to overcome them, particularly under transient states. [49] The CPDs like VSCs connected to the DGs also get influenced by the voltage dips. A Fault Current Limiter (FCL) can be placed to suppress these affects within 3-30 cycles. Grid-interfacing power quality compensator for three-phase four-wire micro-grid applications was developed using the sequence components to inject voltages as a complementary measure Under the Net-metering scenario a Power Quality Control Center (PQCC) would regulate voltage due to the reversal of power flows from the DG and the increase in short circuit current [34].

d. Harmonics:

Harmonic resonances occur due to GCWT systems. The theory behind this introduced and the consequences presented with necessary case studies in [50]. A wide spectrum of current and voltage harmonics is caused by the presence of power converters. An autoregressive-moving-average (ARMA) method determines the harmonic spectrum affectively. In [35] Bandwidth-harmonic power droop has been proposed to share the harmonic power among multiple converters. In [36] author introduces a new Adaptive Notch Filtering (ANF) approach which can address issues like, extracting harmonics, voltage regulation, complex power control, suppressing frequency variations and noise contents using the sequential components of voltages as reference. Some methods for harmonic damping are (i) a shunt harmonic impedance method adaptable for islanded micro-grids application [38], (ii) The voltage-based droop control strategy to have controllable harmonic current and PQ (iii) heuristic optimization techniques such as differential evolution algorithm (DEA) are used to obtain the switching states of CPDs, as a nonlinear optimization problem.

e. Real and Reactive Power:

The seasonal patterns and the diurnal variations of wind are to be addressed for GCWT systems to achieve high-quality power from inverters meeting the specifications of grid codes. A droop control method is proposed based on the reactive power produced by the negative-sequence current and the positive-sequence line voltage [40]. A variant of the droop control strategy is used in [41], which combines P/V droop control with voltage droops to control the active power. A Lyapunov-function-based current tracking controller is proposed to control both active and reactive power flow for GCSPV and GCWT micro-systems through a single-phase parallel-connected inverter. The THD levels were found satisfactory even for nonlinear loads. The real and reactive power drawn from the 1Ø grids can be controlled by optimizing the transformer tap settings [44].

IV. APPLICATION OF FACTS DEVICES

The need for network management under dynamic state and to provide a cost effective solution for mitigating the PQ problems can be addressed using FACTS devices [51], introduced by N.G. Hingorani.. The STATCOM based control schemes are a proven technology to look after the PQ problems for grid- connected systems at PCC [19], [17]. Voltage fluctuation suppression and dynamic simulations were studied [11], to verify the performance of STATCOMs and its control strategies. Static Synchronous Compensators are later devised to overcome voltage sags/swells and unbalances in distributed generators connected to micro-grids [14]. A novel multilevel, hexagram converter method for GCWT systems was developed performing reactive power compensation by One-Cycle Control (OCC) [15]. In [12] authors present a novel night-time application of a PV solar farm powering a STATCOM for voltage control, improving power transmission capacity during nights.

For low and medium power applications, DSTATCOM are employed to compensate for poor load power factors [18]. A DSTATCOM can also be used for Reactive Power Compensation in 1Ø Operation of Micro grid [16]. The placement and current ratings of these devices are optimization problems and various techniques are available for solving it [13].

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Recent reports [20],[21], [52] shows the application of UPQC to DG integrated network to compensate almost all existing multipurpose PQ problems in the transmission and distribution of power.

CONCLUSION

A review of PQ problems associated with the GCSPV and GCWT systems are presented, quantifying various features of research papers published in those areas. The causes, affects, mitigation technologies featuring their topologies, highlighting the advantages of the grid integrated solar and particularly wind power systems are examined. The cost effective solutions of CPDs and FACTS devices are highlighted to give an insight to the scope of research in low and medium level voltage networks and for 1Ø and 3Ø micro-grids technologies. Most of the references listed here have laboratory results.

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