Impact of Wind Electric Generator on Power Quality

Vaishali Kuralkar
vaishali.kuralkar@gmail.com

Abstract— The use of renewable energy sources (RES) for electricity generation is increasing to reduce the dependence on fossil fuels. The trend is to connect renewable energy sources, such as wind energy, with grid to meet the increasing power demand. Also, power quality (PQ) is gaining importance in recent past due to the increase in sensitive loads, application of non linear loads and switching devices and increasing awareness of implication of poor power quality. With a view to these issues this paper presents a review of PQ problems associated with the wind electric generation. Wind farms are not only affected by poor power quality, but also affect the quality of power. Based on both the aspects various PQ issues are discussed in detail.
Keywords—*Power quality, wind electric generation, wind farm, wind turbine, grid interconnection, voltage variations.*

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I. INTRODUCTION

In view of the major changes taking place in the power system infrastructure, the trend is to connect renewable energy sources (RES) with grid to meet the increasing power demand. But the high penetration level of intermittent RES in existing power system may pose a threat to network in terms of stability, voltage regulation and power quality (PQ) issues. In order to develop regulatory policies, standards and technology for better utilization of renewable energy sources, it is necessary that the issues associated with large scale integration of these renewable energy sources with grid be studied in detail.

The most popular renewable energy technologies include microturbines, fuel cells, biomass, diesel, small wind, and photovoltaic (PV) generators [1]. Out of these wind energy is one of the fastest growing renewable energy sources because of its abundant availability in nature and the maturity of its technology [2]. It is necessary to identify the issues associated with large scale integration of wind electric generators (WEG) with utility power grid. The electricity generation from wind fluctuates greatly, requiring additional reserves of conventional capacity. The impact of wind power depends on the power system size, generation capacity mix, the degree of interconnection to neighboring systems and load variations [3]. Technical issues can not be discarded as the penetration of wind power increase in grid, specially power quality issues such as voltage variations, harmonics, flicker etc.

The PQ issues related to WEG integration with grid can be classified as 1) grid side PQ issues and 2) WEG side PQ issues. This paper deals with identifying both the issues associated with large scale integration of wind electric generators with utility power grid. Along with the problems associated some of the possible solutions are also discussed.

II. WIND ENERGY SYSTEM

The prime mover or the drive system of wind turbines is mainly categorised into two parts: 1) variable speed drives and (2) fixed speed drive systems. The most common types of machines presently associated with variable-speed systems incorporate synchronous generators. An emerging design in the market is based on permanent magnet synchronous generators [4]. The induction generators is common for both fixed and variable speed systems. The types of induction generators used in wind turbines employ squirrel cage rotor machines, wound rotor machines (with controllable rotor resistance to change the slip) and doubly-fed induction generators. From the design perspective some generators are directly connected to the grid (through dedicated transformers)
while others incorporate power electronics (based on the design the rating of power electronic systems vary). Many designs, however, include some level of power electronics to improve controllability. A simplified diagram representing some common types of wind energy systems are shown in **Fig. 1.**

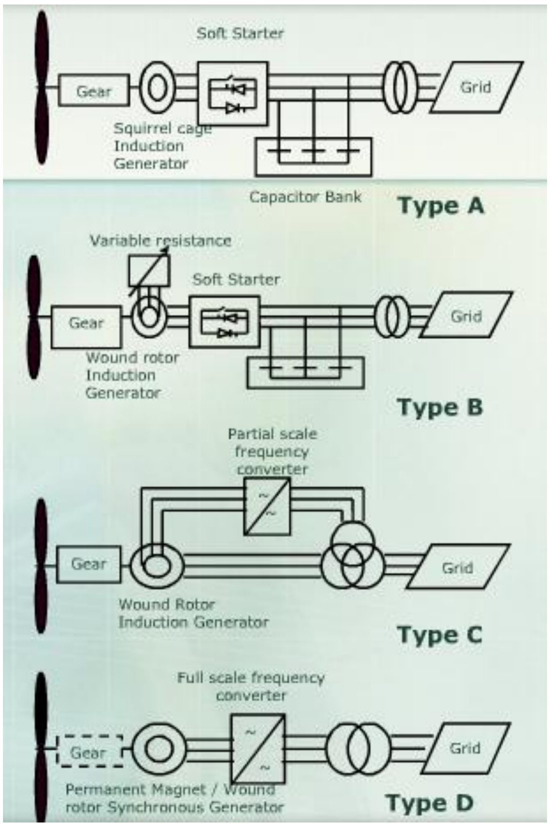

Fig. 1. Present day wind energy system

III. GRID SIDE PQ ISSUES

Grid power quality problems that affect the WEG are mainly concerned with the quality of voltage that is being supplied by the utility. The supply of "Good" quality voltage is utility responsibility. Some of the parameters (attributes) of voltage are:

- Voltage variations (sag/swell)
- Frequency variations
- Voltage transients
- Voltage unbalance
- Voltage harmonics
- Black out (grid drop)

A. Voltage Variations

Voltage variation has implications on both real and reactive power associated with wind farms. A low voltage condition (sag) increases the current through the generator, associated power equipment and the lines (for the same power) there by increasing the losses. Low voltage also affects the power factor as the capacitive VAR generated out of the installed capacitor decrease as voltage decreases.

High voltage (swell) condition apart from increasing the stress on the insulation (leading to reduced life) increase the magnetizing VAR requirement of the transformers. Most of the step up transformers are operated near saturation and even a marginal increase in voltage causes the magnetizing current to increase drastically, there by affecting the power factor.

The increase in voltage is compounded by the fact that most systems operate always at lowers than rated frequencies, thereby increasing the flux (vii) substantially. This phenomenon also increases the no load losses in the transformers, there by reducing the net real power generated by the WEG. In extreme cases transformer saturation can also lead to generation of appreciable amount of current harmonics. [6],[5]

Possible solutions to minimize the effect of voltage variations are as follows:

1. Use of on-load tap changers with transformers. These OLTC's could be incorporated into the central sub-station transformer or into each of the individual WEG transformers. The choice of OLTC location is a techno-commercial decision based on a through analysis of system conditions.
2. Use an asynchronous link for interfacing the WEG to the grid. By proper control algorithm the WEG side voltage can be kept a constant irrespective of grid side variations.
3. Use amorphous metal transformers instead of conventional CRGO transformers with individual WEG's.. It has been shown that the no-load power loss as well as the magnetizing VAR requirement with these transformers is much lower compared to conventional CRGO core transformers. Also the increase in magnetizing current with over fluxing is lower with amorphous metal transformers. The power law index is 6.7 for AMT as against 10.7 for CRGO transformers. Amorphous metal transformers are less sensitive to over fluxing and harmonics.

B. Frequency Variations

The variation in frequency affects the power generation in a WEG to a large extent, by affecting the aerodynamic efficiency. Frequency variations lead to operational at non-optimal tip speed ratios and reduced aerodynamic efficiencies. These leads to reduced energy capture and power output of wind turbines.

Another impact of frequency variation is that at low frequencies the VAR out put of power factor correction capacitors reduce thereby affecting the power factor. Also operation at low frequencies increases the flux in transformer thus pushing them near saturation and these results in increased VAR consumption and increased losses (and reduced generation). Though the ideal solution would be to control the grid frequency through generation control, it is not in the control of individual WEG operators. One possible solution is to interface the individual WEG to grid using an asynchronous link. By appropriate control logic the WEG side frequency is kept constant even as the grid side frequency is varying **[**6]..

C. Voltage Transients

Large voltage transients could be created due to switching of capacitors using mechanical switches, which are provided as an integral part of WEG for reactive power compensation. The magnitude (and frequency of occurrences) of such transients are large, especially if back to back switching is involved (as in the case of a capacitor bank switching). These internally generated transients could result in damage to sensitive electronic devices of the WEG control system. Due to repeated exposure to voltage transients the insulation system becomes weak leading to premature failure. Apart from this other switching operations also result in switching over voltages. Though direct lightning strikes on the OH lines in a wind farm are rare, the blades are very susceptible to lightning hits. This could cause an induced overvoltage in the electrical system associated with the tower.

Use of adequately rated lightning arrestors (gapless type) has been found to be effective in protecting the equipment from transient over voltages. Use of RC surge suppressor circuits for protection of low voltage electric circuitry has also been well established**.**[7],[8]

D. Voltage Unbalance

Voltage unbalance is caused due to large unbalanced (e.g. single-phase) loads. The unbalance in voltage causes negative sequence currents to flow in Induction machines, causing over heating. Due to this unbalanced voltage operation the life of the machine reduces and the machine must be suitable de-rated for large unbalance conditions. Voltage unbalance (zero sequence or negative sequence) can also cause metering errors, leading to higher or lower reading of both real and reactive power. Though the use of asynchronous links (AC-DC-AC) is possible to counter the unbalance problem, this might not be an economical solution for correcting only unbalances. The use of asynchronous link can be justified considering the other power quality aspects (voltage & frequency regulation, additional generation due to variable speed operation and elimination of reactive power consumption) also.

E. Harmonics

The hannonic current drawn by the WEG (during motoring - soft starting) could itself be a problem, as these current hannonics would appear as voltage hannonics, as the fault levels at WEG tenninals are quite low. Apart from this the system could itself have voltage hannonics created by non-linear loads connected elsewhere. Voltage hannonics cause over heating of transfonner and generators. These also cause an increase in currents through shunt capacitors thus leading to failure of such capacitors. Though technical solutions such as series filter (active & passive) and asynchronous links are available, these are not very economical (low benefit --cost ratio). A practical solution would be to provide shunt filters at the PCC of non-linear loads and reduce the harmonic currents flowing all over the network. This would result in lower voltage distortions. [10],[11]

F. Black Out

The most significant effect of a breaker opening is the possibility of a self-excitation in a windfarm. Recently this has been observed in a large number of windfarms where additional capacitors have been connected to the WEG tenninals to improve the power factor and avoid power factor penalties. In most cases these capacitors (either fixed or mechanically switched) are connected without any special control or protection features. This leads to selfexcitation conditions when an upstream breaker opens and results in large over voltages and over speeds of wind electric generators thus damaging the entire system.,[6],[7],[10]

Possible solutions for protection against selfexcitation include installation of group reactive power compensation using thyristor switched capacitors with special protection with selfexcitation rather than conventional individual compensation with fixed or mechanically switched capacitors.

Black out / grid drop also wind power generation to come to come to a halt as power evacuation is not possible without a grid. One possible solution for this is to operate the WEG's in stand alone mode configured as an integrated energy system. With such configurations it is possible to operate the WEG's either in standalone configuration or in grid interactive mode. In stand alone operation these can be either made to supply some local loads or can be used to store energy (pumped hydro, battery charging etc. depending upon the size & operating conditions) which can be released at a later time to meet the load requirements.

IV. WEG SIDE PQ ISSUES

WEG power quality problems that affect the WEG are mainly concerned with the quality of current that is being drawn / generated by the WEG's. The quality of current that is drawn / injected into the grid is the responsibility of the consumers (connected loads). Some of the power quality aspects associated with WEG operation, that affect the grid power quality are as follows:

- Reactive power Consumption
- Generation of current harmonics
- Injection of Fluctuating power

A. Reactive Power Consumption

This is the most important aspect in today's condition. Reactive power consumption in a wind farm is mainly due to the use of induction generators for energy conversion. The basic principle of Induction generators is that they consume reactive power (to set up the excitation / magnetic field) in order to generate real power. The magnetizing currents drawn by step up transformers also contribute to reactive power consumption to some extent. This reactive power consumption leads to increased T & D losses, poor voltage profile (and reduced voltage stability margins) over loading of T & D equipment and blocked capacity and over loading and reduction in life of T & D equipment.

If the typical pattern of reactive power consumption in a windfarm is observed, It is evident that the reactive power requirement is widely & dynamically varying with time and provision of a fixed compensation would not solve the problem. Of the various solutions, the one that is technically simple and economically viable is to provide reactive power compensation system for reactive power control. The reactive power compensation system is normally configured as mechanically switched capacitors or thyristor switched capacitors. Due care must be taken in proper sizing and provision of protection & control features to prevent over compensation / self-excitation and subsequent damage to WEG. Considering the nature of the load (induction generator), the compensation system should incorporate special control & protection features to prevent self-excitation. Mechanical switches are prone to failure due to frequent switching operations. Compensation through ASVC, though technically feasible is not a economically viable solution and also has larger real power losses in the compensation system. A hybrid reactive power compensation is the optimal solution. This incorporates a fixed capacitor branch a semi-variable mechanically switched bank and a fully variable thyristor switched capacitor panel. The total size, configuration and proportioning are done as to minimize the life cycle cost. [4],[12],[9] Use of asynchronous link also eliminates the reactive power requirement from the grid.

B. Generation of Current Harmonics]

Current harmonics are generated due to soft starting of induction generators during motoring mode. Due to the large generators concentrated at small geographic locations and large series impedance (low fault levels) associated with windfarms, these current harmonics get reflected ad voltage harmonics. This distorts the voltage on the line and affects all the consumers connected to the line. Current harmonics also causes over heating of transformers and capacitors and could lead to premature failure of capacitors. The possibility of a resonance / harmonic amplification also exists, with dangers of catastrophic failures. Solutions for this range from simple passive shunt filters to active filters. For large integrated windfarms, series tuned LC passive filters can be provided at the point of common coupling and these filters can be designed to provide the reactive support also at fundamental frequency. This would be the most cost- effective solution.

C. *Injection of Fluctuating Power*

Power (energy) in wind by nature is not steady and is characterized by annual, monthly, daily and hourly variations. This results in generation and injection of a power (current) that is fluctuating. This leads to operational problems, especially if the grids are weak and the portions of such fluctuating sources are more than certain limits (generally 25%).

Solutions for this include connection of a large number of WEG's at the point of common coupling, as due to spread in operating point the variations in power at the PCC is lower than with single turbines (due to the averaging effect). Another solution is to configure the WEG's as an integrated energy system for operation in conjunction with other renewable energy sources, conventional energy sources and/or storage elements. Most popular of these are the wind-diesel, wind-SPY-diesel and wind pumped hydro systems. By proper sizing of the various elements and selection of control logic a near constant output power can be achieved. Also integrated energy systems can be either operated in a grid-connected mode or stand-alone mode. This apart from imparting additional operating flexibility also can be used to address a few other power quality problems.

V. CONCLUSION

As presented in the paper, there is a strong interaction between the grid and the wind electric generators in determining the power quality. Poor quality of the grid affects wind electric generator's performance and wind generators create power quality problems. Due to this not only the operational efficiency of the windfarms reduces, this also results in poor grid power quality and increased looses for the utilities and other consumers.

For all the power quality problems discussed above, both from the grid side as well as WEG side there are technically proven and commercially viable solutions are available. While developing windfarms an integrated / holistic approach must be taken to incorporate these power conditioning devices to avoid power quality issues in grid interfacing of wind electric generators.

To facilitate improving power quality and operational efficiency of windfarms, standards and guidelines must be framed for power quality norms for grid interfacing of windfarms. Strict compliance must be enforced from either side to ensure power quality. Apart from standards & regulations, tariff structures must be developed to provide incentives for improving power quality and penalize those polluting the system. The tariff structure must be realistic and should reflect the true cost of poor power quality.

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