Power quality problems and solutions

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Abstract. This paper addresses the power quality problems and solutions related to (i) wind power generation and (ii) large industrial customers. Intermittent nature of wind power affects the quality of its electrical power output. The usage of low cost energy saving equipments also generates harmonics and voltage flicker thus affects the quality of supply voltage. A wide range of solutions are being already proposed with the development on power electronic devices and electrical machines. This paper is organized to discuss the (i) power quality problems in brief, (ii) four major developments in wind generator technologies and (iii) solutions to large industrial customers using Dynamic Voltage Restorer (DVR), Active Power Filter (APF) and Static Compensator (STATCOM). Finally development in power electronic devices’ control is briefed in each of the devices, which has utilizes these power electronic devices with integrated solutions to solve number of power quality problems.

1. Introduction to the power quality problems

The common power quality problems are voltage sag, voltage flicker, harmonics and switching transients. Mostly these are caused by intermittent nature of the non conventional power generations, large industrial non linear loads, power system faults due to thunder attack, transients due to switching of capacitor and large load feeders. Malfunction of devices and random failures of components are some results of power quality issues such as harmonic, voltage sags, flickering and interruptions [1, 2].

The conventional power generation technologies are well developed and they produced high quality of power. However, the popular renewable energy generation technologies, such as wind and solar, were in developing phase to maximise the power extraction while satisfying the grid code requirements. The research on wind generation technology and interconnection of solar plants using power electronics has brought the power quality at the grid connection point within the acceptable level [3]. The industrial loads are mostly driven by power electronic devices, which are mostly based on chopping techniques of supply voltages to achieve energy efficient operations. These kind of large industrial loads also severely affect the quality of power supply. However, the latest technologies on rectifiers and variable speed drives, which are used by modernised industries, reduce the harmonic injection. Some external devices such as APF (filter harmonics from load), DVR (compensate voltage sag from supply), STATCOM (applied to both load and supply sides) are also used to maintain power quality from both industries and utility [4].
2. Power quality improvement and development in wind generator technologies

![Fixed Speed Induction Generator Technology](image1)

Figure 1. Fixed Speed Induction Generator Technology

Fixed Speed Induction Generator (FSIG), shown in Figure 1, is one of the oldest generator technology used in wind power development. Here, the generator speed is almost fixed with less than 5% of speed adjustment. Power Factor Correction capacitors are used at the generator terminal to compensate the reactive power absorbed by the generator. The speed control especially at high wind speeds is achieved by pitch control. Later this technology was improved with changing of number of poles in two steps, which allows the turbine to operate around two speeds.

![Opti-slip Induction Generator Technology](image2)

Figure 2. Opti-slip Induction Generator Technology

The second generation of the wind turbine was the opti-slip wind turbine, shown in Figure 2. The wound rotor induction machines were used with an external resistor bank at the rotor. The effective rotor resistance was varied through a power electronic to vary the operating speed by about 10%. Hence, it improves the power quality and reduces the mechanical loading on turbine components. However, the copper losses across the rotor resistors decrease the efficiency of the wind turbine.

![Doubly Fed Induction Generator Technology](image3)

Figure 3: Doubly Fed Induction Generator Technology
The Doubly Fed Induction Generator (DFIG) was introduced to cover larger speed range, shown in Figure 3. The rotor can be operated at a different electrical frequency by absorbing or injecting active power by the rotor converter. Hence, the generator speed can be varied about 40% of its rated. Decouple operation of the DFIG results in the following advantages: (i) terminal voltage or power factor control, (ii) reduced mechanical stress, (iii) maximized power extraction and (iv) improved fault ride through performance. However, fault transient affects the generator since the stator is directly connected with the grid.

![Figure 3. Synchronous or induction generator configuration](image)

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![Figure 4. Full Range wind Generator Technology](image)

**Figure 4.** Full Range wind Generator Technology

The full range wind generation technology is shown in Figure 4. The generator is fully decoupled from the grid through a back to back voltage source converter. Since the generator has the full control of speed and decoupled from the grid, any network transients do not affect the generator dynamics and vice versa. The generator side converter to supplies the reactive power and controls the generator torque by shifting torque slip curve. The grid side converter maintains the dc link voltage at its reference value by controlling the active power flow to the grid. Wide speed operation, flicker elimination, direct control on real and reactive power, maximum power extraction, reduced mechanical stress and full controllability during a fault are some of the advantages exists in this wind turbines. The evolution of wind turbine technologies has resulted in power quality issues such as flicker and harmonics. These issues can be solved using a STATCOM or advance wind turbine controllers.

3. Power quality improvement at Industrial loads through power electronic devices

![Figure 5. Dynamic Voltage Restorer for large industrial loads](image)

**Figure 5.** Dynamic Voltage Restorer for large industrial loads
The DVR, shown in Figure 5, is used to compensate voltage sags, swells and flicker from power grid and maintain the power quality at the load side. In DVR controls: pre-sag, in-phase and hybrid of both compensation techniques have been well reported. Further, minimising energy storage requirement is also addressed through reactive power injection to boost the voltage by injecting voltage 90 degree leading with respect to load current [4, 5].

![Figure 6. Active Power Filters (series and shunt)](image)

The APFs are used to compensate or block the harmonic current injection from the industrial load centres [6]. Shunt APF control technique extracts the harmonic current components from the measured load currents and absorbs the harmonic current. Series APF block the harmonic current by injecting voltage, which represent the high impedance to the harmonic while low impedance to the fundamental. Therefore, it forces the harmonic current to be absorbed by the Passive Filter (PF). The STATCOM is also has similar configuration of shunt APF but with system level control to look after supply and load side problems [7]. All stable control technique must obtain the phase angle, where the vector based PLL [8] shows excellent performance in the power system control applications.

4. Conclusion

This paper has summarized the development of wind generator technologies, power quality improving devices for large industrial load customers with the brief on device integrated control concepts. This overall analysis on solutions for power quality problem will help to develop a premium city electricity supply concept.

References

[1] Stones J, Collinson A, 2001 Power quality. IEE Power Engineering J., 58-64.
[2] Rodney H G, Ramachandaramurthy V K, 2012 Voltage Sag Acceptability Assessment Using Multiple Magnitude-Duration Function. IEEE Transactions on Power Delivery, 27(4), 1984 – 1990.
[3] Arulampalam A, Ramtharan G, Jenkins N, Ramachandaramurthy V K, Ekanayake J B, Strbac G, 2007 Trends in wind power technology and grid code requirements, IEEE second International Conference on Industrial and Information Systems, 129 - 134.
[4] Ramachandaramurthy V K, Fitz, C, Arulampalam A, Zhan C, Barnes M, Jenkins N, 2002. Control of a battery supported dynamic voltage restore. IEE Proceedings on Generation Transmission and Distribution, 149(5), 533-542.
[5] Changjiang Z, Ramachandaramurthy V K, Arulampalam A, Fitz, C, Kromlidis S, Barnes M, Jenkins N, 2001 Dynamic voltage restorer based on voltage-space-vector PWM control. IEEE Transactions on Industry Applications, 37(6), 1855-1863.
[6] Hirofumi A. Trends in Active Power Line Conditioners, 1994, IEEE Transaction on Power Electronics, 9(3), 263-268.
[7] Arulampalam A, Barnes M, Jenkins N, Ekanayke JB., 2006. Power quality and stability improvement of a wind farm using STATCOM supported with Battery Energy Storage. IEE Proceedings on Generation Transmission and Distribution, 153(6), 701 - 710.
[8] Changjiang Z., Fitz, C, Ramachandaramurthy V K, Arulampalam A, Barnes M, Jenkins N., 2001. Software phase-locked loop applied to dynamic voltage restorer (DVR). IEEE Power Engineering Society Winter Meeting, 3, 1033-1038.