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Review on Power Quality Enhancement in weak Power Grids by Integration of Renewable Energy Technologies

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Abstract - *During Last decade power quality problems has become more complex at all level of power system. With the increased use of sophisticated electronics, high efficiency variable speed drive, power electronic controllers and also more & more non-linear loads, Power Quality has become an increasing concern to utilities and customers. The modern sensitive, Non-linear and sophisticated load affects the power quality. This paper deals with the issues of low power quality in weak power grids. Initially the various power quality issues are discussed with their definition or occurrence and then finally the solution to mitigate this power quality issues are discussed. The innovative solutions like integration of renewable energy systems along with energy storage to enhance power quality by interfacing with custom power devices are explained in detail. Nearly all sorts of solution for mitigating power quality issue require some sort of DC source for providing active power, which can be supplied by renewable energy source. Also the various energy storage systems are studied.*

Key Words: Power Quality, Grid, Harmonics, Distributed Generation, STATCOM, UPQC, etc...

1. INTRODUCTION

Power quality problems have become important issues for electricity consumers at all the level of usage. The deregulation of electric power energy has boosted the public awareness toward power quality among the different categories of users. Electrical power quality is a broad field which covers all aspects of power systems engineering, from transmission and distribution, to end user problems. It has become a source of concern for utilities, end users, civil or construction engineers and manufacturers. For these problems to be addressed, electric utilities must understand the sensitivity of end-user equipment to the quality of voltage. Consumers must also learn to control the quality of their loads.

The [4] gives the status of the present conventional power grid. Conventional power sources are insufficient to meet the ever increasing power demand and deteriorating power quality. Custom power devices like STATCOM (Shunt Active Power Filter), DVR (Series Active Power Filter) and UPQC (Combination of shunt and series Active Power Filter) are the latest development of interfacing devices between distribution supply (grid) and customer appliances to overcome voltage/current disturbances and improve the power quality by compensating reactive and harmonic power generated or absorbed by the load[3].Various strategies to mitigate power quality issues is been discussed in this paper and review of each method is given.

2. POWER QUALITY

For good quality of energy, voltage, current and frequency of distribution system should be proper. Thus, the investigation of energy quality can be divided into three parts, voltage quality, current quality and frequency. In good condition, the voltage of distribution system is changed by a sinusoidal function with the frequency of power system. The effective amount of voltage should be constant in all times and conditions. But, nonlinear loads and short circuit faults can produce voltage harmonics, unbalance voltages and negative and zero sequences of the voltage.

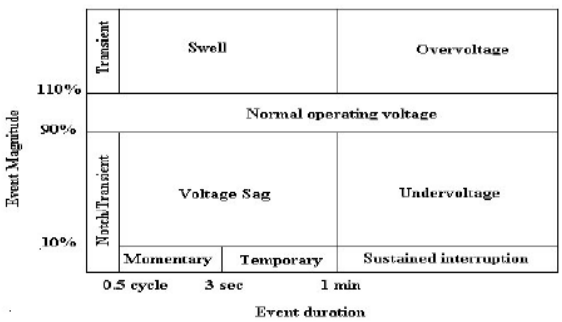

Fig -1: Demarcation of the various Power Quality issues defined by IEEE Std. 1159-1995[1]

2.1 Voltage Sags

One of the most common power frequency disturbances is voltage sag. By definition, voltage sag is an event that can last from half of a cycle to several seconds. Voltage sags typically are due to starting on large loads, such as an electric motor or an arc furnace. Induction motors draw starting currents ranging between 600 to 800% of their nominal full load currents. The current starts at the high value and goes to the normal running current value in about 2 to 8 sec, based on the motor design and load inertia. Depending on the instant at which the voltage is applied to the motor, the current can be highly asymmetrical [2]

2.2 Harmonics

Harmonic frequencies in power system are the integral multiples of the fundamental frequencies. The harmonic current generated by any non-linear load flows from the load into the power system [1]. This current, seeking a low impedance path to ground, causes a voltage of the drop through the system according to Ohm's Law. The harmonic voltage combines with the 50 Hz voltages producing a distorted power system voltage. The harmonic laden power system voltage is then imposed on all of the remaining loads connected to the system this voltage distortion may result in more harmonic currents being produced as other linear loads experience the distorted system voltage.

2.3 Transients

The term transients have long been used in the analysis of power system variations to denote an event that is undesirable and momentary in nature. The notion of a damped oscillatory transient due to an RLC network is probably what most power engineers think of when they hear the word transient. Other definitions in common use are broad in scope and simply state that a transient is "that part of the change in a variable that disappears during transition from one steady state operating condition to another. Unfortunately, this definition could be used to describe just about anything unusual that happens on the power system.

2.4 Long-Duration Voltage Variations

Long-duration variations can be either overvoltages or undervoltages. Overvoltages and undervoltages generally are not the result of system faults, but are caused by load variations on the system and system switching operations. Such variations are typically displayed as plots of rms voltage versus time.

2.4.1 Overvoltage

An overvoltage is an increase in the rms ac voltage greater than 110 percent at the power frequency for duration longer than 1 min. Overvoltages are usually the result of load switching (e.g., switching off a large load or energizing a capacitor bank). The overvoltages result because either the system is too weak for the desired voltage regulation or voltage controls are inadequate. Incorrect tap settings on transformers can also result in system overvoltages.

2.4.2 Undervoltage

An undervoltage is a decrease in the rms ac voltage to less than 90 percent at the power frequency for duration longer than 1 min. Undervoltages are the result of switching events that are the opposite of the events that Cause the overvoltages. A load switching on or a capacitor bank switching off can cause an undervoltage until voltage regulation equipment on the system can bring the voltage back to within tolerances. Overloaded circuits can result in undervoltages also.

2.5 Voltage Imbalance

Voltage imbalance (also called voltage unbalance) is sometimes defined as the maximum deviation from the average of the three-phase voltages or currents, divided by the average of the three-phase voltages or currents, expressed in percent. The ratio of either the negative- or zerosequence component to the positive-sequence component can be used to specify the percent unbalance. The primary source of voltage unbalances of less than 2 percent is single-phase loads on a three-phase circuit. Voltage unbalance can also be the result of blown fuses in one phase of a three-phase capacitor bank. Severe voltage unbalance (greater than 5 percent) can result from single-phasing conditions.

2.6 Voltage Fluctuations

Voltage fluctuations are systematic variations of the voltage envelope or a series of random voltage changes, the magnitude of which does not normally exceed the voltage ranges of 0.9 to 1.1 p.u. Loads that can exhibit continuous, rapid variations in the load current magnitude can cause voltage variations that are often referred to as flicker. The term flicker is derived from the impact of the voltage fluctuation on lamps such that they are perceived by the human eye to flicker. To be technically correct, voltage fluctuation is an electromagnetic phenomenon while flicker is an undesirable result of the voltage fluctuation in some loads. However, the two terms are often linked together in standards.

2.7 Power Frequency Variations

Power frequency variations are defined as the deviation of the power system fundamental frequency from it specified nominal value (e.g., 50 or 60 Hz). The power system frequency is directly related to the rotational speed of the generators supplying the system. There are slight variations in frequency as the dynamic balance between load and generation changes. The size of the frequency shift and its duration depend on the load characteristics and the response of the generation control system to load changes.

3. DISTRIBUTED GENERATION

It is the production of electricity at the customer premises point-of use in the distribution network. This is an alternate to the conventional method. Renewable energy, co-generation plant and standby generators are considered as DG. RE is defined as an inexhaustible and sustainable energy source moreover RE reduces the CO2 emission. To primary RE technologies integrated into the distribution level are rooftop solar PV and small scale wind turbine. However to manage generated electricity from these sources requires energy storage to store electricity when generates excess energy and to supply at a later time. Therefore storage also considered as a DG. For typical household, storage integrated grid connected PV and wind system presents a sustainable and economically viable solution.

4. MITIGATING OF POWER QUALITY PROBLEMS

There are two ways to mitigate the power quality problems – either from customer side or from utility side. The first approach is called load conditioning, which insures that the equipment is less sensitive to power disturbances, allowing the operation even under significant voltage distortion. The other solution is to install line conditioning systems that suppress o counteracts the power system disturbances. Several devices like flywheels, super capacitors other energy storage systems, constant voltage transformers, noise filters, isolation transformers, transient voltage surge suppressors, harmonic filter are used for the mitigation of specific power quality problems. Custom power devices like DSTATCOM, DVR and UPQC are capable of mitigating multiple PQ problems associated with utility distribution and end user applications.

4.1 STATCOM

STATCOM is a shunt compensator based on usually multi-level VSC design, utilizing IGBT as reliable high speed switching elements and a control concept based on pulse-width modulation. The VSC operates as a fully controllable voltage source matching the system voltage in phase, frequency and with amplitude which can be controlled continuously and rapidly so as to control reactive power [5].

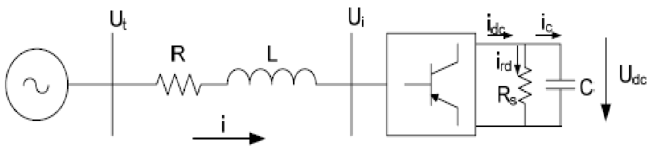

Fig -2: STATCOM model configuration

STATCOM allows voltage stabilization, improvement of power factor and dynamic control at the point of connection to industrial load using reactive power compensation. This is not enough in situations when a variable load is connected to the grid and produces voltage fluctuations. In this case, using additional active power compensation is required because the voltage drop is

$$\Delta U_{ph}=ZI=(R+jX)[P+jQ/\sqrt{3}U]=[RP\pm XQ/\sqrt{3}U]+[jXP\mp RQ/\sqrt{3}U] \quad ...1$$

caused by reactive and active power consumption too. Equation (1) has upper sign "+" in real part for inductive and bottom "-" for capacitive load character. We can see from this formula that voltage drop cannot be eliminated just by compensating reactive power. However, using active power injection can eliminate small fast voltage disturbances during variable load operation. Such disturbances are the main cause of flicker in transmission and distribution grids.

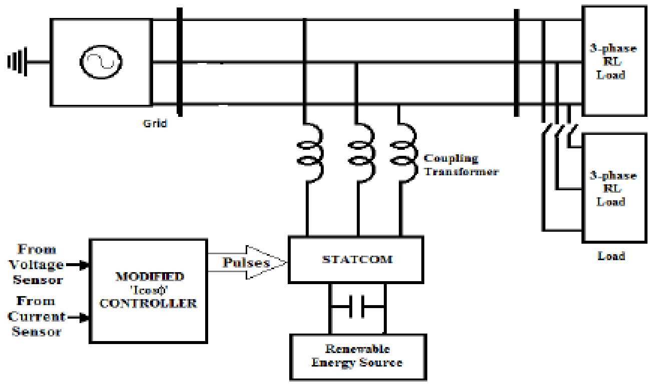

Fig -3: STATCOM with RE support

STATCOM with active power compensation could be realized by adding an element which can inject and consume active power, i.e. to store the active energy. It can be reached by parallel connection of a battery to the DC capacitor. STATCOM uses VSC technology which enables 4-qudrant operation in case of active power exchange possibility. It makes possible to convert AC to DC and back for active current.

Usage of active power compensation has a big potential for many applications, such as:

- Voltage and power compensation in distribution and transmission systems
- Power compensation during short-circuits and network reconfigurations
- Stability increasing during grid reconfigurations or generator failures
- Compensation of voltage dip during short time failure

4.2 Grid Interfacing Inverter

A grid interfacing inverter is a combination of both current controlled VSI and APF. Thus both the functions can be performed selectively or collectively.

Functions of grid interfacing inverter

- Active power generation Transfer from RES to the grid system.
- It supports the demand of load reactive power.
- Compensation of Current harmonics at the point of common coupling.
- Neutral current and current unbalance compensation in case of three phase three wire and three phase four wire system.

The proposed method consists of renewable energy sources connected to the dc-link of a grid-interfacing inverter as shown in Fig. 4. The key element of the Distributed Generated system is the voltage source inverter it interfaces the RES to the grid system and it delivered the generated power of the power system. The renewable energy source may be an AC source or an DC source coupled to dc-link with rectifier arrangements.

Normally, the photovoltaic energy sources and fuel cell energy sources generate the power at very low variable DC voltage and the wind turbines of variable speed generate power at very low variable ac voltage and the generated power from these renewable sources needs the power conditioning before connecting on the dc-link capacitor. The dc-link capacitor allows the separate control of converters on the both side of dc-link and it de-couples the Renewable energy sources from grid power system [4].

Grid-connected PV systems are currently being widely installed in many of the developed countries. In addition to their environmental benefits, PV systems have a number of technical and economical benefits. They can be operated to decrease the losses and improve the voltage profile of the feeder to which they are connected. One of the main characteristics of PV systems is the high variability of their output power.

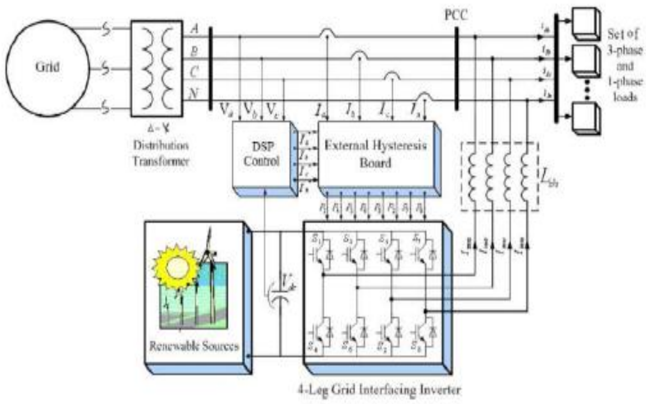

Fig -4: Grid interfacing inverter

4.3. UPQC

The UPQC (Unified Power Quality Conditioner) is one of the major custom power solutions, which is capable of mitigating the effect of supply voltage sag at the load end or at the point of common coupling (PCC) in a distributed network. It also prevents the propagation of the load current harmonics to the utility and improves the input power factor of the load. The control of series compensator (SERC) of the UPQC is such that it injects voltage in quadrature advance to the supply current as shown in fig. 5. Thus, the SERC consumes no active power at steady state.

The UPQC is a versatile device which could function as series active filter and shunt active filter [6]. UPQC can simultaneously fulfill different objectives like, maintaining a balanced sinusoidal (harmonic free) nominal voltage at the load bus, eliminating harmonics in the source currents, load balancing and power factor correction. Keeping the cost effectiveness of UPQC, it is desirable to have a minimum VA loading of the UPQC, for a given system without compromising compensation capability. For UPQC, its series compensator and parallel compensator can be regarded as two dc voltage inverter. Therefore, maintaining a constant value for dc voltage is necessary for UPQC to performance normally.

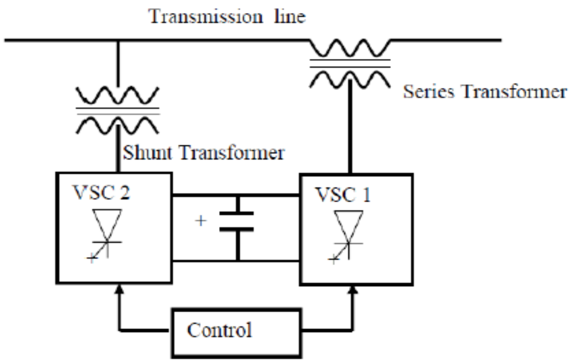

Fig -5: Schematic diagram of UPQC

The constant dc voltage is related to the power balance between UPQC and sources, namely when the input active power of UPQC is equivalent to its consumption theoretically. So the controlling of dc voltage involves in the active current of sources. UPQC with PV support is as shown in fig. 6.

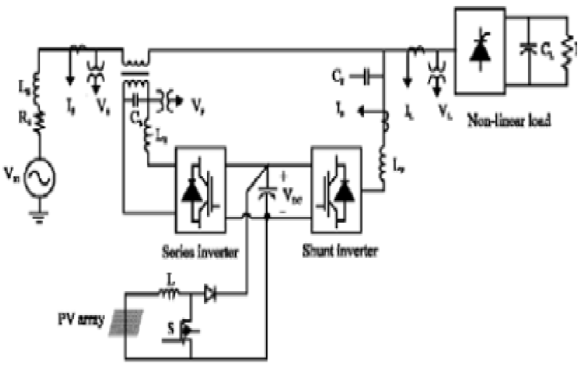

Fig -6: UPQC with PV support

4.4. DVR

The Dynamic Voltage Restorer (DVR), also referred to as the Series Voltage Booster (SVB) or the Static Series Compensator (SSC), is a device that utilizes solid state (or static) power electronic components, and is connected in series to the utility primary distribution circuit. It is normally installed in a distribution system between the supply and the critical load feeder at the point of common coupling (PCC). Other than voltage sags and swells compensation, DVR can also added other features like: line voltage harmonics compensation, reduction of transients in voltage and fault current limitations. Pulse width modulated inverter is used to vary the amplitude and the phase angle of the injected voltages, thus allowing the control of both real and reactive power exchange between the distribution system and the load.

The DVR is a series connected custom power device used to mitigate the voltage unbalance, sags, swells, harmonics and any abrupt changes due to abnormal conditions in the system. The basic configuration of DVR as in fig.7 consists of:

- Injection / Booster transformer: The Injection / Booster transformer is a specially designed transformer that attempts to limit the coupling of noise and transient energy from the primary side to the secondary side;

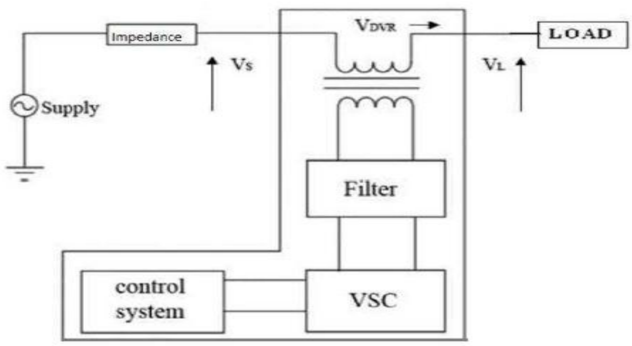

Fig -7 Schematic diagram of DVR

- Harmonic Filter: The main task of harmonic filter is to keep the harmonic voltage content generated by the VSC to the permissible level;
- Energy Storage Unit: It is responsible for energy storage in DC form. Flywheels, batteries, superconducting magnetic energy storage (SMES) and super capacitors can be used as energy storage devices [9]. The purpose of storage devices is to supply the necessary energy to the VSC via a dc link for the generation of injected voltages;

- Voltage Source Converter (VSC): A VSC is a power electronic system consists of a storage device and switching devices, which can generate a sinusoidal voltage at any required frequency, magnitude, and phase angle;
- Capacitor: DVR has a large DC capacitor to ensure stiff DC voltage input to inverter.

4.5. DPFC

The DPFC (Distributed Power Flow Controller) consists of one shunt and several series-connected converters. The shunt converter is similar as a STATCOM, while the series converter employs the D-FACTS concept, which is to use multiple single-phase converters instead of one large rated converter. Each converter within the DPFC is independent and has its own dc capacitor to provide the required dc voltage [9]. The configuration of the DPFC is shown in Fig 8, besides the key components, namely the shunt and series converters, the DPFC also requires a high-pass filter that is shunt connected at the other side of the transmission line, and two Y-Δ transformers at each side of the line. The unique control capability of the UPFC is given by the back-to-back connection between the shunt and series converters, which allows the active power to exchange freely or easily. Within the DPFC, there is a common connection between the ac terminals of the shunt and the series converters, which is the transmission line.

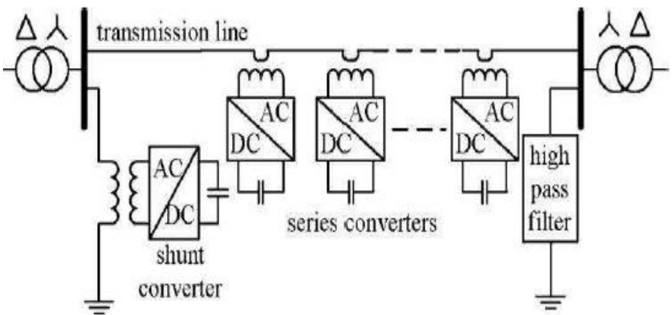

Fig -8: DPFC Configuration

Therefore, it is possible to exchange the active power through the ac terminals of the converters.

5. ENERGY STORAGE

Energy storage as buffer is essential with renewable energy (RE) such as solar photovoltaic (PV) for stable operation of grid by load management and by keeping voltage, frequency within allowable limit. However performance of PV module depends on load resistance, solar irradiance, cell temperature, cell shading and PV crystal-line structure. Electricity generated from DG introduces bi-directional power flow at the point of connection in the distribution network that influences the voltage regulation, balancing between phases and loading on distribution transformer (DT). Storage can delay the bi-directional power flow by supporting load. By supporting the load demand, storage reduces load on grid and eventually increases the node voltage.

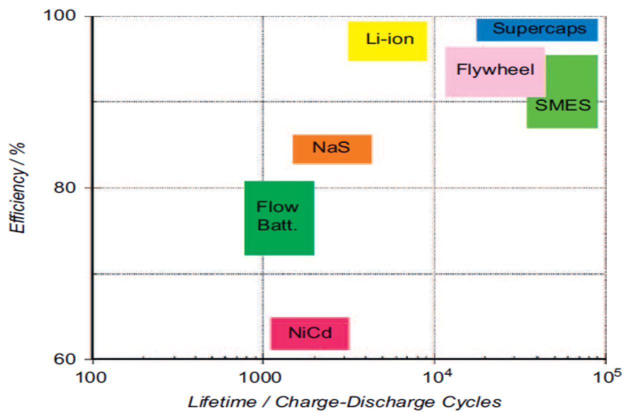

Fig 9: Efficiency/Lifetime Properties [11]

5.1 Electrochemical energy storage: batteries and super capacitors

Batteries are generally considered to represent a high-energy density, low-power-density technology. Batteries are the most popular energy storage system up to date due to their ease of operation and availability. Around 90% of total energy storage systems are consisting of battery for the energy storage .Supercapacitors represent a high-power-density, low energy-density energy-storage technology, which, as shown in Fig. 9, is able to bridge the gap in energy density between batteries and the common capacitor.

Supercapacitors may thus be used in hybrid energy-storage systems to complement batteries and to offer periods of pulsed power that would otherwise be difficult to engineer. It is therefore essential to note that supercapacitors do not offer an alternative to batteries and that a synergy exists between the two technologies in order to meet the challenges of contemporary energy-storage/ power-delivery systems.

5.2 Flywheel

A flywheel is an electromechanical device used to store energy for short durations. During a power disturbance, the kinetic energy stored in the rotor is transformed to DC electric energy by the generator, and the energy is delivered at a constant frequency and voltage through an inverter and a control system. The flywheel provides power during a period between the loss of utility supplied power and either the return of utility power or the start of a back-up power system (i.e., diesel generator). Flywheels typically provide 1-100 seconds of ride-through time, and back-up generators are able to get online within 5-20 seconds.

5.2Superconducting magnetic energy storage (SMES)

The basis of SMES is the storage of energy in the magnetic field of a DC current flowing in a superconductor. Energy losses are effectively zero because superconductors offer no resistance to electron flow. Since it is possible to inject and extract current very quickly in and out of superconducting coils, SMES has been developed for use in high-power devices [11]. To maintain the superconducting state, the device must be cooled to the temperature at which superconductivity is attained. For low temperature superconductors, liquid helium is necessary, and if high-temperature superconductors are used, liquid nitrogen could be used. The main advantages of SMES being used in devices for power quality are the high efficiency of storage (energy losses are associated with the cooling system but total system efficiencies of 98% can be achieved), length of storage, and the devices can be cycled almost infinitely.

6. CONCLUSIONS

The associated problems of Power Quality that a customer may encounter depend on how the voltage waveform is being distorted. There are transients, short duration variations (sags, swells and interruption), long duration variations (sustained interruptions, under voltages, over voltages), voltage imbalance, waveform distortion (dc offset, harmonics, inter harmonics, notching, and noise), voltage fluctuations and power frequency variations. Therefore, in this paper, it is investigated to use different mitigation technique that is suitable for different type of voltage sags source, voltage fluctuations, harmonics and transients. So the proposed mitigation technologies here are utilized to:

- inject real power generated from Renewable Energy System to the grid, and/or
- operates as a shunt or series Active Power Filter (APF),
- Store the energy in certain energy storage systems.

The paper focused on use of custom power devices for mitigation of power quality problems. Various control strategies of different CPD's is studied along with different energy storage systems.

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