Applying analysis of power quality enhancement by using UPQC

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Abstract. The current power sector is dealing with the weak power quality issues and the main reasons hiding behind the weak power quality are harmonics, fluctuations of voltage, transients and reactive power consume. These problems are caused by arising trends in our consume. Nowadays, the share of supply from power electronic devices has greatly increased among our consume. Coupling of the grid to a symbiosis of wind farms and PV parks has also raised matter of weak power quality. There is no doubt that shunt and series compensation is efficient but if they are utilized as a single unit simultaneously, this will increase the efficiency of the device and become a greater beneficiary of the power sector, which together serve as UPQC (Unified Power Quality Conditioner). Therefore, to improve the power quality is the main task of UPQC and through compensation to the above problems proves that it has considerable advantages in improving power quality. So UPQC is considered to be an effective method to solve power quality problems. Since UPQC is used for both shunt and series compensators, it contains two inverters to provide this service. They are voltage source inverters with a common DC link, which are called shunt and series converters. These controllers can be controlled by various techniques such as PI controllers, Fuzzy controllers, Neural Networks etc. The series converter is in charge of the smoothing of the voltage, and the shunt converter compensates for the distorted load current.

1. Introduction
The main motive for power distribution systems is to provide uninterrupted power to all consumers with supply being purely sinusoidal and acceptable frequency but the same is not fulfilled because of nonlinear loads, implementation of power electronic devices as loads and clubbing of power from different sources[1]. Apart from these above mention loads harmonics and transients arises due to abrupt switching of heavy appliances such as sudden shut down of generators of connection a generator to the transmission line without synchronizing its output to the grid or taking out transformers from the circuit cause such problems. The poor power quality hampers the growth as the most affected are the industries which totally rely on electricity and due to substandard power quality of power the efficiency of machines reduces hence the output decrease. The problems subjected to transmission and distribution can be bifurcated into power quality and power reliability. Impulses, swells and harmonic distortion are included in power quality and power reliability comprises of voltage sags and outages[2]. The harmonics within the power supply system as well as cause interaction with communication signals and cause distortions in communication signals and these high frequency harmonics cause insulation failures[3]. We can remove power quality problems by implementing FACTS (Flexible AC Transmission System) devices in the system but in FACTS
devices UPQC is found to be quite efficient in improving power quality as it have series and shunt converters which mitigate both current and voltage based power quality problems simultaneously.

2. Function analysis of power quality

The definition of power quality is as individual as the person. The layman is willing to define power quality in some way, yet an engineer is willing to have his or her own views. The power quality according to IEEE is defined as “the concept of powering and grounding electronic equipment in such a manner that is suitable to the operation of that equipment and compatible with the premise wiring and other connected equipments”.[4]

Due to the implementation of diverse power electronic circuits and devices, the power quality of power systems has declined, causing people's attention. As a result, the power quality of the system aggravates and sensitive loads are affected.

Weak power quality can be discovered by the following signs:

| No. | Poor power quality signs                      |
|-----|-----------------------------------------------|
| 1   | Lamp’s flickering                             |
| 2   | Black-outs                                    |
| 3   | Sensitive load mal-operation                  |
| 4   | Interference to neighbouring communication lines |

2.1. Voltage variations

If there is any variation in the RMS value of the voltage occurring within a period of time as minutes or more, is called a voltage variation. There are also voltage variations in the grid, mainly due to load changes and changes in the power generator set. Whenever wind power is introduced into the grid, the wind turbine will also generate voltage changes and be introduced into the grid. The voltage change is not only due to changes in the speed of the wind turbine, but also due to a sudden shutdown of the wind turbine or sudden load shedding. Various wind turbines produce voltage variations.

2.1.1. Short-term voltage variation

The main reason for short-term voltage variation is that the voltage changes when certain a large-capacity load is increased or decreased from the system. As the name implies, they are short time intervals, i.e. several power frequency cycles.[5]

- Voltage sag. This occurs when the voltage in the line is below the RMS value of the voltage. On the graph depicts the voltage sag, the above axis represents a regular voltage having amplitude of 1, and the lower axis represents a voltage waveform of lower amplitude sagging affected.
- Voltage swell. The voltage in the case increases right from the RMS value. There is no doubt that the voltage increase is not large, but it will definitely affect the quality of the sine wave. The swell view is given on the figure on account of the upper axis represents a regular voltage and the lower axis gives a view of voltage swell.
- Interruption. Under certain conditions, the voltage/current decreases below 10% of the RMS value in the line.

2.1.2. Long-term voltage transients

- Undervoltage. For long duration of time, the voltage value stays below RMS of the line. It is generally at 90% of rated power supply and the reasons could be taking capacitor banks or synchronous condensers out of the system. It can last for a few minutes or even longer.[6]
- Overvoltage. The voltage increases and stays for a longer duration of time above the RMS value, and its continuance in time are a few minutes or even longer. Due to long-term changes in voltage, the efficiency of the device/load is diminished or the device is damaged. Since the
voltage is too low, the device will not operate at its rated capacity, so the output of the device will be reduced; on the other hand, when an overvoltage occurs, the device will be subjected to high voltage, so insulation failure may occur in the device and may be damaged. Therefore, in all cases, overvoltage and undervoltage can damage the system and its components.

2.2. Harmonics

All grid harmonics are constantly flowing in the power line. There are a large number of harmonic sources, such as sudden unloading or loading of transmission lines, inverters, rectifiers, non-linear loads, motors, and so on. In the circuit along with the injection of harmonics, the device will face adverse effects such as equipment failure, overheating, and faulty operation of the protection device, as well as interference in communication systems and interference in pilot line communications.

The frequency of the harmonic components is higher than the system frequency. For example, if we have a system with a frequency of 50 Hz, the harmonics present in the system will be orders of 2*50 Hz, 3*50 Hz etc. i.e. they are integer multiples of the fundamental frequency. Constant speed turbines do not produce significant harmonics [7].

2.3. Transients

2.3.1. Impulsive transients. The impulsive transients are generally caused by lightening, switching of long transmission lines or switching of heavy inductive loads such as induction furnaces. In impulsive transients there is little unidirectional change in either current, voltage, or both of them in the power line. The reliable method of removing such transients is using Zener diode.

2.3.2. Oscillatory transients. The above are caused by capacitor banks, which are designated for correction of power factor and due to this capacitor a bidirectional variation is caused in voltage, current or both in power line.

2.4. Flicker

The old method of measuring voltage changes is flicker. It is based on a measurement method of voltage amplitude change. During this process, the magnitudes of the change are measured. The flicker of wind turbines has been studied in numerous studies. Wind turbines produce flicker in two different modes of operation, switching mode or continuous mode. On figure that describes the voltage change as a function of frequency. The graph shows the maximum allowable voltage variation in regard to the number of voltage variation per second.[8]

3. Control strategy of UPQC

A UPFC and UPQC are quite similar in means of construction[9]. In UPQC two voltage source inverters are connected in series and shunt via DC link. A transmission line needs a balanced, distortion free environment to deliver power so series or shunt compensation is provided by UPFC (Unified Power Flow Controller) but if the power system contain DC components and distortion then UPQC is effective for such situations. UPQC injects series voltage to mitigate current harmonic else it is added as voltage fluctuation at the PCC (Point of Common Coupling). Thus this task of series inverter is to remove any sort of deficiency in voltage and the shunt inverter takes care of reactive power demand and removes the current harmonics. A number of techniques are there to control the two VSIs like PI technique, Fuzzy controllers, Neural Networks, by using Synchronous Reference Frame theory etc.

UPQC is quite effective as it provides simultaneous compensation at series and shunt levels and hence enhancing the circuit power.
4. Power circuit topology

4.1. Right shunt UPQC

In right shunt UPQC the shunt inverter i.e. $I_c$ is connected after the series compensator i.e. $V_c$.

The UPQC comprises of two VSIs (Voltage Source Inverters) connected in shunt and series either in left shunt topology or right shunt topology. The main task of UPQC is to condition the power supply by mitigating the harmonics from the power supply[10].

4.2. Left shunt UPQC

In the configuration, the shunt inverter is connected on left of the series inverter.
4.3. Equivalent circuit of UPQC

![Equivalent circuit diagram of UPQC](image)

Figure 4. Equivalent circuit diagram of UPQC

In the above circuits,

- $V_s =$ source voltage
- $V_t =$ terminal voltage at PCC
- $V_L =$ load voltage
- $I_s =$ source current
- $I_L =$ load current

The series inverter is provided to inject the voltage in the power line to mitigate these harmonics and that shunt inverter is desired to balance the reactive power by injecting current in the circuit. The injection of both current and voltage takes place from the injecting transformers and during balanced condition or in standby mode of UPQC the secondary of injecting transformer acts short circuited.

Another important component of UPQC is active power filters, which are included in UPQC in order to provide safety to the power line from undesired frequencies which get generated by harmonics and hence which cause insulation failure and malfunctioning of the devices. These filters prevent harmonics generated by inverters to penetrate into the system.

5. Controller for UPQC

Controller of UPQC is the most complex part of UPQC it in this where all the calculation regarding gate signals to be given to the inverters is to take place. Both series and shunt inverters have different controllers as the task of one is to provide voltage and other is to compensate the reactive power by injecting current in the circuit.[11]

The controllers are developed by employing various type of controlling techniques, which include Proportional Integrator controller (PI), Fuzzy logic controllers, Neural Networks, and Fast Fourier Transformations etc. are being employed. The main task of these controllers is to provide accurate gate signals to the inverters so as to provide good compensation. Synchronous reference frame theory is utilized to provide reference signals. According to the requirement the series inverter controller provides the required gate signal to the series VSI and hence voltage compensation takes place and the voltage sag/swell gets removed.

To generate the gating signal of the controllers, we employ the hysteresis band which compares the line and reference currents in case of shunt controller, and in series controller it compares the voltages, and hence provides required gating signals.

The power balance in UPQC is provided by the DC link, and in some place a PV array is introduced for the sake of balancing the power.

6. Conclusion

By controlling UPQC, the problem of current harmonics and voltage fluctuations can be decreased in the power system. Consequently we can connect UPQC at the point of common coupling to improve
power quality. As the shunt and series inverters are working simultaneously on the reactive power and voltage compensation takes place. The series inverter provides voltage compensation and shunt provides reactive power compensation. This UPQC is capable of providing a hassle free power supply. We can apply number of controlling techniques as given in this paper.

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