Enhancement of Power Quality for Microgrid Applications using UPQC

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Abstract— One of the major concerns in electricity industry today is power quality. It becomes important with the introduction of advanced and complicated devices, whose performance is very sensitive to the quality of power supply. The electronic devices are very sensitive to disturbances and thus industrial loads become less tolerant to power quality problems such as voltage dips, voltage sags, voltage flickers, harmonics and load unbalance etc. At present, a wide range of very flexible controllers, which capitalize on newly available power electronics components, are emerging for custom power applications. Among these, unified power quality conditioner which is based on the VSC principle is used for power quality improvement. In this paper, UPQC is used. This is used to compensate current and voltage quality problems of sensitive loads. The results are analyzed and presented using MATLAB/SIMULINK software.

Key words: Unified Power Quality Conditioner, MATLAB/ SIMULINK Software

I. INTRODUCTION

Power quality is often defined as the electrical network's or the grid's ability to supply a clean and stable power supply. In other words, power quality ideally creates a perfect power supply that is always available, has a pure noise-free sinusoidal wave shape, and is always within voltage and frequency tolerances. However, with increasing and varying energy demands from various industrial processes, many loads regularly impose disturbances on the grid, making deviations from these ideal conditions are frequent. Electricity is not the stable, uniform source of power. It is not, in fact, simply a matter of plugging in and sitting back to enjoy an unending stream of electrical. On a domestic level we might have seen lights dim and then return to their previous brightness, a variation in supply that is much more common in more developing countries. On a more commercial, or industrial scale, other issues might be larger scale voltage swings and sags, wave shape faults, voltage impulses or transients and high frequency noise. Of course this runs right up to total power outage, which might follow an extreme event, such as the major storms we have experienced this winter. Many of these issues can be put down to “power quality”; in other words, the relationship between your electrical equipment and electric power that drives it. Electrical power is considered to be of “good quality” if electrical equipment operates properly, and reliably, without its operation causing any damage to the equipment. Conversely, electrical power is viewed as “poor quality” if it damages equipment during normal usage, or causes equipment to malfunction or perform unreliably.

II. MICROGRID

A Micro grid is a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid.

− A small-scale, flexible, reliable source of electricity.
− A small-scale power system that uses a combination of generation, load and storage devices to several local customers.
− The power is generated by the community for the community, and any excess is fed directly into the power grid. Size of the Micro grid may range from homes to municipal regions to industrial parks.

A. Power Quality Issue in Microgrid

In distribution network high penetration of DG’s (Distribution Generator), enough power support is used to restrain output power fluctuation. The power could be supplied by energy storage technology, which includes two aspects: one is high efficient mass storage, and the other is fast and efficient energy conversion. Energy storage technology applied in power system can realize peak load shifting and system reserve demand reduction. Meanwhile, it would provide technical support for reducing network power loss and improving power quality. Super capacitor storage is normally used for smoothing the power of short duration, high power load or used in high peak power situation such as high power DC motor starting and dynamic voltage restorer. When it comes to voltage sags or instantaneous disturbance, Super capacitor storage technology is able to improve the power supply and quality. Thus, this technology is suitable for solving power quality problems in distribution network with high penetrations of DG’s. Custom power technology, based on power electronic technology, and could provide power supply up to reliability and stability level which users required in MV/LV distribution network system. UPQC, with feature of series compensation and parallel compensation being integrated together, has been considered as the most full featured and effective one of all DFACTS technologies so far. To improve power quality of distribution network with the high penetrations of DGs, developing custom power technology based on UPQC, which can inject active power during the voltage regulation and integrate to reactive compensation, is a feasible strategy.

Traditional UPQC used in power distribution system, integrating series compensation voltage principle and parallel compensation voltage principle in one device, can compensate three-phase asymmetric and harmonic both mains supply voltage and nonlinear loads. UPQC is composed of the main circuit shown in Fig.1, including series and parallel PWM converter, and the control circuit. There are two basic control strategies, i.e. direct control scheme and indirect control scheme. Direct control scheme means series.
III. UNIFIED POWER QUALITY CONDITIONER (UPQC)

UPQC is an active series / shunt power line conditioner. It is used to compensate power quality issues such as Voltage sags, swells, Voltage imbalance, flicker, harmonics and reactive current. Unified power quality conditioners (UPQCs) consist of combined series and shunt active power filters (APFs) for simultaneous compensation of voltage and current disturbances and reactive power. They are applicable to power distribution systems, being connected at the point of common coupling (PCC) of loads that generate harmonic currents. Diverse topologies has been proposed in literature for UPQCs in single-phase configurations, i.e. two IGBT half bridges or multilevel topologies, but this paper focuses on the commonly employed general structure depicted in Fig 1.

The electric interfaces A1, B1, C1, and N1 connect distribution network source and the A2, B2, C2, and N2 connect various loads. Two sets of three-phase four-leg converter respectively compose the series and parallel converters of the UPQC. The series converter output enters into distribution network via LC filter and transformer in series, while the parallel device output enters into distribution network with filter inductance in parallel. The switching sequence could be shown in Fig 3.

A. Structure of UPQC

As shown in Fig. 2, the major components of UPQC includes series converter, parallel converter, booster and discharge unit which consisting of super capacitor energy storage and DC/DC converter, outputting power transformer TsA~TsCof series converter, output filters Ls and Cs of series converter and inductance Lp of parallel converter.

The electric interfaces A1, B1, C1, and N1 connect distribution network source and the A2, B2, C2, and N2 connect various loads. Two sets of three-phase four-leg converter respectively compose the series and parallel converters of the UPQC. The series converter output enters into distribution network via LC filter and transformer in series, while the parallel device output enters into distribution network with filter inductance in parallel. The switching sequence could be shown in Fig.3.

As can be seen, the power converters share a dc-bus and, depending on their functionalities, employ an isolation transformer (series APF) or an inductance (shunt APF) as voltage or current links.

- The series APF must compensate the source voltage disturbances, such as harmonics, dips or over-voltages, which might deteriorate the operation of the local load while the shunt APF attenuates the undesirable load current components (harmonic currents and the fundamental frequency component which contributes to the reactive load power). Moreover, the shunt APF must control the dc-bus voltage in order to ensure the compensation capability of the UPQC. These functionalities can be carried out by applying diverse control strategies which can operate in the time domain, in the frequency domain or both. Time domain methods, such as pq or dq based methods, allow the fast compensation of time-variant disturbances but make more complex their selective compensation. In this sense, frequency domain methods are more flexible but their dynamical response is slower. This paper proposes a new control technique for UPQC’s based on a Kalman filtering approach. The proposed method operates both in the time and frequency domains allowing the selective compensation of voltage and current harmonics with fast dynamical responses. Moreover, the impact of dips and over-voltages can be attenuated by applying the proposed controller.

As shown in Fig. 1: Schematic of UPQC

As shown in Fig. 2, the major components of UPQC includes series converter, parallel converter, booster and discharge unit which consisting of super capacitor energy storage and DC/DC converter, outputting power transformer TsA~TsCof series converter, output filters Ls and Cs of series converter and inductance Lp of parallel converter.

When UPQC accesses to distribution network and sets to work, the DC bus voltage equals to that of the super capacitor bank. Then close contactors KMp2, 380V AC power supply charges to the dc side via pre-charge resistance R1 and parallel converter. When charging completes, close KMp1, and break KMp2 and DC/DC converter starts to work. Adjust the DC side voltage to nominal reference level 690V. Detect unbalanced degree and harmonic content of mains supply voltage and load current in load side, in order that parallel converter could be put into operation when over ranging problem happens. And when voltage problems like voltage sag and swell happen to mains supply, series converter will be put into operation and output compensation voltage until the problems are solved.

In general, the load voltage in Figure 1. Can be expressed as

\[ V_S + V_{SR} = V_L \]
Where, \( V_s \) is Supply voltage, \( V_{SR} \) is the voltage of series-APF. The equations for real and reactive power through the line are as follows

\[
P = \frac{V_s V_{SR} \sin(\delta_1 - \delta_2)}{X}
\]

(2)

\[
Q = \frac{V_{SR} (V_s - V_{SR})}{X}
\]

(3)

These equations are given by neglecting the resistance of the line.

UPQC is able to compensate current harmonics, to compensate reactive power, voltage distortions and control load flow.

Inductance and capacitance are calculated by using the following equations

\[
L = \frac{V_s \delta}{\frac{2\delta}{\omega}}
\]

(4)

\[
C = \frac{\delta}{\omega}
\]

(5)

IV. MATLAB/SIMULINK MODEL

The power circuit is modeled as a three phase system with a nonlinear load that is composed of a three phase diode bridge rectifier with RL load as shown in figure 4.

![MATLAB/SIMULINK model of system](image)

Fig. 4: MATLAB/SIMULINK model of system

V. SIMULATION RESULTS

In this paper, three phase 415V (line-neutral) 50Hz system is considered. The tabular form of the system is shown in table 1.1. There are two operation modes in the proposed system. One is called the interconnected mode, in which the DG provides power to the source and the load. The other is called the islanding mode, in which the DG provides power to the load only within its power rating.

The operation of proposed system was verified through MATLAB/SIMULINK software. Fig.5 shows the Fast Fourier Transform (FFT) analysis of load current and source current. Before connecting UPQC, the supply current is highly distorted with 14.21% of THD. After connecting UPQC, the THD is reduced to 1.11%, which falls within the limits of IEEE 519 standard.

![Fast Fourier Transform (FFT) analysis](image)

(a) Load current

![FFT analysis](image)

(b) Supply Current

Fig.5. Harmonic spectrum analysis With UPQC connected;

Fig.6 represents source voltage, series inverter voltage, load voltage waveforms. The balanced voltage sag occur (all phases has 50% of sag) from 0.2s to 0.6s. During this time interval series inverter injects voltage to cover this voltage sag and to maintain load voltage constant.

<table>
<thead>
<tr>
<th>System Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source voltage</td>
<td>22kV</td>
</tr>
<tr>
<td>Source Frequency</td>
<td>50Hz</td>
</tr>
<tr>
<td>Step-down transformer</td>
<td>Nominal power 8MVA, 50Hz, Primary (V_{1ma})=22kV, R1(pu)= 0.002, L1(pu)=0.08, Secondary (V_{2ma})=381.05V, R2(pu)= 0.002</td>
</tr>
</tbody>
</table>

Table 1: System parameters

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>L2(pu)</td>
<td>0.08</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>12 Terminal three-phase transformer</td>
<td>R(pu)= 0.0566, X(pu)=0.0667e-4, Secondary (V_{2ma})=20V, R(pu)= 0.280, X(pu)=1.1106e-4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Three-phase series RLC load</td>
<td>Nominal phase-to-phase voltage = 381.05 V, 50Hz, Active power = 100W</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>RL load</td>
<td>R = 0.5 Ohms, L = 10mH</td>
</tr>
</tbody>
</table>

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VI. CONCLUSION

In this paper, the operation of UPQC is explained. The proposed system is composed of series and shunt inverter. The proposed system is able to compensate voltage sag, voltage swell, and current harmonics in the line. Hence, the proposed system improves power quality at the point of installation on power distribution system or industrial power systems. The operation of UPQC has been evaluated through simulation studies using MATLAB/SIMULINK software.

REFERENCES


