Performance Analysis of FACT Devices Under Various Load Configurations

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Abstract—Modern power system consists of many interconnected generating stations and load centres. So the consumers look for the reliability and quality of power supply. Power quality is one of the biggest problems in the present day. It deals with the problems of voltage sag, voltage flicker, power swing, distortion etc. which can be improved by using the FACTS devices. DVR, DSTATCOM, and UPQC are the devices used for the improvement. These devices have quick response and high reliability. The objective of this paper is to develop Simulink model of DSTATCOM, UPQC and DVR. It is then simulated the performance at different load configurations such as three phase distribution network, dynamic load and DTC induction motor drives. The PI controller is used with the d-q theory to analyse the performance at series, shunt and combined series shunt compensators.

1. INTRODUCTION

From the last few years, in the power industry during the last few years the term power quality has become one of the most common expressions. It is observed that there is countless number of phenomena of power quality in electric power systems. Although this type of disturbances has always occurred in the systems, so the greater attention has recently been dedicated to minimizing their effects to the end users. In the past, it can be said that power quality the concepts and reliability were very similar because the amount of power electronics components was negligible and the loads were mostly linear. The loads were typically lighting, heating, and motors, these loads are not very sensitive to voltage deviations. Moreover, the loads were maximum or minimum isolated from each other and automation process was almost non-existent. These loads were not making the resume if there is any interruption in the process. Power quality has been a topic of great interest. Several issues triggered interest in monitoring and improvement of power quality. The power quality include all possible situations in which the waveform of the supply voltage or load current deviate from the sinusoidal waveform. In all three phases of a three-phase structure the voltage and current should be ideal i.e. at regulated frequency with the amplitude corresponding to the rated Root Mean Square value. The problems of power quality are steady state deviations, such as harmonics and flicker, as well as impulsive and oscillatory transients, voltage sags, short interruptions. On the cause basis, one can easily differentiate, between disturbances linked to the quality of the supply voltage and are interrelated to the quality of the current taken by the load. The main responsibilities of a utility system are to supply ideal electric power with regulated magnitudes and frequency for the customers at the points of common coupling (PCC). Although the voltage generated by the generated synchronous machines in power plants are almost sinusoidal, but there are some unsighted conditions such as short circuit faults, lightning and non-linear loads cause the deviation in voltage and current, some oscillations transient and disturbances. With the advancement of the technology, the industries growing their technology to make the system completely automated. For the automation process the power electronic devices are mostly used in the system which causes fluctuations in voltage, current harmonics and distortion in voltage waveforms, and short circuits faults result in voltage sags and swells. The other electronics devices are sensitive and unprotected to power quality disturbances such as computers, microcontrollers and hospital equipment and their proper operation depends on the quality of the voltage that is supplied to them.

For improving the quality and to make the system reliable the only possibility is an uninterrupted flow of power at proper voltage and frequency levels. So the FACTs and customer power devices are used in the electrical system to improve the power quality of the electrical power. These devices we are capable to reduce the problems faced to power quality. There are number of Custom Power devices include Active Power Filters (APF), Surge Arresters (SA). Static VAR Compensator, Dynamic Voltage Restorer, Distribution Series Capacitors, Distribution Static synchronous Compensators and Uninterruptible Power Supplies, Unified power quality conditioner these devices are designed for the protection of the transmission line, but at present more attention is on the distribution system. DSTATCOM are used in the distribution system. The other devices are, DVR and UPQC. A DSTATCOM is a shunt compensator which is connected in shunt at PCC to protect critical loads. The DSTATCOM is an effectible device to reduce current variations and harmonics from the distribution network. The DVR is the series compensator to reduce voltage dip or fluctuations and the UPQC is the combination of series and shunt compensator to protect the system for both the harmonics and the voltage problems. The harmonics current is generated by the nonlinear loads that can be at other locations in the power system and ultimately return back to the source. Therefore, the harmonic current produces harmonic voltages throughout the power systems. Many techniques have been employed to maintain the harmonic voltages and currents within the proposed levels.
From the literature review, it is observed that field of power quality and custom power devices such as DVR, DSTATCOM and UPQCs plays an important role in power system. It is very important to make the power supply reliable for the end users. For these custom power devices there are different types of controlling fuzzy, hysteresis, PID, and PI controller reported in literature to compensate various power quality problems. Different types of custom power devices are used to improve the power quality and to maintain ideal voltage and current profile. Utility is responsible for maintaining ideal voltage profile supplied to the consumers, while for maintaining ideal current profile at the PCC consumers are responsible. In the industrial system, dynamic loads and Induction motor drive causes fluctuations and degrade the power quality. In order to improve the quality of power, custom power devices (DSTATCOM, DVR and UPQC) have been used. The results are obtained by using MATLAB/SIMULINK Models.

The main objectives of the thesis are to develop simulink model for DSTATCOM, DVR and UPQC for the enhancement of power quality in high power distribution network consisting of industrial drive and Dynamic load. The effectiveness of these FACTS devices in solving the power quality problems has been proved through simulations, model development and analysis. Research has been carried out to achieve the above mentioned objectives of the proposed work.

2. METHODOLOGY

For the improvement in the performance of distribution system, the FACTS Device (D-STATCOM, DVR and UPQC) was inserted to the distribution system. We are using MATLAB simulink version R2010a to design the model. The test system consists of a 440kV or 240 kV, at 40Hz, 50Hz and 60 Hz transmission system, represented by a Thevenin equivalent, feeding into the primary side of a 2-winding 3 phase transformer connected in Y/Y, 440/440 kV. For the energy storage of D-STATCOM a dc source is connected.

For the testing a dynamic load and a DTC motor are connected at the load point. This Three-Phase Dynamic Load implements a three-phase, three-wire dynamic load with varying active power P and reactive power Q as function of positive-sequence voltage. We introduced three phase fault with transition time from 0.3s to 0.5s. A two-level D-STATCOM is connected to the system to provide instantaneous voltage compensation whereas DVR provides current support and the UPQC provides both type of compensation at the load point. Model Simulations and Results for THD Total harmonic Distortion, or THD, is the summation of all harmonic components of the Voltage or current waveform compared against the fundamental component of the voltage or current wave:

\[
THD = \sqrt{\sum \text{amplitude of all harmonics}} \div \text{fundamental component}
\]

Power factor (PF) is defined as the ratio between true power and the apparent power, i.e.

\[
\text{power factor} = \frac{\text{true power}}{\text{apparent power}} = \frac{\text{KW}}{\text{KVA}}
\]

The relationship between PF and THD for non-linear loads can be determined by,

\[
\text{power factor} = \sqrt{1 + (\text{THD})^2}
\]

The PWM (Pulse Width Modulation) generates pulses for carrier-based, self-commutated IGBTs, GTOs or FETs bridges. Arms are selected on the bases of number of bridge selected in the "Generator Mode" parameter. The PI controller is used to control the PWN modulation. This is using Park transformation for input and output signal conversion from dq0 reference frame to abc reference frame.

3. dq0toabc TRANSFORMATION

The process of conversion from the actual coil of machine itself to the equivalent d-axis and q-axis pf the generalized machine or vice-versa is known as the transformation. Perform Park transformation from dq0 reference frame to abc reference frame. A discrete version of this block is available in the Extras/Discrete Measurements library. The dq0_to_abc Transformation block performs the reverse of the so-called Park transformation, which is commonly used in three-phase electric machine models. It transforms three quantities (direct axis, quadratic axis, and zero-sequence components) expressed in a two-axis reference frame back to phase quantities. The following transformation is used:

\[
V_a = [V_d \cdot \sin(wt) + V_q \cdot \cos(wt)] + V_o \\
V_b = [V_d \cdot \sin(wt - 2\pi/3) + V_q \cdot \cos(wt - 2\pi/3)] + V_o \\
V_c = [V_d \cdot \sin(wt + 2\pi/3) + V_q \cdot \cos(wt + 2\pi/3)] + V_o
\]

Where,
- \(w\) = rotation speed (rad/s) of the rotating frame.
- Input 1 contains the vectorized signal of \([V_d \ V_q \ V_o]\) components
- Input 2 must contain a \([\sin(wt) \ \cos(wt)]\) two dimension signal, where \(w\) is the rotation speed of the reference frame.
- Output is a vectorized signal containing the three \([V_a \ V_b \ V_c]\) phase sinusoidal quantities. The
transformation is the same for the case of a three-phase current; you simply replace the \( V_a, V_b, V_c, V_d, V_q \) and \( V_0 \) variables with the \( I_a, I_b, I_c, I_d, I_q, \) and \( I_0 \) variables.

The dq0_to_abc Transformation block is used in the model of the Synchronous Machine block where the stator quantities are referred to the rotor. The machine consists of a stationary field winding at the direct axis, and the rotator armature at the q-axis. These are at right axis to each other. For the transformation the magnitude and direction of mmf setup by the three phase current \( i_a, i_b, i_c \) and the two coil currents \( i_{ds}, i_{qs} \) is identical. The Park transformation then eliminates time-varying inductances by referring the stator and rotor quantities to a fixed or rotating reference frame. The three phase armature current \( i_a, i_b, i_c \) in three phase winding produced rotating magnetic field and the same is achieved by two axis dq armature winding. The \( I_d \) and \( I_q \) currents represent the two DC currents flowing in the two equivalent rotor windings (d winding on the same axis as the field winding, and q winding in quadratic) producing the same flux as the stator \( I_a, I_b, \) and \( I_c \) currents. This block transforms three quantities (direct axis, quadrature axis and zero-sequence components) expressed in a two axis reference frame back to phase quantities.

3.1 Inputs and Outputs

- \( dq0 \): Connect to the first input a vectorized signal containing the sequence components \([d q 0]\) to be converted.
- \( \sin \_cos \): Connect to the second input a vectorized signal containing the \([\sin (\omega t) \cos (\omega t)]\) values, where \( \omega \) is the rotation speed of the reference frame.
- \( abc \): The output is a vectorized signal containing the three-phase sinusoidal quantities \([A B C]\)

4. SIMULATION AND RESULTS

In this work, the role of custom power device (DSTATCOM) is analyzed:
- Distribution network having DTC motor as non-linear load
- Dynamic load is also placed with DTC motor load
- Compensation is analyzed over 3-phase ground fault
- Synchronous Reference Frame(SRF) theory has been implemented in both series and shunt compensator
- Controlling is done through PI controller

4.1 Dynamic Load

The Dynamic Load block implements a three-phase, three-wire dynamic load whose active power \( P \) and reactive power \( Q \) vary as function of positive-sequence voltage. Negative- and zero-sequence currents are not simulated. The three load currents are therefore balanced, even under unbalanced load voltage conditions. The load impedance is kept constant if the terminal voltage \( V \) of the load is lower than a specified value \( V_{min} \). When the terminal voltage is greater than the \( V_{min} \) value, the active power \( P \) and reactive power \( Q \) of the load vary as follows:

\[
P(s) = P_{o} \frac{V}{V_o} \left( \frac{1 + T_{p1}s}{1 + T_{p2}s} \right)^{n_p} \]

\[
Q(s) = Q_{o} \frac{V}{V_o} \left( \frac{1 + T_{q1}s}{1 + T_{q2}s} \right)^{n_q}
\]

Where,
- \( P_o \) is the initial positive sequence voltage.
- \( Q_o \) and \( Q_o \) are the initial active and reactive powers at the initial voltage \( V_o \).
- \( V \) is the positive-sequence voltage.
- \( n_p \) and \( n_q \) are exponents (usually between 1 and 3) controlling the nature of the load.
- \( T_{p1} \) and \( T_{q1} \) are time constants controlling the dynamics of the active power \( P \).
- \( T_{q1} \) and \( T_{q2} \) are time constants controlling the dynamics of the reactive power \( Q \).

### Table I

<table>
<thead>
<tr>
<th>S.No.</th>
<th>SYSTEM ELEMENTS</th>
<th>PARAMETERS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>SOURCE</td>
<td>3-Phase, 440V, 50Hz</td>
</tr>
<tr>
<td>2</td>
<td>Inverter Parameter</td>
<td>IGBT based, 3- arm, 6-Pulse, Carrier Frequency=1080 Hz, Sample Time= 5 ( \mu )s</td>
</tr>
<tr>
<td>3</td>
<td>PI Controller</td>
<td>( K_p = 0.5, K_i = 100 )</td>
</tr>
<tr>
<td>4</td>
<td>Transformer1</td>
<td>440/440V Y/Y</td>
</tr>
<tr>
<td>5</td>
<td>Injection Transformer</td>
<td>440/440-440 V Y/Y</td>
</tr>
<tr>
<td>6</td>
<td>DTC motor load</td>
<td>225MVA</td>
</tr>
<tr>
<td>7</td>
<td>Dynamic load</td>
<td>( P_o=50e3W, Q_o=25e3Var )</td>
</tr>
</tbody>
</table>

5. SIMULINK MODELS

![Figure 5.1: Simulink Model of UPQC](image)
5.1 Frequency Spectrum Analysis

Figure 5.2: Source Voltage/Current, Load Voltage/Current Waveform of DSTATCOM DVR

Figure 5.3: Source Voltage/Current, Load Voltage/Current Waveform of DVR OPEN UPQC

Figure 5.4: Source Voltage/Current, Load Voltage/Current Waveform of UPQC

Figure 5.5: Frequency Spectrum of Source Current and Load Current of DSTATCOM

Figure 5.6: Frequency Spectrum of Source Voltage and Load Voltage of DVR
6. CONCLUSIONS

This thesis work is based on the simulation modeling of FACTS devices (DSTATCOM, DVR AND UPQC). These custom power devices have been used for the improvement of power quality problems by connecting them in series, shunt, and series-shunt compensators respectively. Further analysis has been done by comparing their performances.

In this paper a performance analysis of DSTATCOM, DVR and UPQC is presented. These devices are effective device for current harmonics and voltage sags and dip. The voltage sags on sensitive equipment is very effective. Therefore, DVR is used as an efficient solution because it has low cost, small size, and fast dynamic response. The simulation results show clearly the performance of a DVR in mitigating voltage sags and swells. The DVR handles both balanced and unbalanced situations without any difficulties and injects the appropriate voltage component to correct rapidly any anomaly in the supply voltage to keep the load voltage balanced and constant at the nominal value.

DSTATCOM, DVR and UPQC are proved that these devices can compensate the deviation of voltage and current. By using the different schematic circuits with the controlling technique the compensation is achieved. In the industries, different types of loads are introduced to the transmission system which introduced different deviations as described in the above chapter. If we use these loads at different voltage or frequency level there capacity of introducing the deviation is different. So the FACTS devices are studied at their different levels of voltage and frequency of loads. With the change in the level of these two quantities, the performance of the custom power devices will also change. The performance of the DSTATCOM, DVR and UPQC is described in the Table II.

### TABLE II
**Performance Analysis**

<table>
<thead>
<tr>
<th>Name of FACTs devices</th>
<th>Compensator type</th>
<th>Harmonics type</th>
<th>Voltage level of devices</th>
<th>frequency</th>
<th>Total harmonic distortion (THD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DSTATCOM</td>
<td>Series</td>
<td>Current harmonics</td>
<td>240v, 40Hz, 50Hz, 60Hz</td>
<td>4.16%</td>
<td>4.42% 4.68%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>440v, 40Hz, 50Hz, 60Hz</td>
<td>4.15%</td>
<td>4.47% 4.68%</td>
</tr>
<tr>
<td>DVR</td>
<td>Shunt</td>
<td>Voltage harmonics</td>
<td>240v, 40Hz, 50Hz, 60Hz</td>
<td>5.08%</td>
<td>5.48% 5.68%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>440v, 40Hz, 50Hz, 60Hz</td>
<td>4.64%</td>
<td>4.93% 5.10%</td>
</tr>
<tr>
<td>UPQC</td>
<td>Series-Shunt</td>
<td>Voltage current</td>
<td>440v, 50Hz, 60Hz</td>
<td>4.06%</td>
<td>4.06% 50.48%</td>
</tr>
</tbody>
</table>

The presented work can be extended in other following related areas: The more advanced controllers such as fuzzy controller, artificial neural network, AUPF, ISCT, AGCT, IGCT theories can also be used with UPQC to make the system more effective. Effectiveness UPQC can
be investigated by multi-level converters. Effectiveness of Z-source inverters can be investigated for various CP devices.

REFERENCES


