MITIGATION OF POWER QUALITY ISSUES IN GRID INTEGRATED PV AND WIND ENERGY SYSTEMS USING UPQC

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ABSTRACT

Photovoltaic systems and wind energy systems are recognized as most mature, clean and cost efficient renewable energy sources in the electricity market. These energy systems have been increasingly used in the generation of electrical energy, either by providing electricity in areas where there is no grid connection (standalone systems), or by providing electricity to the grid. For flexible interconnection to the grid, both the energy systems often relies on power electronic converters. Power quality problems are increases due to the need of inverters for the integration of these energy systems into the grid. This paper presents power quality problems associated with the Photovoltaic (PV) and wind energy systems integrated into the grid and also discusses the role of Unified Power Quality Conditioner (UPQC) in the mitigation of those power quality problems and enhancing the integration of renewable energy sources.

KEYWORDS: Distributed Generation, Power Quality, PV System, Wind Energy Systems, p-q Theory and UPQC

INTRODUCTION

Electrical power generation systems are facing major problems like deficiency of fossil fuel, the need to reduce emissions and power losses in Long transmission lines. These reasons increases the stress on integration of nonconventional energy systems into the grid by means of Distributed Generation (DG) networks, which in turn increases the efficiency of electrical power and reduction in emissions. With the integration of nonconventional energy systems into grid, several power quality issues are raised in the power transmission system. Almost every nonconventional energy systems are integrated into grid takes place with the help of power electronic converters. The power electronic converter circuit consist of several high frequency switching devices which can add harmonics in the electrical supply [1].

Nowadays, PV and wind energy systems are most widely used as DG systems, their integration with the grid also increases. In addition to the benefits of voltage support, diversification of power sources, reduction in transmission and distribution losses and improved reliability, power quality problems due to both PV and wind energy systems are also of budding concern. In order to overcome the PQ problems, custom power devices such as DVR, DSTATCOM, and UPQC are used. DVR is a voltage injecting device in series to the line, DSTATCOM is a current injecting device in parallel to the load whereas UPQC is a device which injects both voltage and current to the system i.e. it performs both the operation of DVR and DSTATCOM. This device is located between distribution supply and load terminals to overcome voltage / current disturbances as illustrated in the Figure 1 and improve the power quality by compensating the reactive power and harmonic generated or absorbed by the load. This paper deals with power quality problems injected by the...
distributed generation into the grid. Circuit topology and control schemes of UPQC to mitigate the PQ problems are also discussed. The simulation work is carried out in the MATLAB/ Simulink environment.

**Figure 1: Circuit Connection of UPQC**

**MODELLING OF PV SYSTEMS**

The building block of PV arrays is the solar cell, which is basically a p-n junction that directly converts light energy into electricity. It has an equivalent circuit as shown below in Figure 2. In this circuit, $I_{pv}$ represents the cell photo current as source current. $R_j$ represents the non-linear impedance of the p-n junction. $R_{sh}$ represents the intrinsic shunt resistance of the cell. $R_s$ represents the intrinsic series resistance of the cell.

**Figure 2: Equivalent Circuit of a PV Cell**

Generally the value of $R_{sh}$ is very large and that of $R_s$ is very small, hence they may be neglected to simplify the analysis. PV cells are grouped in larger units called PV modules which are further interconnected in series-parallel configuration to form PV arrays or PV generators. The PV mathematical model used to simplify our PV array is represented by the equation,

$$I = N_p I_{pv} - N_p I_{rs} \left[ \exp \left( \frac{n}{kT} \right) \right] - 1 \right]$$

(1)

Where $I$ is the output current of PV array, $V$ is the output voltage of PV array, $N_s$ is the number of cells in series, and $N_p$ is the number of cells in parallel, $q$ is the charge of an electron, $K$ is the Boltzmann’s constant, $A$ is the p-n junction...
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Ideality factor. T is the cell temperature (K). $I_{rs}$ is the cell reverse saturation current. The cell reverse saturation current $I_{rs}$ varies with temperature according to the following equation,

$$I_{rs} = I_{rsr} [T/T_r]^2 \exp \left( \frac{qE_g}{kT_r} \left( \frac{1}{T_r} - \frac{1}{T} \right) \right)$$  \hspace{1cm} (2)

Where $T_r$ is the cell reference temperature, $I_{rsr}$ is the cell reverse saturation temperature at $T_r$, and $E_g$ is the band gap of the semiconductor used in the cell. The temperature dependence of the energy gap of the semiconductor is given by

$$E_g = E_g(0) - \left( \frac{q^2 T}{\beta} \right)$$  \hspace{1cm} (3)

The photo current $I_{ph}$ depends on the solar radiation and cell temperature as follows,

$$I_{ph} = \left[ I_{scr} + K_i (T - T_r) S \right] \frac{100}{100}$$  \hspace{1cm} (4)

Where $I_{scr}$ is the cell short circuit current at reference temperature and radiation, $K_i$ is the short circuit current temperature coefficient, and $S$ is the solar radiation in m W/cm$^2$.

The PV power can be calculated using equation as follows,

$$P = IV = N_p I_{ph} V \left[ \left( \frac{q}{RT_A} \right) \left( \frac{T}{T_A} - 1 \right) \right]$$  \hspace{1cm} (5)

**Power Quality Issues**

The PV system may be a single phase or three phase depending on the grid connection requirements. The PV array can be available as a string of panels either in series or parallel mode connection. The PV system can be operated in centralized or decentralized mode of operation and the general idea of these PV inverter grid connection topologies along with their merits and demerits are discussed [2].

The PV panel output depends on sun light intensity and shading effects. The PQ problems due to PV panels depends on PV modules, inverter, filter controlling mechanisms etc., the PV system becomes unstable in terms of grid connection due to irradiation, cloud cover or shading effects. Therefore special attention should be paid to the voltage profile and the power flow on the line. When large amount of load is disconnected from the supply, voltage increases rapidly and leads to voltage swell. In case of DG, any voltage disturbances would result in disconnection of converter circuits and hence loss of energy occurs. Due to the variation of performance of source and inverter shows a notable degradation of efficiency in grid connected PV systems for long duration [3]. Since the power electronic converters are connected to the non-linear loads, harmonics are injected into the grid. A grid connected PV inverter cannot control the reactive and harmonic currents drawn from nonlinear loads. Therefore, an efficient controller design is needed for the inverter.

**MODELLING OF WIND SYSTEMS**

The Wind Turbine and the Doubly-Fed Induction Generator (WTDFIG) are shown in the Figure 3. The AC/DC/AC converter contains two converters: the rotor-side converter ($C_{rotor}$) and the grid-side converter ($C_{grid}$). Both are Voltage-Sourced Converters [4] and consists of forced-commutuated power electronic devices (IGBTs) to synthesize an AC voltage from a DC voltage source. A capacitor acts as the DC voltage source which is connected on the DC side. An inductor $L$ is connected between $C_{grid}$ and 3-phase grid. The rotor winding is connected to $C_{rotor}$ by slip rings and...
brushes and the stator winding is directly connected to the grid. The wind turbine is used to convert wind energy into electrical energy by the induction generator and it is transmitted to the grid by the stator and the rotor windings. The power of the wind turbine, the DC bus voltage and the reactive power or the voltage at the grid terminals can be controlled by control system which generates the pitch angle command and the voltage command signals $V_r$ and $V_{gc}$ for $C_{\text{rotor}}$ and $C_{\text{grid}}$ respectively.

![Double Fed Induction Generator](image)

**Figure 3: Double Fed Induction Generator**

**Power Quality Issues**

Wind farms are available with fixed speed induction generators and variable speed double fed induction generators. Voltage or frequency control is not possible in fixed speed induction generators. Such control is possible in existing wind farms with variable speed double fed induction generators by frequency response in the turbine control system.

For the grid connected converter system[5], double fed induction generators is the most efficient model for controlling the reactive power and angular velocity adjustments to obtain maximum efficiency in the output power. It can also support the system during voltage sags. However, these converter based systems are injecting harmonics into the system.

**UPQC CONTROLLING MECHANISMS**

During linear or nonlinear load conditions, energy extraction from the wind turbine into the grid is done by injecting sinusoidal current with inverter control. Inverters can also act as active power filters for harmonic and reactive power compensation during nonlinear load conditions. To control the performance and the effectiveness of the WECS, the VSI is operated based on the concept of p-q theory [6]. The control input is a current error signal which in this application, is the difference between the actual current injected by VSI and the desired or reference current waveform.

The “p-q theory” is based on a set of instantaneous powers defined in the time domain. Hence it is valid both in the steady state and in the transient state. This theory uses the $\alpha\beta0$ transformation in stationary reference frame, also known as the Clarke transformation. This method is used for calculating real and reactive power requirements of the load instantaneously.
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Using this method, reference currents are determined for active filters [7] in order to obtain the reference currents, measured voltages and currents are transformed from three phase to two phase by using the equations (6) and (7). These equations are used for calculating instantaneous real and reactive power with equation (8).

This instantaneous power consists both DC and AC components (9 and 10). Harmonics and negative sequence components originates AC components of the power. Therefore, Active power filters are used to eliminate the AC components and applying the equations (11), (12) and (13) for obtaining the compensator reference current [8]. Here $T^{-1}$ is the reverse transformation matrix.

\[
\begin{bmatrix}
i_a \\
i_b \\
i_c
\end{bmatrix}
= T
\begin{bmatrix}
i_a \\
i_b \\
i_c
\end{bmatrix}
\]

\[
T = \begin{bmatrix}
\sqrt{3}/2 & -1/2 & -1/2 \\
+1/2 & \sqrt{3}/2 & -\sqrt{3}/2 \\
0 & \sqrt{3}/2 & \sqrt{3}/2
\end{bmatrix}
\]  
(6)

\[
\begin{bmatrix}
v_a \\
v_b \\
v_c
\end{bmatrix}
= \begin{bmatrix}
-v_\beta \\
v_\alpha \\
v_\alpha
\end{bmatrix}
\]

\[
p = \bar{p} + \bar{p}
\]

\[
q = \bar{q} + \bar{q}
\]

\[
\begin{bmatrix}
i_\alpha \\
i_\beta
\end{bmatrix}
= \frac{1}{v_\alpha^2 + v_\beta^2}
\begin{bmatrix}
v_\alpha \\
v_\beta
\end{bmatrix}
\begin{bmatrix}
\bar{p} \\
\bar{q}
\end{bmatrix}
\]

\[
\begin{bmatrix}
i_\alpha \\
i_\beta \\
i_\alpha
\end{bmatrix}
= T^{-1}
\begin{bmatrix}
i_\alpha \\
i_\beta
\end{bmatrix}
\]

\[
T^{-1} = \begin{bmatrix}
1 & 0 & 0 \\
-1/2 & \sqrt{3}/2 & -\sqrt{3}/2 \\
-1/2 & -\sqrt{3}/2 & \sqrt{3}/2
\end{bmatrix}
\]

(9)

(10)

(11)

(12)

The gate signals required for power electronic converter circuits are generated by using Space Vector Pulse Width Modulation (SV-PWM) method. The power system network with power supply grid, wind energy system, PV system with UPQC[9 and 10] control is illustrated in the Figure 4.
SIMULATION WORK AND RESULTS

The entire simulation work is carried out in MATLAB/ Simulink environment. In this simulation, the details of generator, load, transmission line, transformer, wind turbine system and PV system are tabulated as follows:

Table 1: Details of Power System Network Used for Simulation Work

<table>
<thead>
<tr>
<th>Generator Details</th>
<th>Load Details</th>
<th>Transmission Line Details (pi-Section)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase-Phase voltage</td>
<td>Load1</td>
<td>415 V, 10kW, 1kVAR</td>
</tr>
<tr>
<td>Frequency</td>
<td>50 Hz</td>
<td>Load2</td>
</tr>
<tr>
<td>MVA rating</td>
<td>10</td>
<td>Resistance 0.1153Ω</td>
</tr>
<tr>
<td>Transformer Details</td>
<td>Wind Turbine Details</td>
<td>PV System Details</td>
</tr>
<tr>
<td>Transformer1</td>
<td>10 MVA, 11kV/33kV, 50Hz</td>
<td>MVA rating 1.5</td>
</tr>
<tr>
<td>Transformer2</td>
<td>10 MVA, 33kV/11kV, 50Hz</td>
<td>Voltage 415 V</td>
</tr>
<tr>
<td>Transformer3</td>
<td>10 MVA, 11kV/415V, 50Hz</td>
<td>Frequency 50 Hz</td>
</tr>
</tbody>
</table>

Here the circuit with generator, transformer, pi-section transmission line and loads are considered to be as grid. This simulation is carried out in 4 circuits. First circuit contains the simulation of grid integrated wind turbines. Second circuit carries simulation of grid integrated PV systems.

Third step discusses about simulation of grid integrated wind and PV systems without series and shunt active power filters. Last circuit deals with simulation of grid integrated wind turbines and PV systems with series and shunt active power filters. After completing the simulation of every circuit, FFT analysis is carried out on the Voltage waveform (only one phase voltage is shown) and THD value is compared for all the four cases.

Figure 5: Simulation Circuit for Grid Connected Wind Turbines
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Figure 6: Voltage Waveform Due to Grid Integration of DFIG

Figure 7: FFT Window for Voltage Waveform Due to Grid Integration of DFIG

Figure 8: Simulation Circuit for Grid Connected PV System
Figure 9: Voltage Waveform Due to Grid Integration of PV Systems

Figure 10: FFT Window for Voltage Waveform Due to Grid Integration of PV Systems

Figure 11: Simulation Circuit for Grid Connected Wind Energy and PV Systems

Figure 12: Voltage Waveform Due to Grid Integration of Wind Energy and PV Systems
Figure 13: FFT Window for Voltage Waveform Due to Grid Integration of Wind Energy and PV Systems

Figure 14: Simulation Circuit for Grid Connected Wind Turbines and PV Systems with UPQC

Figure 15: Voltage Waveform for Grid Connected Wind Turbines and PV Systems with UPQC
CONCLUSIONS

From the results of the 4 simulation circuits, harmonics are injected into the system increases when distributed generation is installed. These DG requires power electronic converter circuits for the grid integration. This circuits are liable for the injection of harmonics into the system. The series and shunt active power filters constituted in the UPQC can eliminate the harmonics and it is showed in the simulation results.

Table 2: Comparison of THD Values

<table>
<thead>
<tr>
<th>S. No</th>
<th>Integration with the Grid</th>
<th>Total Harmonic Distortion (THD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Only Wind energy system</td>
<td>1.14%</td>
</tr>
<tr>
<td>2</td>
<td>Only PV system</td>
<td>24.7%</td>
</tr>
<tr>
<td>3</td>
<td>Both PV and Wind energy system without UPQC</td>
<td>18.79%</td>
</tr>
<tr>
<td>4</td>
<td>Both PV and Wind energy system with UPQC</td>
<td>0.09%</td>
</tr>
</tbody>
</table>

REFERENCES


