PCS6000 STATCOM ancillary functions: Wind park resonance damping

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Abstract – This paper presents the basic functions of a medium voltage STATCOM used as an add-on for wind parks to comply with the applicable grid code. The theory of a control method for damping the resonance in a wind park is presented. Results from a 24 MVAr PCS 6000 STATCOM installed for a onshore wind park with more than two dozen multi-MW wind turbines underline the performance of the described control method in terms of damping the resonance.

Keywords - medium voltage STATCOM, voltage source converter, resonance damping, cable capacitance, grid code compliance, harmonics.

I. Introduction

The increasing penetration of renewable energy sources, like wind power generation, has forced grid operators to apply similar requirements as for conventional generating units. One requirement that certain wind turbine types can not inherently fulfill is to meet a given power factor or to continuously adjust the reactive power to the operating conditions with a certain dynamic.

There are several add-on solutions which can help a wind park to comply with these requirements, such as switched passive components, SVC's or STATCOMs. Each of them presents a different behavior in terms of reactive power resolution, response time and reactive current capability at low grid voltage.

In this paper, the basic mode of operation of a medium voltage PCS 6000 STATCOM based on a well proven NPC voltage source converter is presented. An additional benefit of this medium voltage STATCOM is that it is able to attenuate a resonance in the wind park. The behavior of the STATCOM for higher order frequencies is controlled by adjusting the output impedance of the STATCOM. The associated theory is presented in the paper.

II. Principle operation of a STATCOM

STATCOMs used in conjunction with wind parks are usually connected to the wind park MV grid, where they run in voltage control mode according to a U-Q characteristic specified by the grid operator.

A medium voltage STATCOM as presented here consists of a voltage source converter, connected to the grid through a transformer ([1]). This is represented in Figure 1, where U_C stands for the STATCOM VSC output voltage, U_t is the voltage across the transformer, U_G represents the grid voltage, and I_C is the output current of the STATCOM.

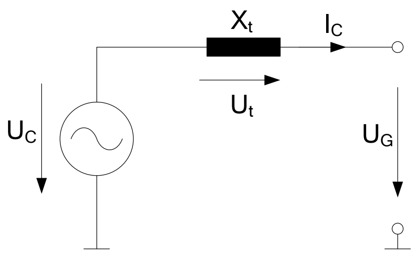

Figure 1 – STATCOM as a voltage source connected to the MV grid through a transformer

In theory, the STATCOM exchanges only reactive power with the grid. Therefore, the STATCOM converter output voltage is in phase with the grid voltage. The reactive power output of the STATCOM can be controlled by adjusting the converter output voltage amplitude (Figure 2): If the amplitude is lower than the grid voltage, the voltage across the transformer is in phase opposition to the grid voltage. Accordingly, the current leads the grid voltage. In that case, the STATCOM behaves like an inductor connected to the grid.

If the converter output voltage is higher than the grid voltage, the voltage across the transformer is in phase with the grid voltage (Figure 2). The output

current, in that case, is lagging the grid voltage. The STATCOM behaves like a capacitor.
In reality, there is always little active power exchange between the grid and the STATCOM, in order to cover the STATCOM losses.

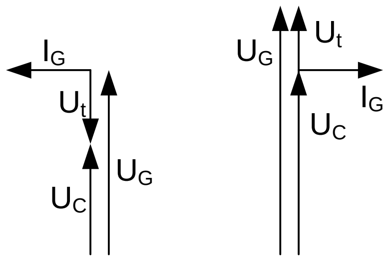

Figure 2 - Principle of operation of a VSC based STATCOM

The STATCOM presented in this paper is realized with a 3-level neutral point clamped (NPC) twin topology, using medium voltage IGCTs (Integrated Gate Commutated Thyristors). The 3-level NPC topology is presented in Figure 3.

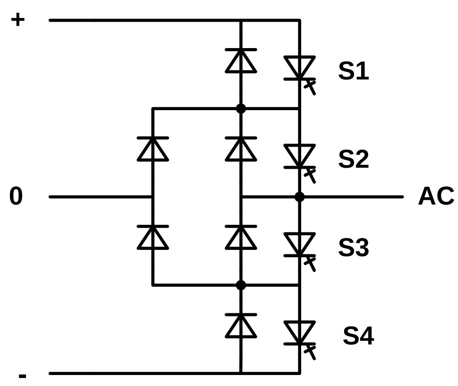

Figure 3 - 3-level NPC topology for one phase

In a twin topology, as shown in Figure 4, both ends of the converter side transformer winding are connected to a 3-level NPC converter output. In that way, the number of output voltage levels is increased.
More details and operational experiences about the PCS 6000 STATCOM are presented in [2].

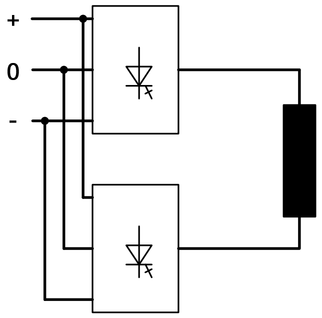

Figure 4 - Twin topology

III. Wind park layout

In the above mentioned wind park, the STATCOM is placed in the substation and connected to the MV distribution network. This is visualized in Figure 5.
The wind park is divided into three feeders. Each feeder is connected to the substation through a several kilometre long cable.

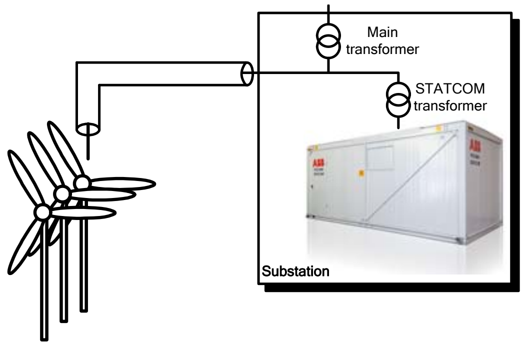

Figure 5 - Wind park and STATCOM

In each feeder, several turbines are connected in series, as shown in Figure 6.

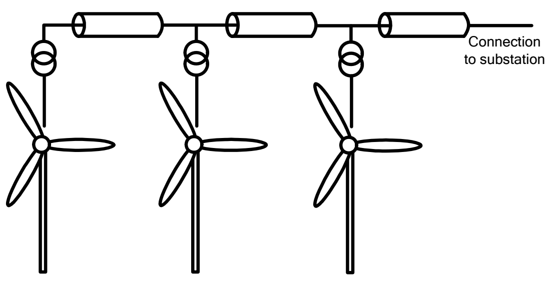

Figure 6 - Connection of wind turbines in a feeder

IV. Problem description

The increasing size of wind parks results in longer connecting cables and entails a larger total cable capacitance inside the wind park. The use of low loss cables with a small cable resistance reduces the damping performance. Combined with the main transformer impedance, the cable capacitance constitutes a circuit with a given resonance frequency (Figure 7). If that resonance is excited, either by harmonics coming from the grid, the wind turbines or the STATCOM, possible problems are non compliant with harmonic requirements, but can go up to disconnection of components due to overvoltage or overcurrent, resulting in the loss of generation. The problem can be solved with passive filters, which have to be dimensioned and usually take several months to be produced and installed.

In [3], it was observed that the resonance frequency of the cable capacitance and the main transformer lies around the 7th harmonic. This resulted in an amplification of 7th harmonic components coming from the grid.

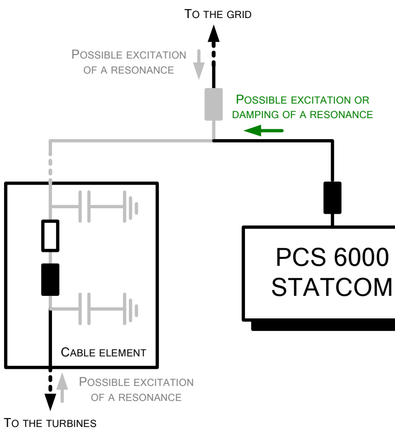

Figure 7 - Resonance between cable capacitances and the main transformer

In the wind park studied here, the resonant frequency, depending on the cable configuration, lies approximately between the 12th and the 35th harmonic and is poorly damped. Depending on the active power output of the wind turbines, the voltage harmonic at the resonant frequency can go up to 8% of nominal MV grid voltage. This activates the protection, and the turbines are disconnected from the grid.

The STATCOM, with a normal control strategy, can excite the resonance and activate an overcurrent protection. This phenomenon is studied in the following section.

V. Damping of the resonance

A simplified control structure is shown in Figure 8. The STATCOM output current is controlled in a rotating orthogonal coordinate system. The STATCOM output current reference I_{Cref} is given by the reactive power the STATCOM has to inject as well as the active power required to cover the STATCOM losses. The difference between the reference current and the measured current is given as an input to the main current controller (S_C in Figure 8). L_t represents the inductance associated to the transformer short circuit voltage.

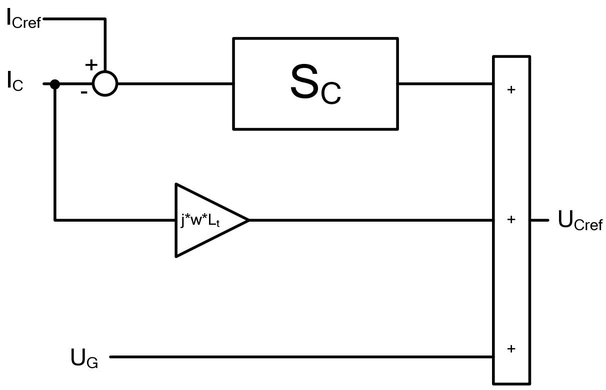

Figure 8 - STATCOM current control

The converter output voltage is, besides the current controller, also influenced by a current and a voltage feed forward. This enables the converter to react faster after a voltage or current disturbance.

The measurements of both current and voltage have a dead time and a phase shift. This delay is added to the modulation delay and results in a time lag at the converter output.

Depending on the frequency of the harmonic component, this delay manifests in a certain phase shift of the converter output voltage compared to the grid voltage. If the phase shift for a given frequency is between 90° and 270°, the signal is amplified. If the phase shift is between 270° and 90°, the signal is attenuated.

Another way to look at it is to examine the output impedance of the STATCOM. It is defined by the output current of the STATCOM divided by the voltage at the connection point of the STATCOM, according to Equation 1 (See Figure 1):

$$Z_{out} = \frac{U_G}{I_C} \qquad (1)$$

The output impedance is calculated, taking into account the controller, voltage and current feed forward, measurement delays and dead times, control delays, sampling times, modulation delays etc.

The STATCOM output impedance can be visualized on a complex plane (Figure 9). If the real part of the impedance is negative, the STATCOM absorbs energy from the grid. If the real part is positive however, it injects energy into the grid.

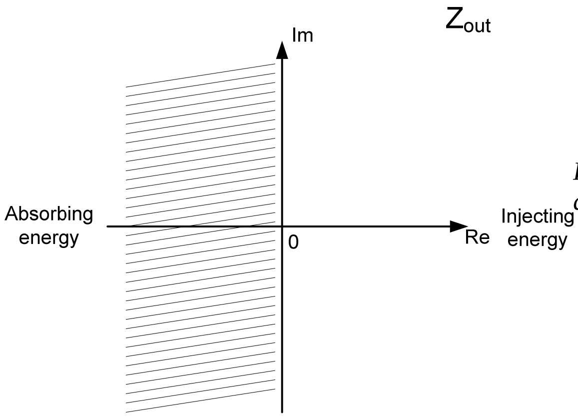

Figure 9 - STATCOM output impedance in the complex plane

Ideally, the STATCOM output impedance is on the left side of the complex plane for all frequencies. That would ensure that the STATCOM does not excite any resonance. However, it is difficult to force the output impedance into the left side of the complex plane over a wide range of frequencies. A certain delay might be small compared to the cycle period of a low frequency component; however it can be in the range of half a cycle period for a higher frequency component.

In the mentioned wind park, the resonance is between the 12th and the 35th harmonic. With a combination of discrete filters in the control loop, the gain and the phase shift for higher order frequencies is adjusted so that the output impedance is on the left half of the complex plane over the whole concerned range of harmonics. This modification is shown in Figure 10, where S_F is the transfer function of a certain discrete filter.

The output impedance of the PCS6000 STATCOM is shown in Figure 11. It is seen that the impedance for the higher order harmonics from 750Hz to 1000Hz is on the energy absorbing side of the complex plane.

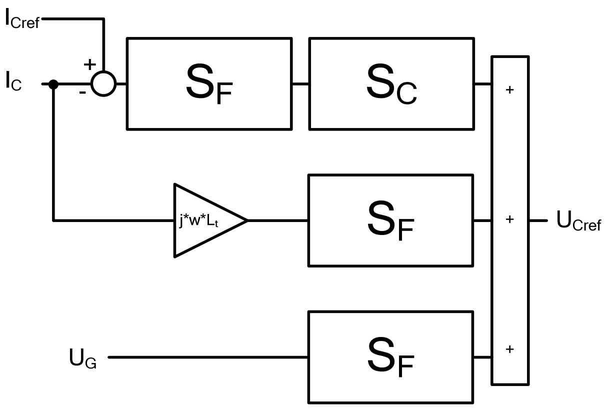

Figure 10 - Addition of discrete filters in the control and feed forward

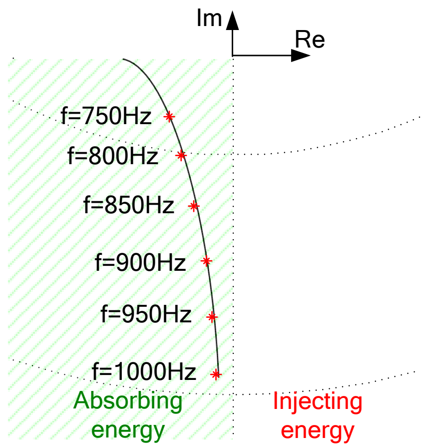

Figure 11 - STATCOM output impedance for higher order harmonics

As the STATCOM is not able to exchange active power except of the power needed to cover its losses, the energy absorbed increases the DC-link voltage. However, in order to mitigate the resonance, only a small amount of energy has to be absorbed.
When the DC-link voltage is increased, the DC-link voltage controller automatically changes the reference value for the active current and thus

injects the energy back into the grid at the fundamental grid frequency.

VI. Results

Figure 12 and Figure 13 show the time and the frequency domain voltage of the wind park medium voltage grid when the STATCOM is disconnected. It is seen that a dominating component around the 15th harmonic heavily distorts the voltage.

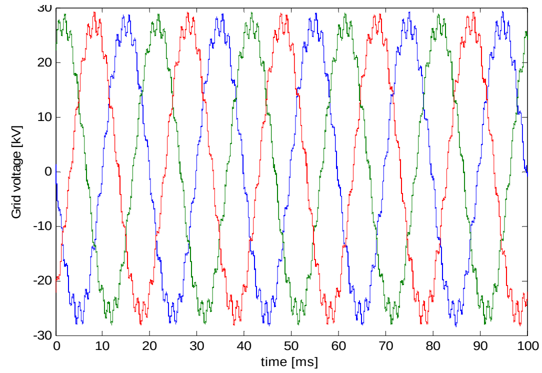

Figure 12 - Measured 33kV voltage when the STATCOM is not in operation

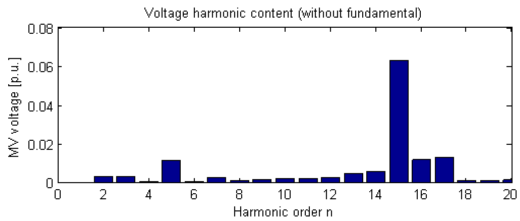

Figure 13 - Spectrum of the 33kV voltage when the STATCOM is not in operation

Figure 14 and Figure 15 show the voltage measured at the same point when the STATCOM is connected. It is observed that the dominating 15th harmonic component has completely vanished.

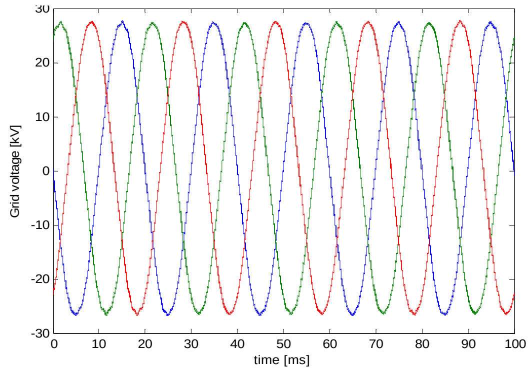

Figure 14 - Measured 33kV voltage when the STATCOM is in operation

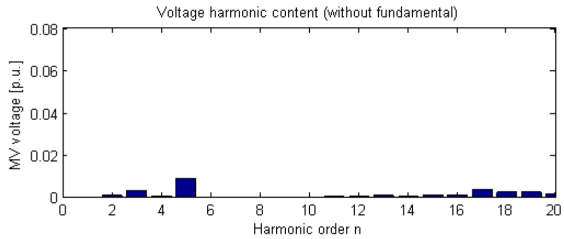

Figure 15 - Spectrum of the 33kV voltage when the STATCOM is in operation

Figure 16 shows the measured voltage at the STATCOM connection point. At t=20ms, the filters in the control and feed forward loop were bypassed for 10ms. It is seen that the resonance builds up immediately. However, after the filters are switched in again (at t=30ms), the resonance disappears.

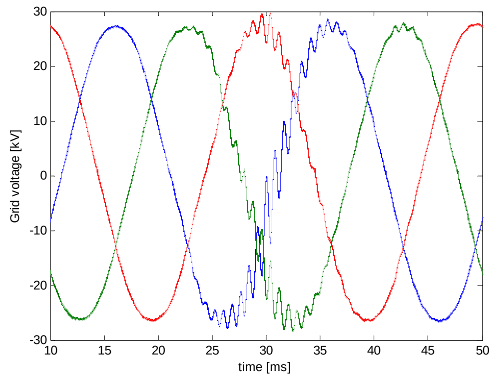

Figure 16 – Measured grid voltage when filters are bypassed for 10ms

VII. Conclusion

The basic function of a STATCOM for a wind park is to enable the park to comply with the grid code in terms of reactive power. It was shown that the PCS 6000 medium voltage STATCOM has a powerful control system which is also able to mitigate resonance problems in a wind park. Resonances in wind parks are currently a topic of interest, as the increase of cable capacitance in large wind parks brings down the resonance frequency.

A STATCOM which is able to mitigate resonance problems allows the wind park owner to run the wind farm on schedule, not having to wait for passive components which might solve the problem.

VIII. References

[1] Maibach Ph., Wernli J., Jones P., Obad M., STATCOM Technology for Wind Parks to Meet Grid Code Requirements, EWEC 2007

[2] Bagnall T., Thurnherr T., Wernli J., Maibach Ph., Obad M., Operational Experiences of STATCOMs for Wind Parks

[3] Plotkin J., Schulz D., Hanitsch R., Influence of Long High Voltage Cables on Total Harmonic Distortion of Currents in Wind Farms, IECON 2006, Paris, p. 4201-4206