$$\underline{u}^{\alpha\beta}(t) = \underline{e}_c^{\alpha\beta}(t) + R_f \underline{i}_f^{\alpha\beta}(t) + L_f \frac{d\underline{i}_f^{\alpha\beta}(t)}{dt} \qquad (7)$$

Where an underline denotes a complex space vector, e.g. $\underline{e}^{\alpha\beta} = e^{\alpha} + je^{\beta}$. The same notation is used for voltages, currents and other quantities.

Since the αβ frame is fixed, the vectors are AC quantities rotating with a frequency in the αβ frame. Moving into the dq-synchronous reference frame transform the vectors into DC quantities, hence, making it more simple to use PI-regulators. Figure 4.4 shows how the αβ and dq-frames are coupled. The transformation from the αβ frame to the dq-frame is given by

$$\begin{bmatrix} x^d \\ x^q \end{bmatrix} = \begin{bmatrix} \cos(\theta(t)) & -\sin(\theta(t)) \\ \sin(\theta(t)) & \cos(\theta(t)) \end{bmatrix} \begin{bmatrix} x^{\alpha} \\ x^{\beta} \end{bmatrix} \qquad (8)$$

Where θ(t) is the transformation angle given by the phase-locked-loop (PLL). The PLL is synchronized with the PCC such that, in steady state, the d-axis in the dq-frame is aligned with the voltage vector as showed in Figure 4.4. See Section 4.5 Synchronization System - PLL for an explanation of the structure of the PLL. Using (8), the system in (7) can be expressed in dq-quantities as

$$\underline{u}^{dq}(t) = \underline{e}_c^{dq}(t) + R_f \underline{i}_f^{dq}(t) + L_f \frac{d\underline{i}_f^{dq}(t)}{dt} + j\omega L_f \underline{i}_f^{dq}(t) \qquad (9)$$

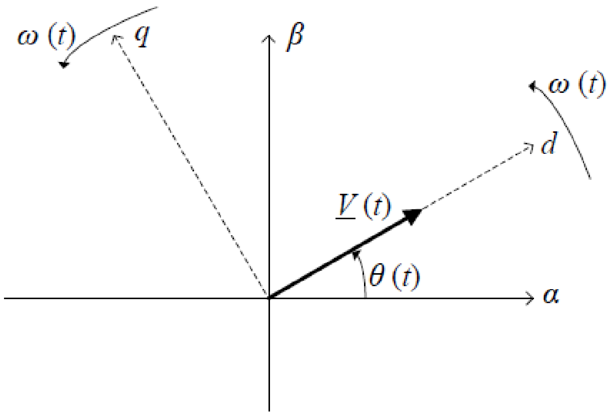
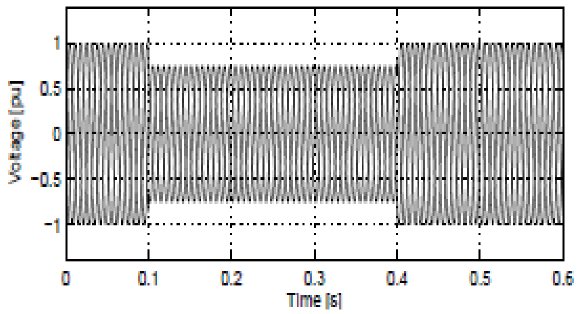


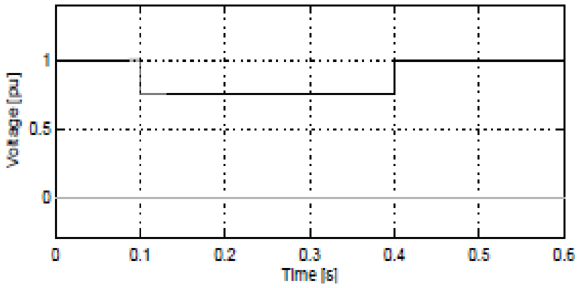
Figure 4: αβ and dq-frames

Since the d-axis, in steady state, is aligned with the voltage vector, the q-component of the voltage is equal to zero. This also means that the current vector easily can be split into an active and a reactive component. The d-component of the current vector, which in steady state is parallel to the voltage vector, therefore corresponds to the active component of the current (power). Also, the q-component of the current vector, which in steady state is perpendicular to the voltage vector, corresponds to the reactive component of the current (power). It should be noticed that, in agreement with Figure 3, a positive current (power) is injected into the grid by the VSC.

6. Result Analysis

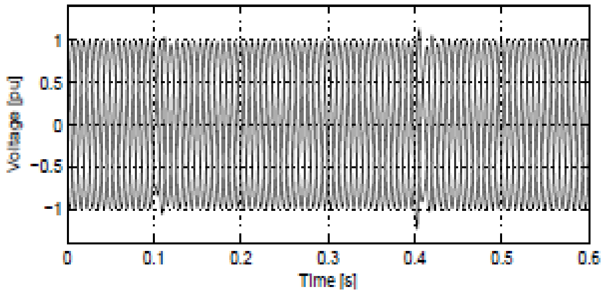


(5.a): three-phase components

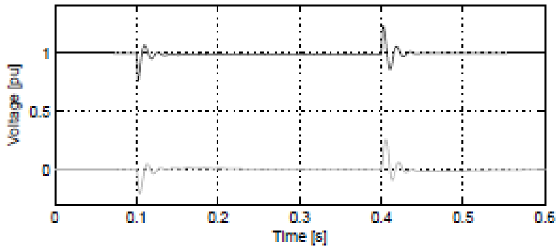


(5.b): dq-components, if the synchronization with respect to the source voltage.

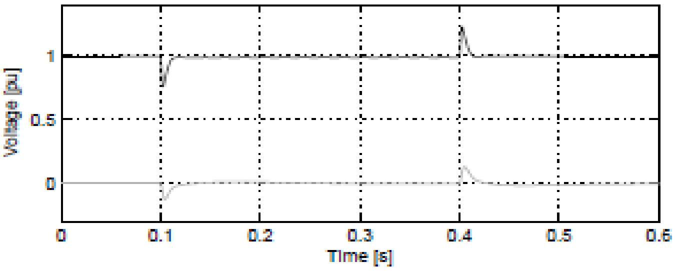
Figure 5: shows the voltage dip in both three-phase components and in dq components (synchronized with the source voltage).



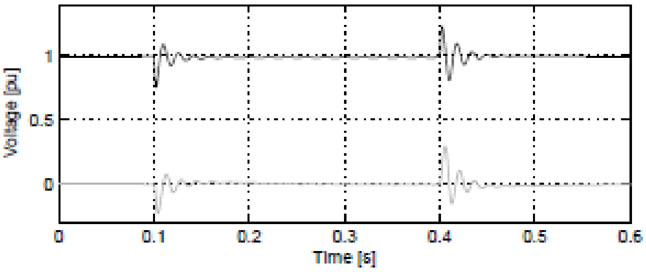
(6.a): three-phase components with $\omega_{cc} = 2\pi$ 1500 rad/s



(6.b): dq-components with $\omega_{cc} = 2\pi$ 1500 rad/s

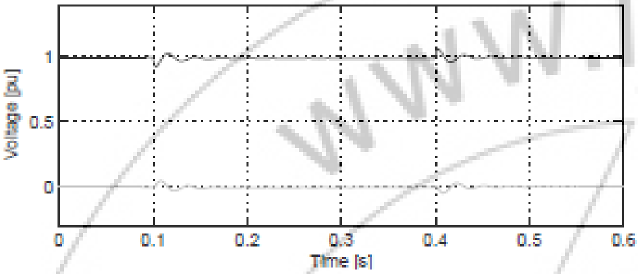


6.(c): dq- components with $\omega_{cc} = 2\pi$ 500 rad/s

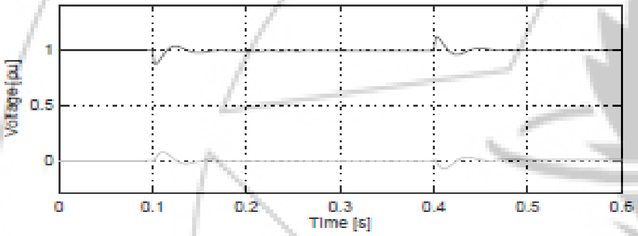


(6.d): dq-components with $\omega_{cc} = 2\pi2000$ rad/s.

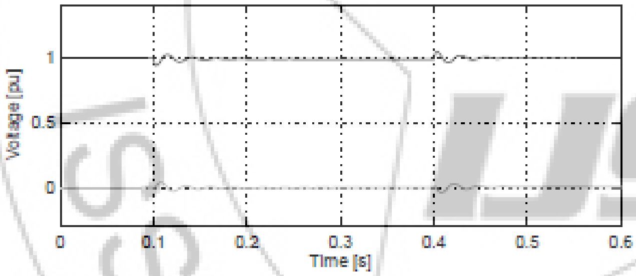
Figure 6: PCC voltage during a voltage dip using an D-STATCOM with different bandwidths in the VCC.



(7.a): $\omega_{cc} = 2\pi1500$ rad/s

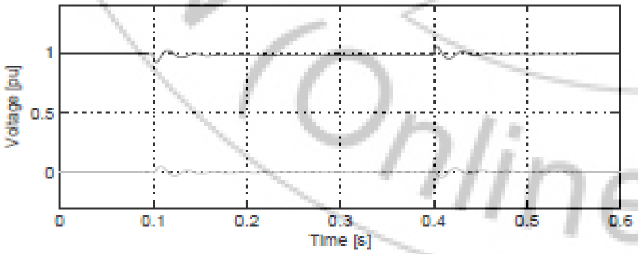


(7.b): $\omega_{cc} = 2\pi500$ rad/s

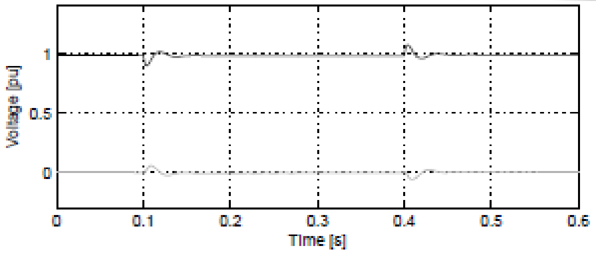


(7.c): $\omega_{cc} = 2\pi2000$ rad/s.

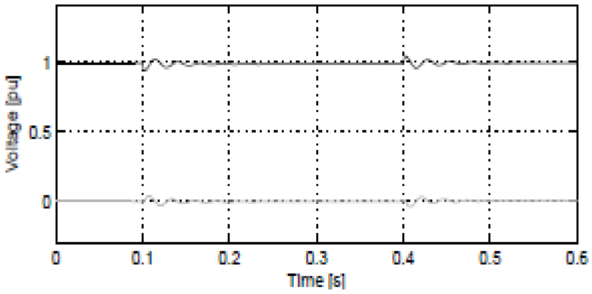
Figure 7: PCC voltage during a voltage dip using an E-STATCOM with different bandwidths in the VCC



(8.a):$\omega_{vc} = 2\pi100$ rad/s



(8.b): $\omega_{vc} = 2\pi50$ rad/s

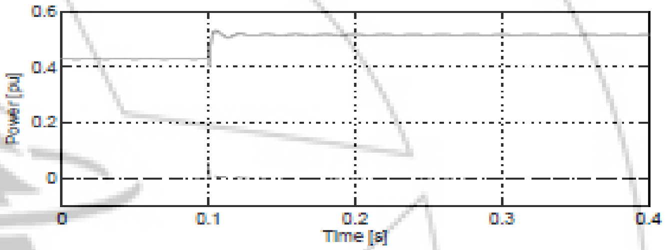


(8.c): $\omega_{vc} = 2\pi150$ rad/s

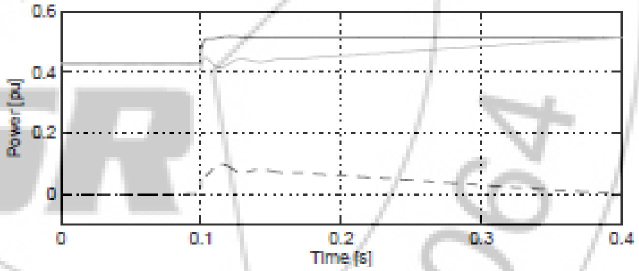
Figure 8: PCC voltage during a voltage dip using an E-STATCOM with different bandwidths in the VC.

6.1 Phase Jump Mitigation

From the simulations in Figure 6.6 (a,b,,C) it is shown that combined active and reactive power compensation completely can mitigate a voltage dip.



(9.a): D-STATCOM



(9.b): E-STATCOM.

Figure 9: combined active and reactive power compensation completely can mitigate a voltage dip.

7. Conclusion and Future Work

The most important FACTS controllers used on transmission level been described. Furthermore, the most common custom power devices used for power quality improvements on distribution level have been described. The energy storage applications been classified with respect to their required response times. A few applications which do not demand a particularly fast response have been described. Some storage mediums which potentially could be used in power quality application on distribution level have been covered. It should be stressed again that no specific storage type is considered in the rest of the project. And the structure of the control system for both a D-STATCOM and an E-STATCOM been presented. The inner vector current control loop and the outer voltage/reactive power control loop, respectively, have been derived. Furthermore, the structure of the PLL and the simplifications done in the derivation of the controllers has been treated. Finally, the system performance during a voltage dip has been studied with different controller settings.

Energy storage equipped STATCOMs are needed, been explained. It has been showed that an E-STATCOM can completely mitigated voltage dips and in particular the phase jumps associated with the dips. However, this only holds if the rating of the converter and the energy storage are large enough. Furthermore, it has been described how E-STATCOMs can be used to balance loads during line tripping.

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