International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Impact Factor (2012): 3.358

Mitigation of the Statcom with Energy Storage for Power Quality Improvement

Mohammed Shafiuddin[1], Mohammed Nazeeruddin[2]

[1]Royal institute of Engineering & Technology (Affliated to JNTUH), India

[2]Nawab Shah College of Engineering & Technology (Affliated to JNTUH), India

Abstract: ***One of the most interesting types of custom power devices, due to its exibility and fast control, is the shunt-connected voltage source converter (VSC), also known as the static synchronous compensator (STATCOM). This project deals with the control, performance and applications of STATCOMs equipped with energy storage for power quality improvements. The additional power quality applications, made possible by the energy storage which enables a STATCOM to support an entry into islanding operation, by rapid balancing of loads, after tripping of a single feeder. STATCOMs equipped with energy storages, due to the ability of controlling both active and reactive power, can keep the system performance practically unaffected during the same conditions. Simulation is done using MATLAB software***

Keywords: Voltage source converter (vsc), STATCOMs, Rapid Balancing, MATLAB software, Custom Power Device.

1. Introduction

In distribution systems, power electronic devices are getting more common. They are utilized both as interfaces in customer loads. The increased interest in power quality, a term which targets the quality of the voltages and currents, focused on distortions from ideal power supplies. With respect to power quality, power electronic based loads are, on one hand, more demanding than conventional loads. At the same time, these loads tend to pollute the power system with more power quality related issues, to overcome these issues the use of power electronic controllers are the best solution, One of the most popular controllers are the static synchronous compensator (STATCOM) which can be applied for many uses. However, by equipping STATCOMs with energy storages, additional applications can be obtained. Hence, there is a need for a study to determine the power quality applications and extra benefits that are gained by equipping STATCOMs with energy storages.

Furthermore, many studies so far have investigated isolated objects of the power system, with the aim to optimize the performance of that specific component. However, this approach does not always give a complete picture since an isolated model cannot show how deferent objects interact with each other in a combined system. This is particularly true when considering dynamics and transients, where almost no studies of system interaction exist. Due to this, dynamic interaction between parts in a power system is a fairly unknown phenomenon, although it can cause serious stability problems. To examine the performance of a complete system, all parts in a real system should ideally be included. However, to identify a phenomenon and analyze why it appears, the model has to be simplified in order to suppress all other effects than the ones investigated. Hence, a model is needed which includes all vital parts of a power system, but with each part simplified to an adequate level. Following the current trend with more power electronic based loads, which possess other dynamic properties than conventional loads, and with more frequent use of compensators like the STATCOM, it creates a need of a study that investigates the interaction between these objects and the impact this has on the performance of power systems.

2. Literature Survey

Power electronics (PE) are integral components of renewable and distributed energy (DE) systems. Successful Smart Grid implementation requires that electricity customers have the advanced technology tools and information needed to participate in the market. Developing interoperable, intelligent technology devices—such as advanced PE technology that will improve and accelerate the use of distributed energy resource (DER) systems is key to successful Smart Grid implementation. In addition to the common power conversion functions, the value of PE can be greatly enhanced by developing advanced control functionalities such improved power quality, voltage/volt-amperes reactive (VAR) support, reduced DE fault contributions, and flexible operation with various DE sources (Kroposki et al. 2006). Working with project partners (Northern Power Systems, GE, and the California Energy Commission), the National Renewable Energy Laboratory (NREL) is modeling, developing, and evaluating advanced power electronics topologies and controls to achieve PE systems that are reliable, energy efficient, and cost competitive. The main objective of this task was to develop and test advanced single-phase inverter controls that would allow DE systems to provide ancillary services such as power flow control and VAR/voltage regulation to the power distribution system. Fast prototyping techniques together with modular PE devices will lead to easier, low-cost implementation and prototyping of the DE interfaces.

In fiscal year 2007 (FY07), NREL developed a generic single-phase DC-AC inverter platform based on a Semikron SKAI module and an F2812 eZdsp controller and conducted some initial testing of the inverter platform (Chakraborty et al. 2007). Also in FY07, NREL developed electrical models for generic insulated-gate bipolar transistor (IGBT)-based interfaces that can be used across multiple DE platforms. Electric loads and electric system components were also modeled to complete the system. NREL then conducted validation testing to verify the electrical models of DE power electronic interfaces, electrical loads, and electrical power system (EPS) components (Chakraborty et al. 2007). In FY08, the laboratory inverter platform was modified and advanced control functionalities were developed, built, and tested using the inverter platform. These advanced PE interfaces can ensure that DE resources not only supply energy for critical site or building functions during a utility grid outage but also enhance power quality and grid support during other abnormal events. As part of the NREL work, researchers developed a simulation model. The model provides a platform for developing control methodologies of the various functions before they are implemented in the actual hardware. The inverter hardware was subjected to various transients to evaluate the system's dynamic performance and compared to the model results. Researchers identified differences between the tested and modeled system performance and the models were fine-tuned accordingly.

3. Methodologies

For renewable energy sources that generate direct current (DC) power, an inverter is required to convert DC into alternating current (AC) for utility connection and consumer use. For low voltage levels such as 120V AC/240V AC, single-phase inverters are very common and available from different manufacturers. These commercial inverters mainly work as a controlled current source when operating in the utility-connected mode. To implement and test new controls such as VAR/voltage regulation, and to increase grid reliability in the transition from grid-tied to islanded operation modes, NREL developed a single-phase inverter hardware platform as detailed in the previous report (Chakraborty et al. 2007). In the present modeling work, we used MathWorks' Simulink SimPowerSystems to model a single-phase inverter and test inverter control algorithms before actually implementing them in the hardware (MathWorks SimPowerSystems 2008). The parameters and simulation conditions for the model were carefully selected so that it accurately emulated the hardware. Also, the control designs were developed in such a way that they can be easily implemented in the hardware DSP platform. As one of the main goals for this research is to use new methods to implement flexible, easy-to-prototype controllers; Simulink was chosen since it presents unique capabilities for developing control algorithms, modeling power electronics, and implementing DSP codes under the same software platform.

4. Power Circuit

The power circuit for the complete inverter system is shown in Figure 1. The DC input stage of the inverter consists of a 300V DC source along with a small series resistance of 0.4Ω. This series resistance is required in order to facilitate convergence of the model in the Simulink environment. The power electronics devices are modeled based on the Semikron SKAI module parameters used in the hardware setup. The SKAI module consists of six IGBT switches along with 1mF of input capacitor. The output of the inverter is fed to the inductor-capacitor (LC) line filter. The series-connected, 0.5mH inductors and parallel, 40uF capacitors are used in order to achieve desired voltage and current ripple characteristics. The output of the inverter is a single-phase, 60 Hz, 120V AC rms waveform.

The test setup includes: the inverter; a 120V, 60Hz AC source that emulates the utility grid; and two sets of resistances representing the utility load and the local load. The inverter, utility, and the local loads are connected to each other through three single-phase breakers. When all three breakers are closed; the inverter operates in the utility-connected mode. In that scenario, both the inverter and utility provide power to the utility load and local load. To simulate islanded operation of the inverter, the utility breaker is opened and the other two breakers remain closed so that the inverter supplies power to the local load.

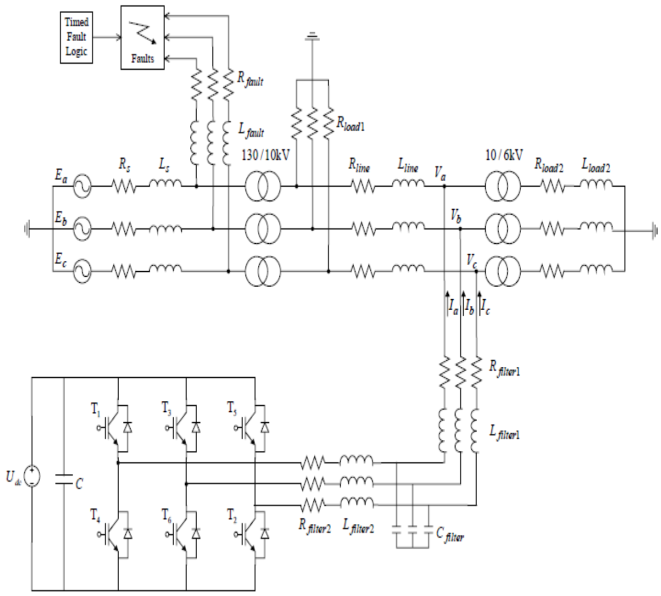


Figure 1

4.1 Basic Inverter Control

The basic inverter controls can be broadly classified into two types: current control and voltage control. When the inverter is connected to the utility, the grid controls the amplitude and frequency of the inverter output voltage and the inverter itself operates in the current control mode. Other types of inverter controls such as power flow control and VAR/voltage control can be derived from the basic current control. In contrast, in case of grid failure (grid faults, maintenance, etc.), the connected loads have to be supplied by the inverter. In such a scenario, which is often referred to as islanded operation, the inverter has to maintain the amplitude and the frequency of the voltage so that the connected loads are not affected by the utility interruption. The inverter operates in voltage control mode for such scenario providing the reference voltage and frequency.

4.2 Voltage Control

For the voltage control mode, the IGBT switches are controlled using bipolar pulse-width modulation (PWM) switching such that the inverter output voltage follows the reference voltage. The Simulink voltage control loop block diagram is shown in Figure 2. An external voltage signal with 120V AC, 60Hz is first fed into a discrete single-phase

phase-locked-loop (PLL). The gain at the input of PLL is used to normalize the actual voltage signal. The output of the PLL block generates a phase angle (tωθ=). The phase angle together with the AC voltage setpoint (Vac_set) is used to generate the reference voltage, V_ref. The PLL is necessary to make sure that when utility voltage is present, although inverter is operating in islanded mode, the inverter voltage is synchronized with the utility voltage.

5. Technique Used

5.1 Vector Current Controller

The key element in the investigated systems is the VSC and its main circuit scheme is shown in Figure 4.2. Pulse width modulation (PWM) technique is used to set the switching signals swa(t), swb (t) and swc (t) to ±1. If the switching signal for one phase is set to 1, the upper valve in that phase is turned on and the terminal voltage in that phase will be equal to udc(t) = 2. Opposite, if the switching signal is set to -1, the lower valve is turned on and the terminal voltage of that phase will be equal to udc (t) = 2. A blanking time is needed to avoid short-circuit of the VSC phase-legs. If the switching frequency is assumed to be very high, the VSC can be modelled as an ideal sinusoidal three-phase voltage source, thus, neglecting all switching harmonics. This is a useful approximation when the performance of the device is of interest and not its exact behavior.

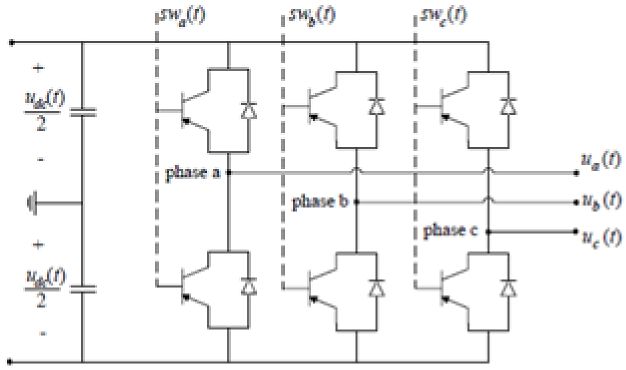


Figure 2: Three phase VSC

5.2 Electric System

Using Kirchhoff's voltage law (KVL) between the VSC terminals and the capacitors in Figure 3, the following differential equations can be obtained

$$u_a(t) = e_{c,a}(t) + R_f i_{f,a}(t) + L_f \frac{di_{f,a}(t)}{dt} \quad (1)$$

$$u_b(t) = e_{c,b}(t) + R_f i_{f,b}(t) + L_f \frac{di_{f,b}(t)}{dt} \quad (2)$$

$$u_c(t) = e_{c,c}(t) + R_f i_{f,c}(t) + L_f \frac{di_{f,c}(t)}{dt} \quad (3)$$

The three-phase equations of (4.1)-(4.3) can be transformed into a two phase stationary system using Clark's transformation. This fixed coordinate system is denoted the αβ system and a three-phase system can, assuming no zero sequence components, be transformed into the αβ system using the following (power invariant) transformation matrix

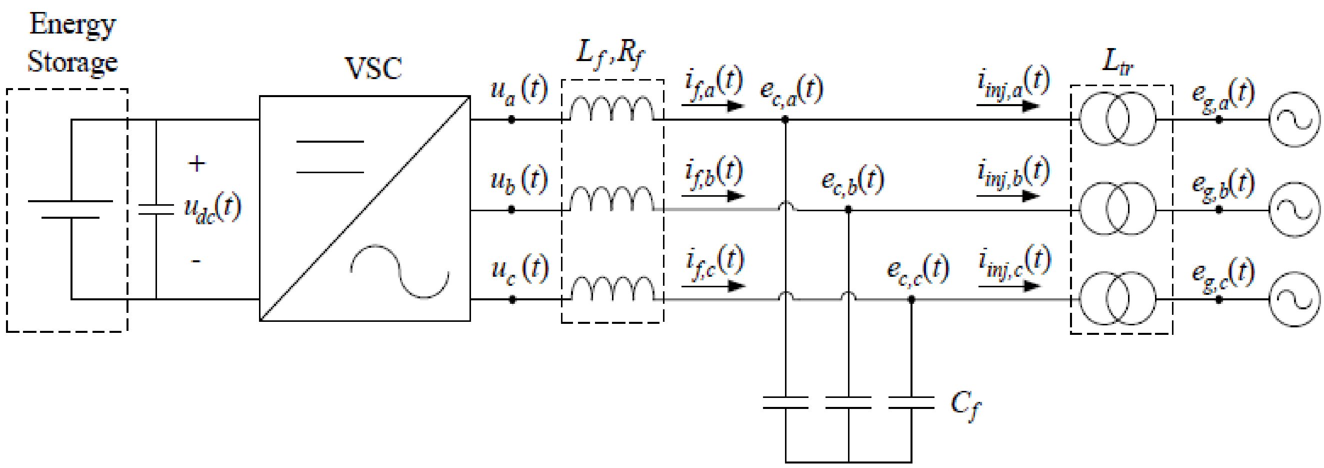


Figure 3: Three-phase VSC connected to the PCC through a LCL-filter. Phase system can, assuming no zero sequence components, be transformed into the αβ system using the following (powe invariant) transformation matrix

$$\begin{bmatrix} x^\alpha \\ x^\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} x_a \\ x_b \\ x_c \end{bmatrix} \quad (4)$$

A Transformation for Three-Phase Systems. Applying (4.4) to the three-phase equations in (4.1) (4.3), the differential equations can be rewritten as

$$u^\alpha(t) = e_c^\alpha(t) + R_f i_f^\alpha(t) + L_f \frac{di_f^\alpha(t)}{dt} \quad (5)$$

$$u^\beta(t) = e_c^\beta(t) + R_f i_f^\beta(t) + L_f \frac{di_f^\beta(t)}{dt} \quad (6)$$

Equations (5) and (6) can be combined and written in space vector form as

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

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

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

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

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

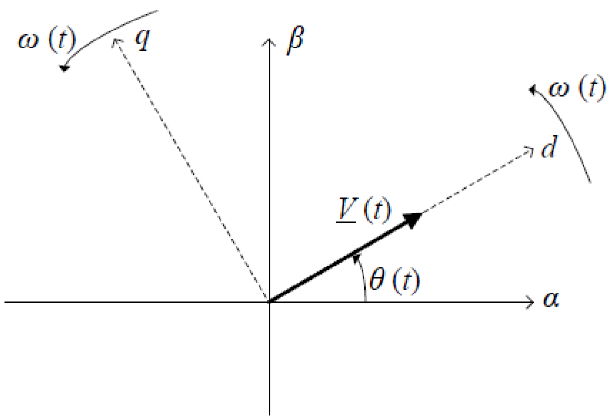
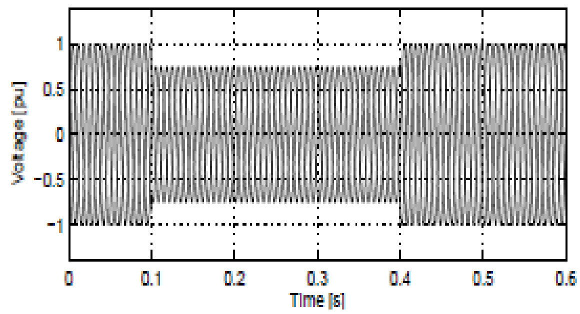


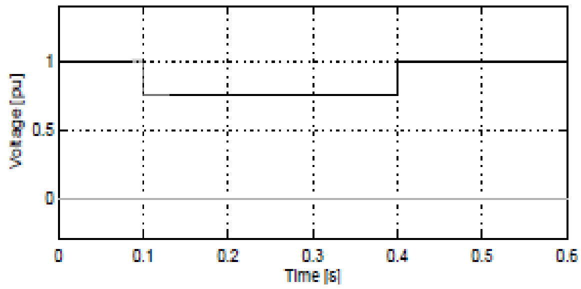
Figure 4: αβ and dq-frames

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

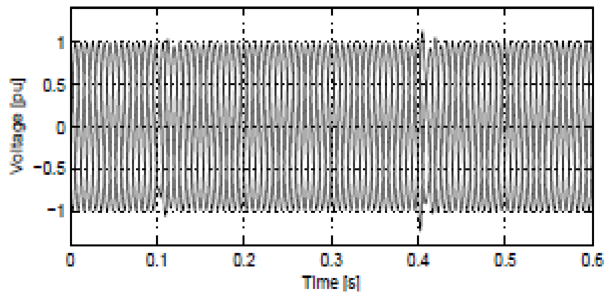


(5.a): three-phase components

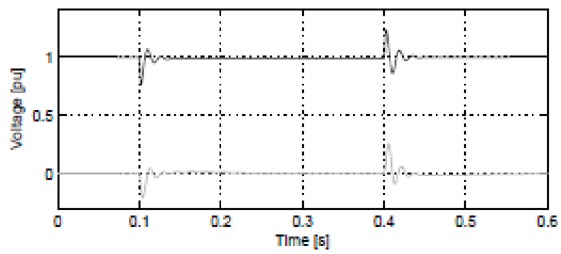


(5.b): dq-components, if the synchronization with respect to the source voltage.

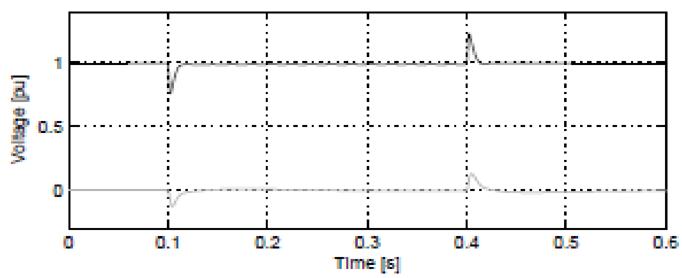
Figure 5: shows the voltage dip in both three-phase components and in dq components (synchronized with the source voltage).



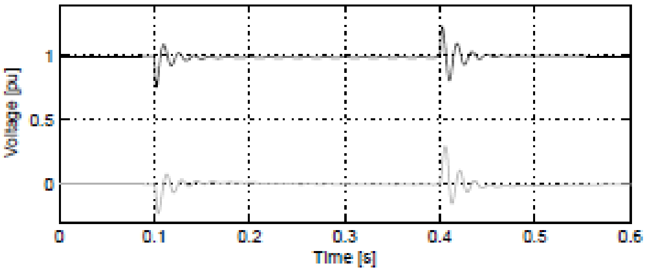
(6.a): three-phase components with $\omega_{cc} = 2\pi$ 1500 rad/s



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

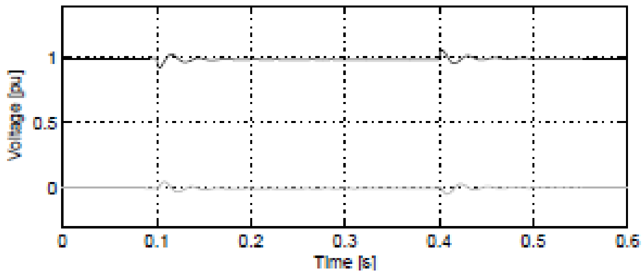


6.(c): dq- components with $\omega_{cc} = 2\pi$ 500 rad/s

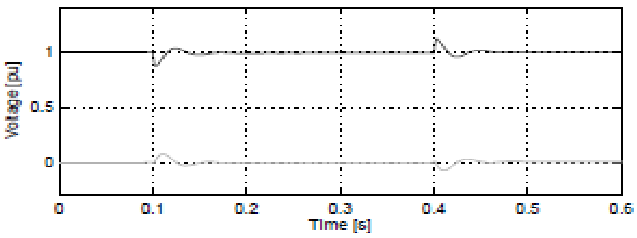


(6.d): dq-components with $\omega_{cc} = 2\pi 2000$ rad/s.

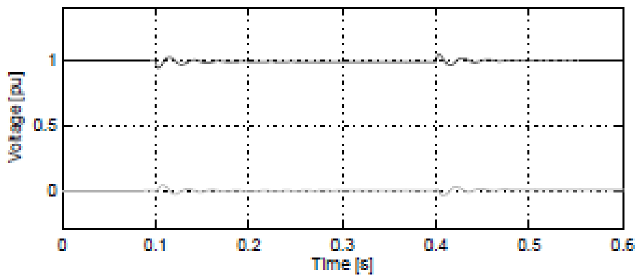
Figure 6: PCC voltage during a voltage dip using an D-STATCOM with different bandwidths in the VCC.



(7.a): $\omega_{cc} = 2\pi 1500$ rad/s

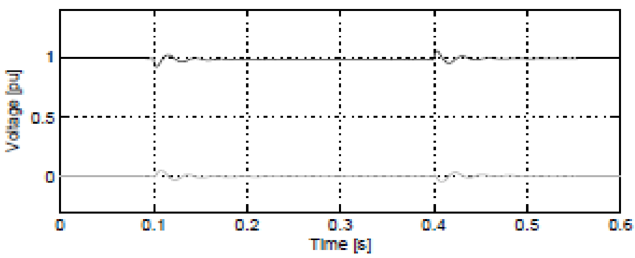


(7.b): $\omega_{cc} = 2\pi 500$ rad/s

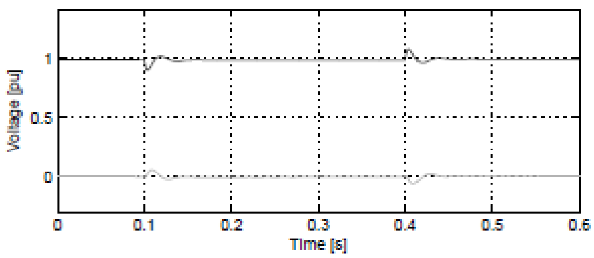


(7.c): $\omega_{cc} = 2\pi 2000$ rad/s.

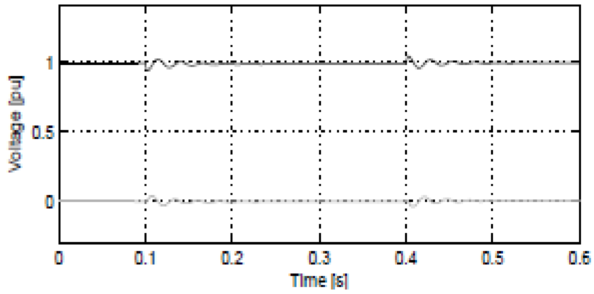
Figure 7: PCC voltage during a voltage dip using an E-STATCOM with different bandwidths in the VCC



(8.a):$\omega_{vc} = 2\pi 100$ rad/s



(8.b): $\omega_{vc} = 2\pi 50$ rad/s

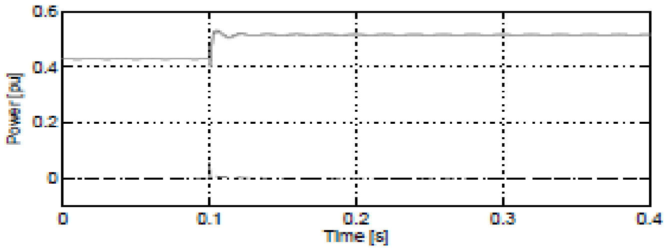


(8.c): $\omega_{vc} = 2\pi 150$ rad/s

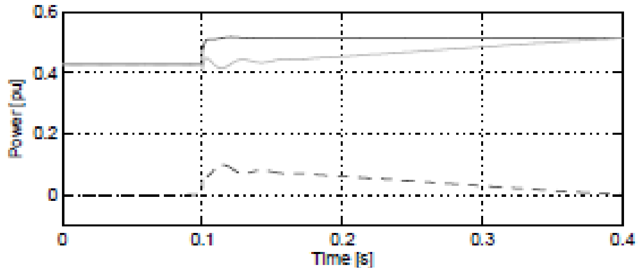
Figure 8: PCC voltage during a voltage dip using an E-STATCOM with different bandwidths in the VC.

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.

References

[1] M. Molinas. \The Role of Power Electronics in Distributed Systems". The 5th AIST Symposium on Distributed Energy Systems (2008).
[2] M. Molinas, D. Moltoni, G. Fascendini, J.A. Suul and T. Undeland. \Constant Power Loads in AC Distribution Systems: An investigation of stability Systems". IEEE International Symposium on Industrial Electronics (2008).
[3] A. Moreno-Munoz. Power Quality: Mitigation Technologies in a Distributed Environment. Springer, 2007.
[4] L. Gyugyi N. G. Hingorani and M. E. El-Hawary. Understanding FACTS: Concepts and Technology of Flexible AC Transmission Systems. IEEE Press, 2000.
[5] M. H. Nordlund. \Use of Energy-storage Equipped Shunt Compensator for Frequency Control". M.Sc. Thesis. Chalmers University of Technology, 2010.

Author Profile

Mohammed Shafiuddin received the M. Tech degree in EEE from Royal Institute College of Engineering.

Mohammed Nazeeruddin is persuing the M. Tech degree in EEE from Royal Institute College of Engineering working in Nawab Shah College of Engineering & Technology as an Assistant Professor in CSE dept.