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Enhancing of Power Quality Using a SPWM Voltage Source Converter

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ABSTRACT

Custom Power is the application of power electronics to improve the quality of power distribution for sensitive industrial plants. Industries reporting production stops due to voltage disturbances, like short interruptions and voltage dips. Power electronics converters connected in series or shunt with the grid and equipped with energy storage can provide protection against voltage disturbances. This work focuses on the Voltage Source Converter (VSC) connected in series with the grid for mitigation of voltage dips as well as swell. The core work is, the dual vector current controller provide the error voltage. By using the Pulse Width Modulation (PWM) it will generate the switching pulses to the voltage source converter which provide the mitigation for sag and swell. The controller consists of two loops as name as voltage control and vector current control loop. In this work PWM is used, and controllable series compensation is used for power quality improvement under sag and swell.

Keywords: Power Electronics, Power Quality, Current Controller, Voltage Dip (Sag, Swell), Voltage Source Converter, PWM.

INTRODUCTION

In the past, the interest of electricity customer was focused mainly on permanency of power supply, i.e. reliability of power supply, but its quality has not been adequately monitored. At present, it is paid more attention to the issue of power quality, because this issue is increasingly associated with economic impact on electricity suppliers and customers. It is important to differentiate between power supply reliability and its quality.[1]

Modern industrial processes are based on a large amount of electronic devices such as programmable logic controllers and adjustable speed drives. Unfortunately, electronic devices are sensitive to disturbances, and thus, industrial loads become less tolerant to power quality problems such as voltage dips, voltage swells, and harmonics.[2]

Voltage dips are considered the most severe disturbances to the industrial equipment. A paper machine can be affected by disturbances of only 10 percent voltage drop lasting for 100ms.Swells and over-voltages can cause overheating, tripping or even destruction of industrial equipment such as motor drives, surge arrestors and control relays.[3]

A Voltage Source Converter (VSC) is a power electronic device, which can generate a three-phase ac output voltage is controllable in phase and magnitude . These voltages are injected into the ac distribution system in order to maintain the load voltage at the desired voltage reference. VSCs are widely used in adjustable-speed drives, but can also be used to mitigate the voltage sags and swells. The VSC is used to either completely replacing the voltage or to inject the 'missing voltage'. The 'missing voltage' is the difference between the nominal voltage and the actual voltage. The converter is normally based on the some kind of energy storage, which will supply the converter with a dc voltage.[4][8]

Power Electronics and Advanced Control technologies have made it possible to mitigate power quality problems and maintain the operation of sensitive loads. Among power system disturbances, voltage dips, swells, and harmonics are some of the severe problems to the critical industrial loads. The Static Series Compensator (SSC) is best suited to protect such loads against those disturbances. This work focuses on the control of the SSC in order to improve the sag and swell under balanced conditions.[10]

To mitigate voltage dips, the work proposes a vector-controlled based algorithm to improve the transient and the steady-state responses of the SSC. The developed algorithm incorporates both current and voltage controllers with an inner current loop and outer voltage loop. Thus, it is referred to as the Dual Vector Current Controller.[3]

In this paper section 1 gives a review of sinusoidal Pulse Width Modulation (PWM) and section 2 gives a review of Static Series Compensator (SSC) and section 3 gives a review of Vector Current Controller (VCC) and section 4 gives a review of the algorithm of the Dual Vector Current Controller (DVCC) and section 5 gives a review of simulation results.

1. Sinusoidal Pulse Width Modulation (SPWM)

The Pulse Width Modulation (PWM) is a technique which is characterized by the generation of constant amplitude pulse by modulating the pulse duration. It requires the carrier signals that are feed into the comparator and based on some logical output, the final output is generated. The reference signal is the desired signal output maybe sinusoidal , while the carrier signal is triangular wave at a frequency significantly greater than the reference. The firing pulses are generated which are fed to switching device in Voltage Source Converter (VSC).[6][7]. Figure 1 shows the PWM method.

1.1 Features for comparing various PWM Techniques Switching Losses.

- Utilization of Dc power supply that is to deliver a higher output voltage with the same DC supply.
- Linearity in voltage and current control.
- Harmonics contents in the voltage and current.

2. Static Series Compensator (SSC)

The principle of operation of the series connected voltage source converter (also called static series compensator, SSC) will be described. The basic idea is to inject a voltage Ec(t) of desired amplitude, frequency and phase between the PCC and the load in series with the grid voltage. A typical configuration of the SSC is shown in Figure 2. The main components of the SSC are the VSC, the filter, the injection transformer and the energy storage. The SSC can be represented as a voltage source with controllable amplitude, phase and frequency.

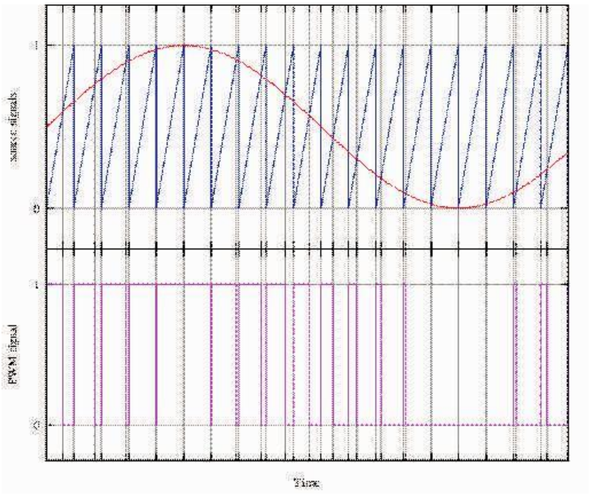

Figure 1. A simple method to generate the PWM pulse train corresponding to a given signal is the intersective PWM: the signal (here the red sinewave) is compared with a sawtooth waveform (blue). When the latter is less than the former, the PWM s ignal (magenta) is in high state (1). Otherwise it is in the low state (0)

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The SSC is mainly used for voltage dip mitigation. The device maintains the load voltage e1(t) to the pre fault condition by injecting a voltage of appropriate amplitude and phase.[3][11]

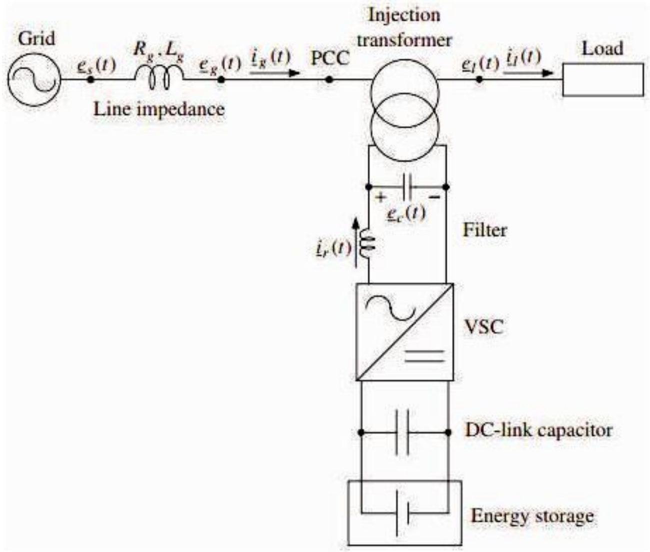

Figure 2. Single-Line diagram of SSC

3. Vector Current- Controller (VCC)

To obtain a high performance system, it is important to maximize the current bandwidth of the VSC. In a vector current-control system, the active and reactive currents (as well as the active and reactive powers) can be controlled independently. As a result, a high-bandwidth controller with a low cross-coupling between the reference currents and the line-filter currents can be achieved.[3][9][12]

The VSC is the most important element in the design of the investigated system. Figure 3 shows the main circuit scheme of a three-phase VSC. The VSC is connected to a symmetric three-phase load with impedance R1+jwL1 and back emfs ea(t) and eb(t) and ec(t). The phase potential, phase voltages and the potential of the floating-star load are denoted by va(t), vb(t), vc(t), ua(t), ub(t), uc(t) and u0(t) respectively. The load currents in the three phase are denoted by ira(t), vrb(t), vrc(t) respectively. The values in the phase-legs of the VSC (usually insulated gate bipolar transistors, IGBTs) are controlled by the switching signals swa(t), swb(t) and swc(t). The switching signal can be equal to 1. When swa(t) is equal to ±1, the upper value in the phase a is turned on while the lower value in the same leg is off.

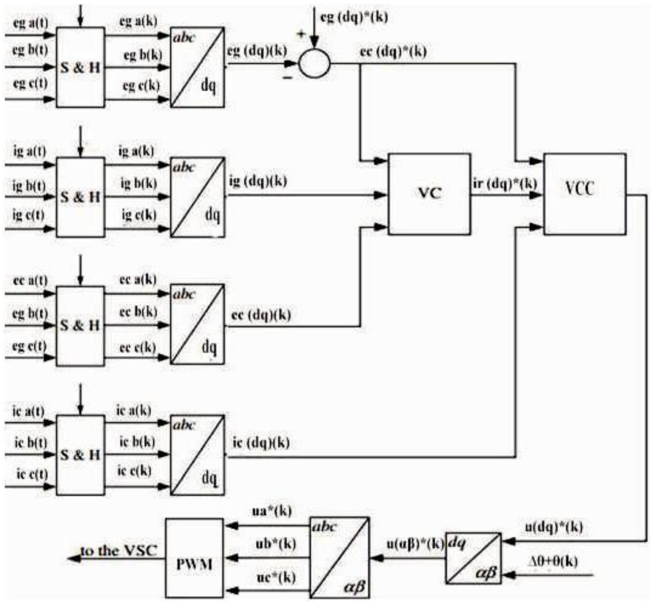

Figure 3. Block Diagram of Dual Vector Current Controller

Therefore, the potential va(t) is equal to half of the DC-link voltage udc(t)/2. Vice-versa, when the switching signal is equal to -1, the upper value is off and the lower one is on and thus va(t) is equal to -udc(t)/2. The potential v0(t) can be written as

$$v_0(t)=1/3\,(v_a(t)+v_b(t)+v_c(t)) \quad (1)$$

4. The Algorithm of The Dual Vector Current Controller

- Measure and sample the grid voltages, grid currents, filter currents and capacitor voltages with sampling frequency fs.
- Transform all three-phase quantities to the rotating dq-coordinate system, using the transformation angle, obtained from the PLL.
- Calculation of the reference filter current ir(dq)*(k) using the VC block.
- Calculation of the reference voltage u(dq)*(k) using the VCC1 block.
- Convert the reference voltages from the dq-coordinate system into the three-phase

voltages using the transformation angle □(k)+□□,where □□= 3/2wTs, explained.

- Calculate the duty-cycles in the PWM block and send the switching signals to the VSC values.[5]

4.1 Voltage Control Equations

$$\begin{aligned} i_{rd}^{*}(k) &= i_{gd}(k)\ \omega C/2\ (e_{cq}^{*}(k)+e_{cq}(k))+C/T_s \\ &\quad (e_{cd}^{*}(k)-e_{cd}(k)) \\ &= i_{ffd}(k)+k_{p,vc}\ (e_{cd}^{*}(k)-e_{cd}(k)) \end{aligned} \tag{2}$$

$$\begin{aligned} i_{rq}^{*}(k) &= i_{gq}(k)+\omega C/2\ (e_{cd}^{*}(k)+e_{cd}(k))+C/T_s \\ &\quad (e_{cq}^{*}(k)-e_{cq}(k)) \\ &= i_{ffq}(k)+k_{p,vc}\ (e_{cq}^{*}(k)-e_{cq}(k)) \end{aligned} \tag{3}$$

4.2 Vector Current Controller Equations:

$$\begin{aligned} u_d^{*}(k) &= e_{gd}(k)+R_r i_{rd}(k)- \\ &\quad \omega L_r/2\ (i_{rq}(k)+i_{rq}^{*}(k))+(L_r/T_s+R_r/2) \\ &\quad (i_{rd}^{*}(k)-i_{rd}(k)) \\ &= u_{ffd}(k)+k_p\ (i_{rd}^{*}(k)-i_r d(k)) \end{aligned} \tag{4}$$

$$\begin{aligned} u_q^{*}(k) &= e_{gq}(k)+R_r i_{rq}(k)+\omega L_r/2\ (i_{rd}(k)+i_{rd}^{*}(k))+ \\ &\quad (L_r/T_s+R_r/2)\ (i_{rq}^{*}(k)-i_{rq}(k)) \\ &= u_{ffq}(k)+k_p\ (i_{rq}^{*}(k)-i_r q(k)) \end{aligned} \tag{5}$$

5. Simulation Results

5.1 Design Parameters Table

	GRID PARAMETERS	
• Grid Voltage	E	400V
• Grid Current	I	25Amp
• Grid Frequency	F	50Hz
• Load Resistance	R1	10Ω
• Load Inductance	L1	23.9mH
• DC-Link Voltage	Udc	600V
	FILTER PARAMETERS	
• Filter Resistance	R_r	0.1Ω
• Filter Inductance	L_r	0.5mH
• Filter Capacitance	C_r	250uF

Table 1. Grid Parameters and Filter Parameters

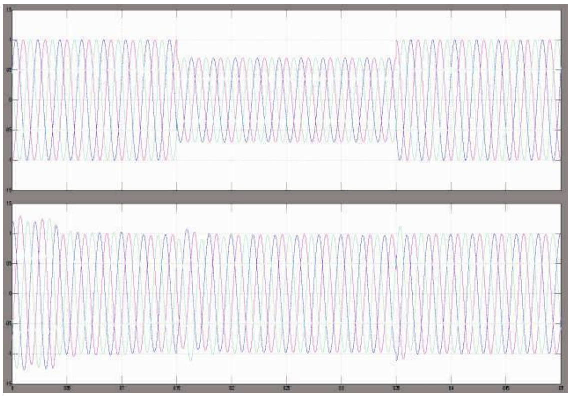

Figure 4. Simulated Response of Sag and improvement of Sag

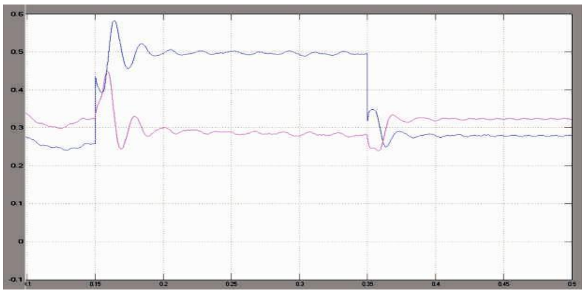

Figure 5. Simulated Response of current id and iq during sag condition in voltage controller block

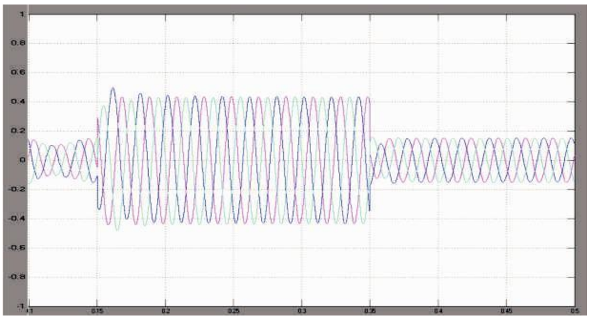

Figure 6. Simulated Response of Uabc during Sag condition

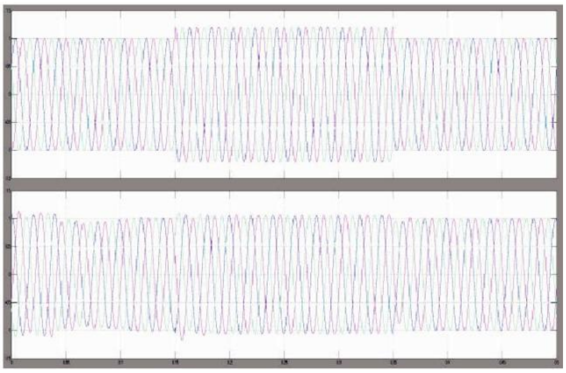

Figure 7. Simulated Response of Swell and Improvement of Swell

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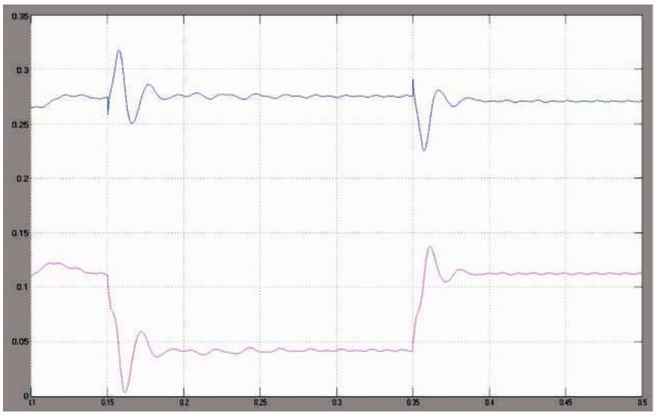

Figure 8. Simulated Response of current id and iq during Swell condition in voltage controller block

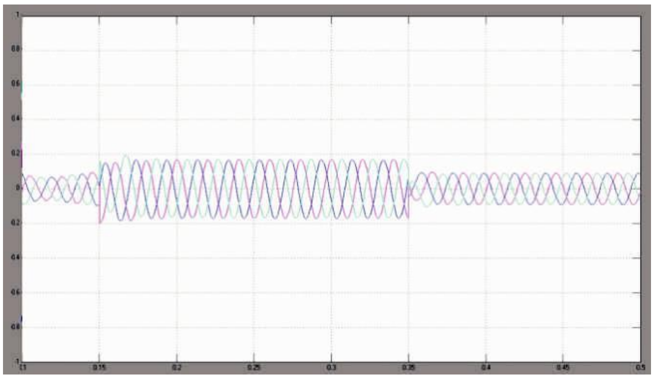

Figure 9. Simulated Response of Uabc during Swell condition

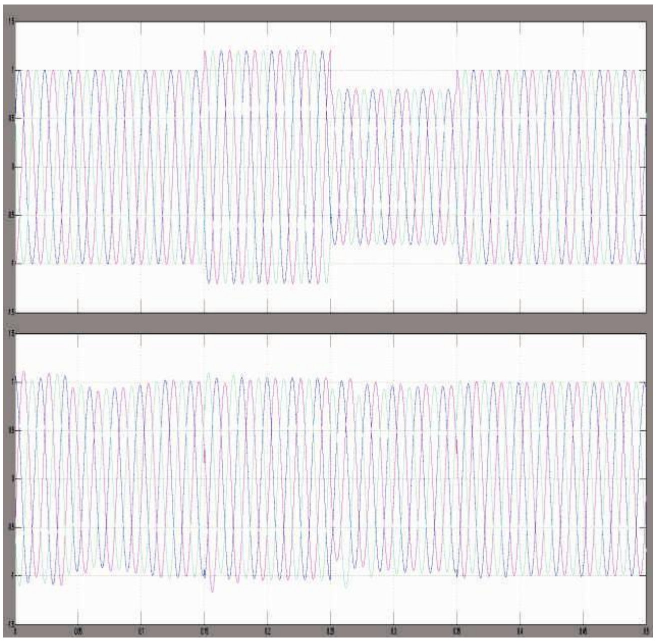

Figure 10. Simulated Response of Sag-Swell and Improvement of Sag-Swell

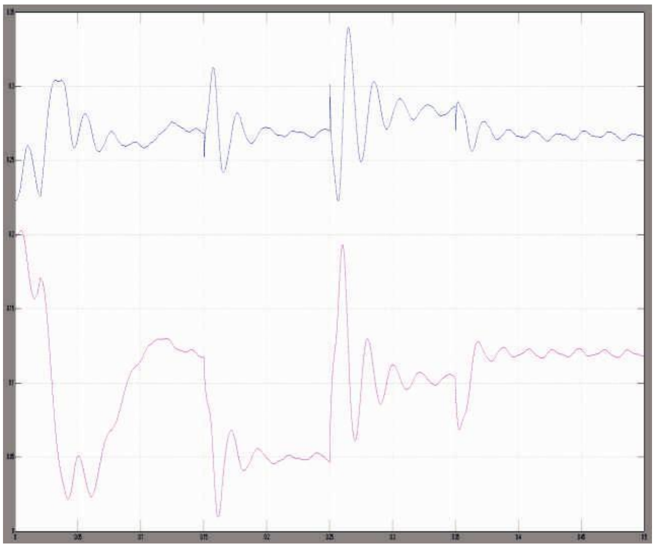

Figure 11. Simulated Response of d- and q-component of current of a Voltage Controller Block

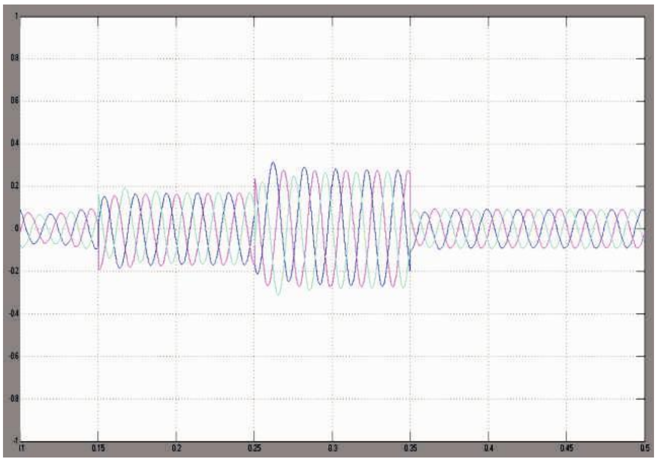

Figure 12. Simulated Response of Uabc during Sag-Swell condition

Conclusions

In this work the use of the series connected VSC for voltage dip and swell mitigation has been discussed. It has been shown that the VSC can maintain the magnitude of the grid voltage by injecting reactive power to compensate for the voltage dip and swell. However, it has been shown that this type of control system is very sensitive to system parameters variations. To obtain high performance and more robust controller, a configuration of series connected VSC with LC filter has be investigated. It has been controlled by outer voltage controller and inner current controller, a more robust controller can be obtained.

The resulting control system connected to PWM technique. Simulation results have shown that with the proposed control strategy satisfactory mitigation of balanced dip and swell can be achieved.

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