

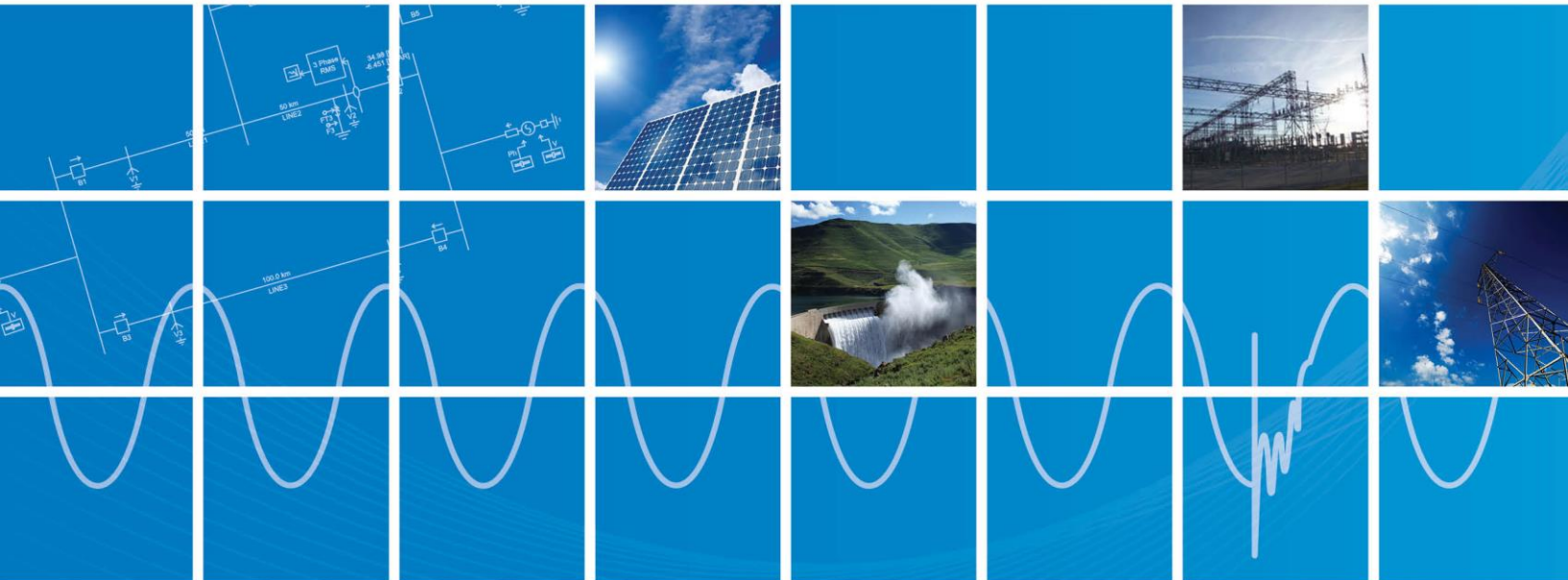


PSCAD Application Note

2-Quadrant AC-DC Conversion using VSC: The Active Rectifier Scheme

September 20, 2018

Revision 1





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1 Introduction

Bidirectional ac-dc conversion is applied when an ac system is linked to a dc system and needs to swap the role of source or load with the dc side; in other words, the direction of real power flow between the two systems may switch continually. Voltage-sourced converter (VSC) is one of the power electronics-based topologies employed in such applications. Variable-speed ac motor drives with energy-recovery regenerative braking¹, VSC-based HVDC transmission, FACTS devices such as STATCOMs², UPFCs, etc. are common examples of bidirectional ac-dc conversion. This application note explains this scheme through an example implemented in PSCAD™/EMTDC.

The converter links a 3-phase ac source to a dc load/source through a voltage-sourced converter (VSC). The VSC employs a voltage-sourced converter and

2 System Description

2.1 Power Circuit

Figure 2-1 illustrates the layout of the model in PSCAD™. The ac side of the converter is supplied by a voltage source 3-phase 208V 60Hz. The VSC comprises 6 IGBT-diode pairs, which form a 2-level 3-pole bridge, as shown in Figure 2-1. The electrical characteristics

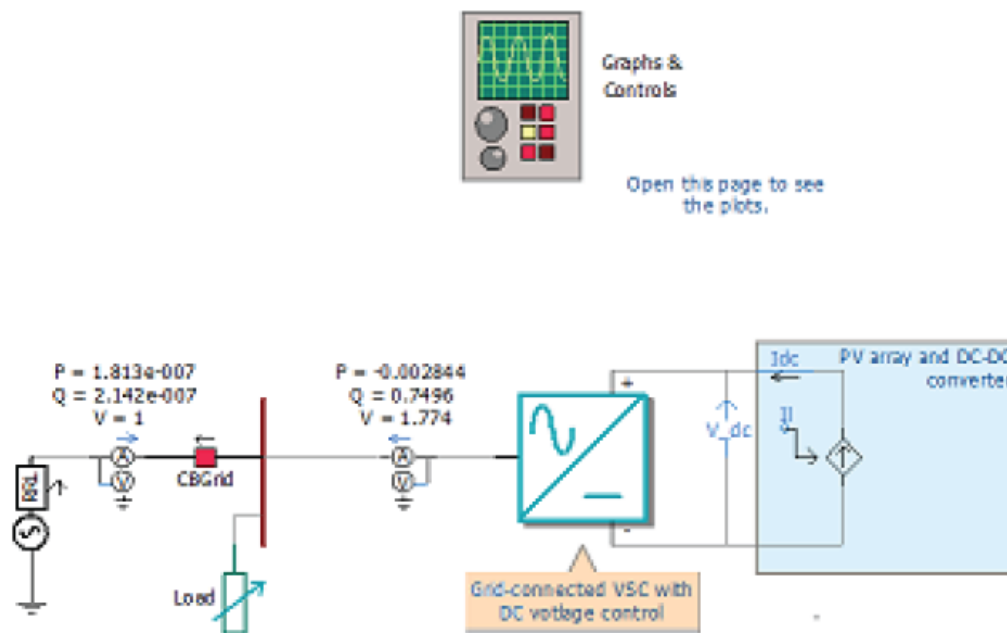


Figure 2-1: VSC-based ac-dc converter

- 1- In this type of regenerative braking, power is returned to the ac source through the braking period.
- 2- In a STATCOM, real power is exchanged between the ac and dc sides to regulate the dc-link voltage.

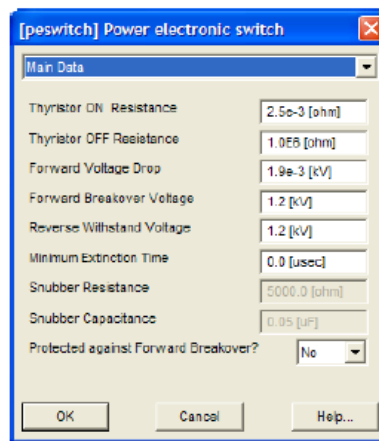
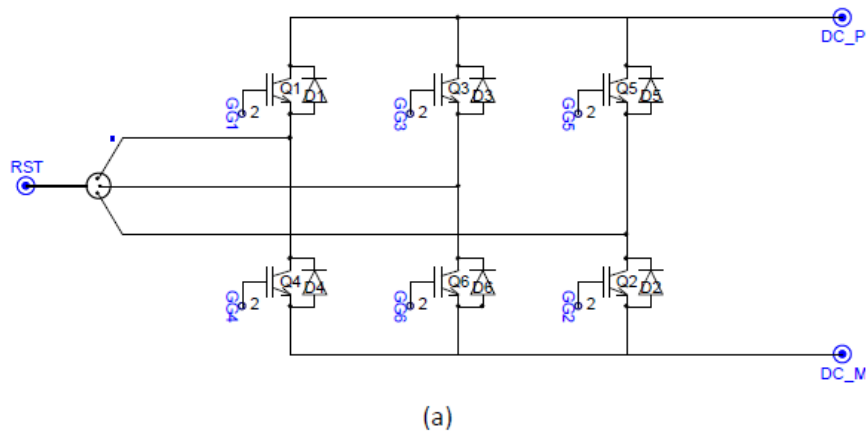


Figure 2-2: a) 3-pole IGBT-diode bridge; b) The electrical characteristics of the switching components.

The dependent current source at the dc side represents the dc system, which can either absorb or produce power, depending on the sign of the signal I_i .

Sinusoidal pulse-width modulation (SPWM) switching technique was chosen in this example. The carrier frequency has been set to 7kHz. Designed for a cutoff frequency of 1.55kHz, the low-pass LCL filter unit at the ac side of the VSC eliminates high-frequency switching disturbances from the 60-Hz current and voltage waveforms. Figure 2-3 displays the 3-line layout of the filter.

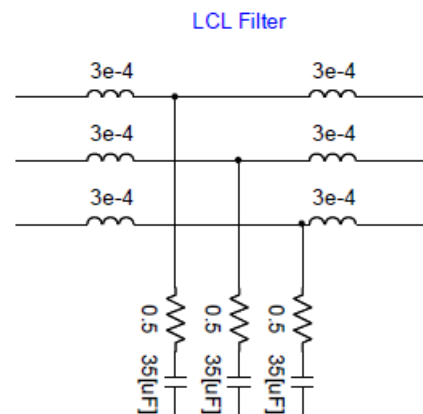


Figure 2-3: The LCL low-pass filter.

2.2 Control Algorithm

Vector control strategy is used in this example. In this technique, the ac current of the VSC is controlled to adjust active power exchange between the ac and dc sides, as well as the reactive power level at the ac terminals of the VSC [1]. The control system block diagram of the model can be found in the *Rectifier Control* function block in Figure 2-1.

The block diagram of the control strategy is presented in Figure 2-4-b. The ac current phasor of the VSC (I_C signal in Figure 2-1) is decomposed into direct (d) and quadrature components, which are in-phase with, and perpendicular to, the ac **phase** voltage E , respectively. The direct component of the ac current i_d regulates the active power transfer between the ac and dc sides. Hence, the dc-link voltage can be adjusted by controlling i_d . The reactive power level at the ac terminals of the VSC can be regulated by controlling of the quadrature component i_q .

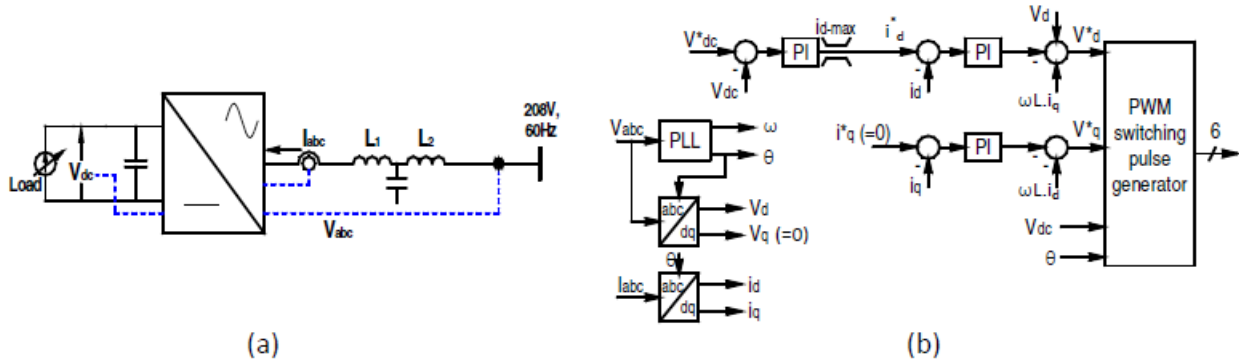


Figure 2-4: The current control strategy for the 2-quadrant VSC: a) The converter and the measured quantities; b) The control algorithm.

Decomposition of the ac current vector d and q components is carried out by applying the Park transform. The Park transform requires a reference phase angle to map 3-phase quantities onto the d-q coordinates. In this application, the ac phase voltage is chosen as the reference vector, whose phase angle information can be obtained using a phase-locked loop (PLL). Figure 2-5 shows the PLL block in PSCAD™. This block is available in [Master Library\CSMF](#).

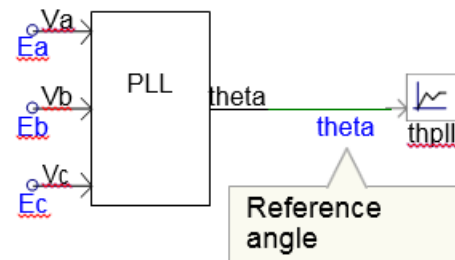


Figure 2-5: The PLL block in PSCAD™ extracts the phase angle information of the phase voltage vector.

The output of the PLL (i.e. $\angle E_a$) is applied to the Park transform blocks. The 3-phase ac currents are mapped onto the d-q reference frame as depicted in Figure 2-6. The function blocks shown in this figure are user-defined components and are provided in the attached library file [ABC_DQ_Transforms.psl'](#).

The three regulators in the control algorithm are implemented using PSCAD™ standard Master Library components, such as summation, PI controller, gain, etc. (see Figure 2-7). The Optimum Run feature of PSCAD/EMTDC can be employed to tune the parameters of the regulators.

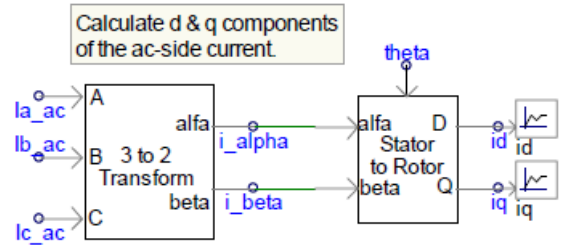


Figure 2-6: Park transform, applied to the VSC 3-phase currents

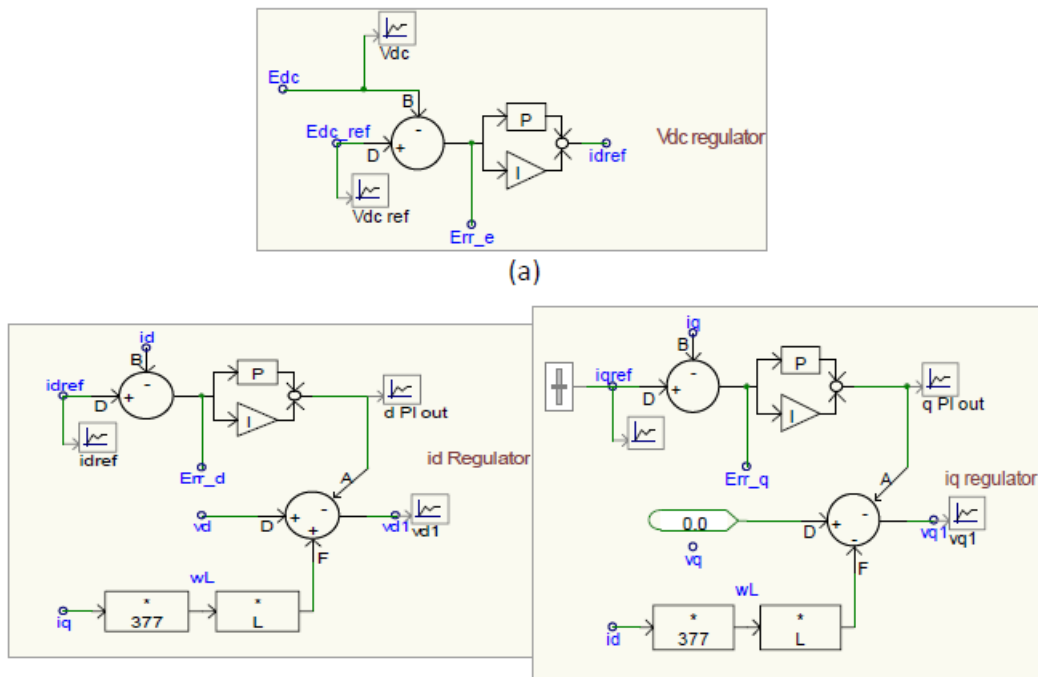


Figure 2-7: Three control loops of Figure 2-4, modeled in PSCAD.

The regulators provide the set points v_d^* and v_q^* . Modulation waveforms Ref_a, Ref_b and Ref_c are obtained by applying Inverse Park transform to v_d^* which are subsequently applied to inverse Park transform blocks to v_d^* and v_q^* , as depicted in Figure 2-8.

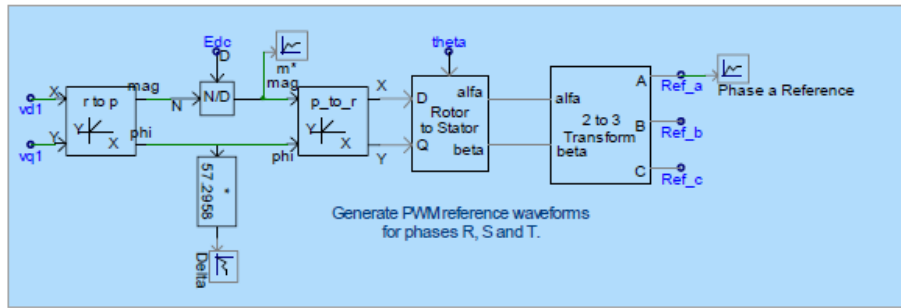


Figure 2-8: Generation of modulation waveforms

PWM switching pulses are produced by comparing the modulation waveforms (Ref_a, Ref_b and Ref_c in Figure 2-8) with a triangular carrier signal, through six ‘Interpolated Firing Pulses’ blocks, found in [Master Library/HVDC_FACTS_PE](#).

The ‘Variable-Frequency Saw-tooth Generator’ block (in [Master Library/CSMF](#)) produces the carrier signal.

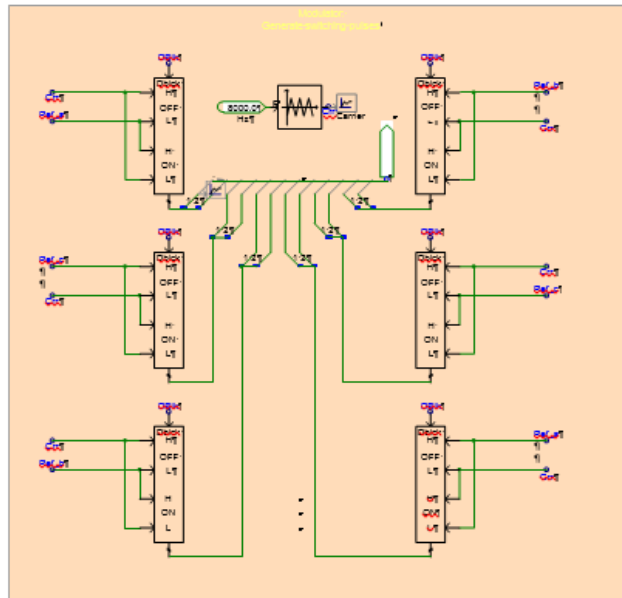


Figure 2-9: PWM switching pulse generation

Responses of the system to a few dc load disturbances are shown in Figure 2-10. In this simulation, the dc-link voltage has been set to 370V.

In Figure 2-10-a, the VSC starts and raises the dc voltage to 370V. In Figure 2-10-b, a 28A load is applied to the dc link. It can be observed that the converter’s control system restores the dc-link voltage. Similar response is presented in Figure 2-10-c, where the dc-side current switches from +28A to -28A, causing the VSC to transfer power from the dc link to the ac system. Again, one can notice that the dc-link voltage is maintained at 370V.

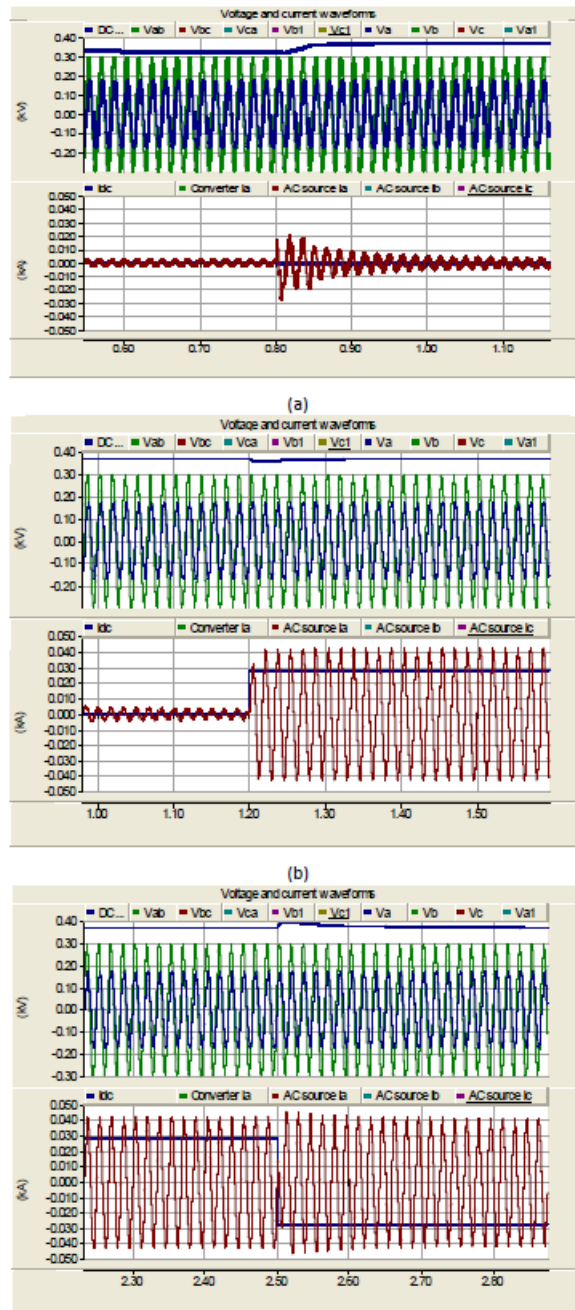


Figure 2-10: Response of the ac-dc converter to dc load disturbances.

a.) Startup: The dc voltage is adjusted to 370V;

b.) Response of the VSC to a +28A dc load;

c.) Response of the VSC to a -56A dc load disturbance



3 References

[1] R. Peña et al. 'Doubly Fed Induction Generator Using Back-to-Back PWM Converters and its Application to Variable-Speed Wind-Energy Generation', IEE Proc. Electrical Power Applications, Vol. 143, No. 3, May 1996, pp. 231-241.