VSC Control Strategy for Systems with high penetration of Power Electronic converters

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363

INTRODUCTION

- Electronic converters are acquiring every day a more important role in the electrical grid. Virtual Synchronous Machine (VSM) control strategies for Voltage Source Converters (VSC) appear as an effective method for both grid supporting and grid forming operations, facing many stability issues and providing virtual inertia to the power system.
- In this paper, a VSM control strategy for VSC using a reactive power synchronization loop is presented, which does not require the use of a PLL.
- The presented case studies which include a synchronous generator connected in parallel with the VSC will demonstrate the capability of the VSM control strategy to make a soft transition between grid supporting and grid forming operation mode.

VSC control

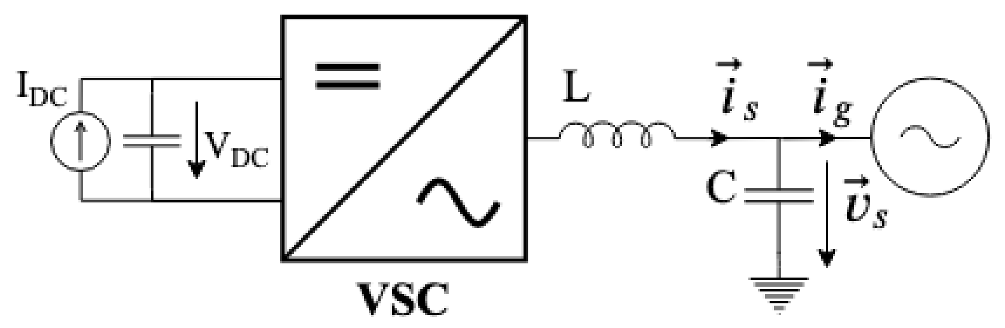

Figure 1: AC capacitor voltage control through VSC output current.

- According to Fig. 1, the following equations can be obtained for the dq components of the current i_g:

$$i_{ds} - i_{gs} = C\frac{dv_{ds}}{dt} - \omega C v_{qs} \qquad i_{qs} - i_{gq} = C\frac{dv_{qs}}{dt} + \omega C v_{ds} \qquad (1)$$

- From (1) it can be deducted that v_{ds} can be controlled by i_{ds} and v_{qs} can be controlled by i_{ds}. When $v_{qs} = 0$, the voltage frequency equals the reference frequency ω^*. When $v_{qs} = 0$ and $v_{ds} = v_s$:

$$P_s - P_g = C v_s \frac{dv_s}{dt} \qquad Q_g = Q_s + \omega C v_s^2 \qquad (2)$$

- Eq. (2) shows a relation between the active power flowing into the capacitor ($P_s - P_g$) and the voltage v_s; and between the reactive power ($Q_g - Q_s$) and the frequency of the system ω.

Reactive power synchronization

- This method is based on obtaining a frequency deviation, Δω, proportional to the reactive power deviation. With the frequency deviation obtained, the reference angle θ is given by:

$$\Delta\omega = k_Q\,(Q_s - Q_s^{ref}) \qquad \theta = \theta_0 + \int(\omega_0 + \Delta\omega)\,dt \qquad (3)$$

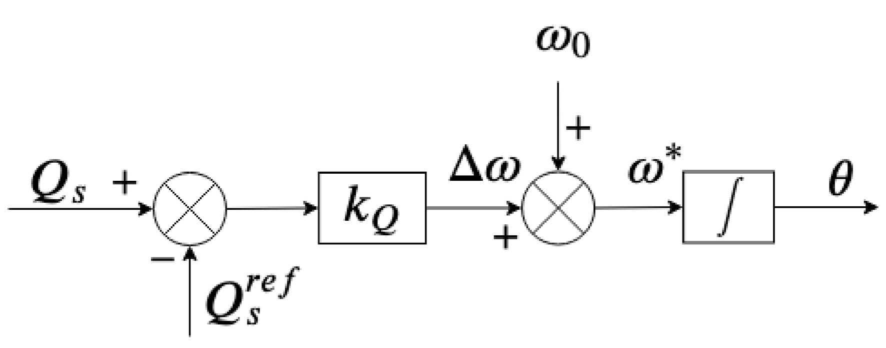

Figure 2: Reactive power synchronization control loop.

- Fig. 2 shows the reference angle θ calculation from $\Delta\omega$ using reactive power deviation with a droop constant k_Q, according to equation (3), which has been proven to be more stable than the active power synchronization, and it has better behavior than the widely used PLL synchronization methods.

Virtual Synchronous Machine

- Fig. 3 and Fig. 4 show the proposed control loops for obtaining the reference current i_s^* dq components, i_{ds}^* and i_{qs}^*. Standard current control loops will impose i_s^* at the converter output, avoiding overcurrent with a fast-dynamic response.

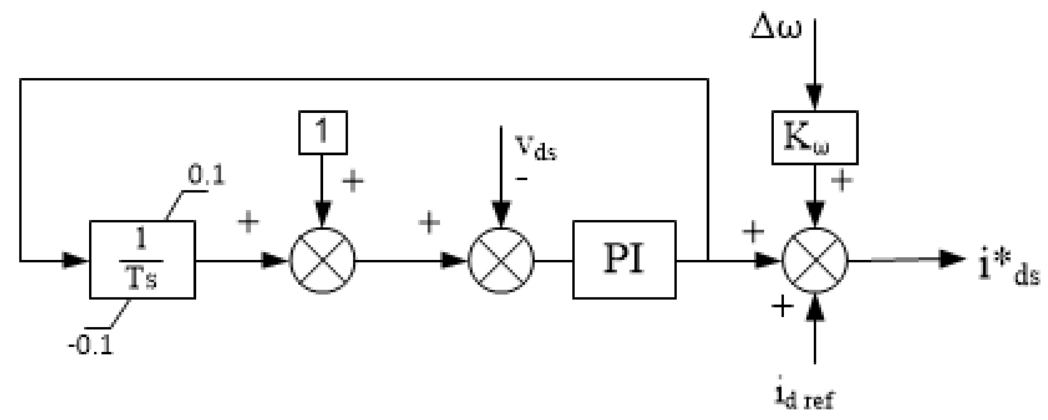

Figure 3: VSM reference current i_{ds}^* calculation.

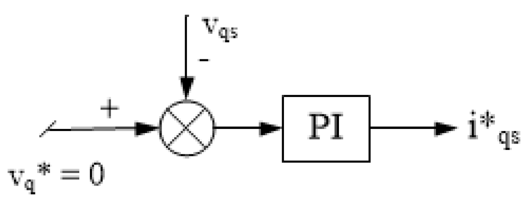

Figure 4: VSM reference current i_{qs}^* calculation.

Simulations and Discussion

A. Case Study I: VSM working as spinning reserve

For this case, only the load R_2 is connected. Starting when the the SG is fully supplying the load ($P_{GEN} \approx 150\ MW$) while the VSC is working as spinning reserve ($P_{VSC} \approx 0\ MW$).
The switch installed in the 220 kV bus bar at the SG transformer's output will open the circuit at T=10 seconds, disconnecting the SG from the system and leaving the VSC controlling an islanded grid.

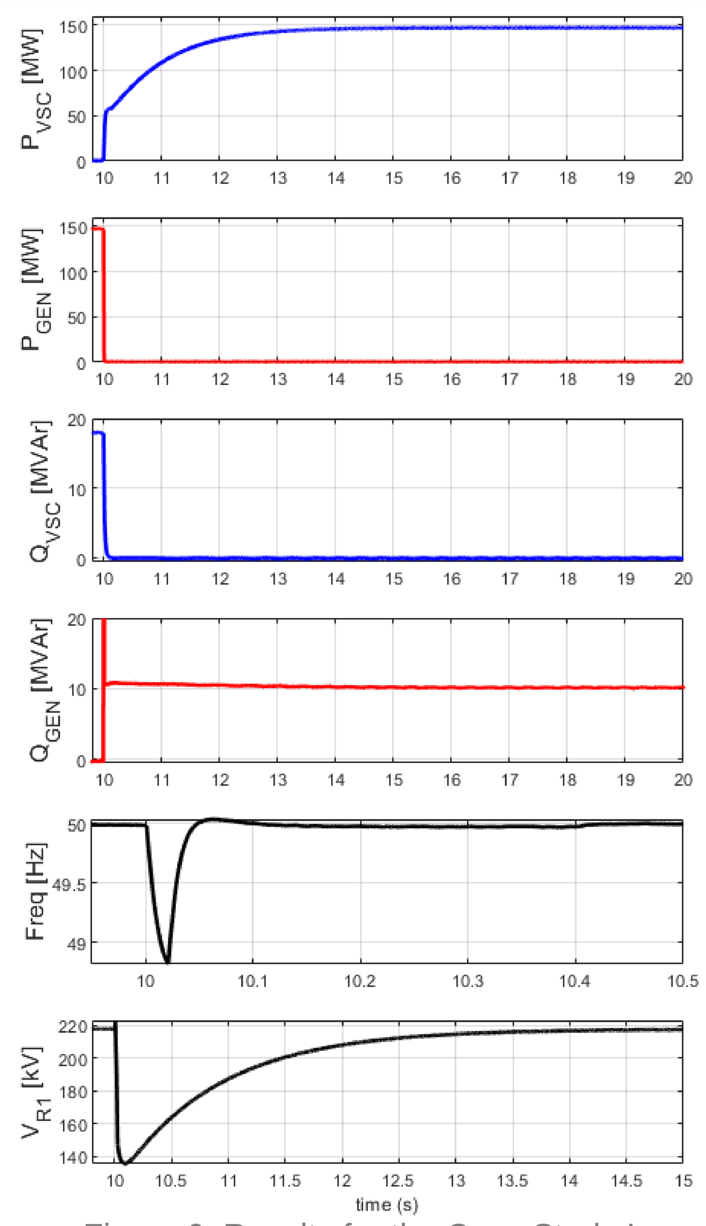

Figure 6: Results for the Case Study I.

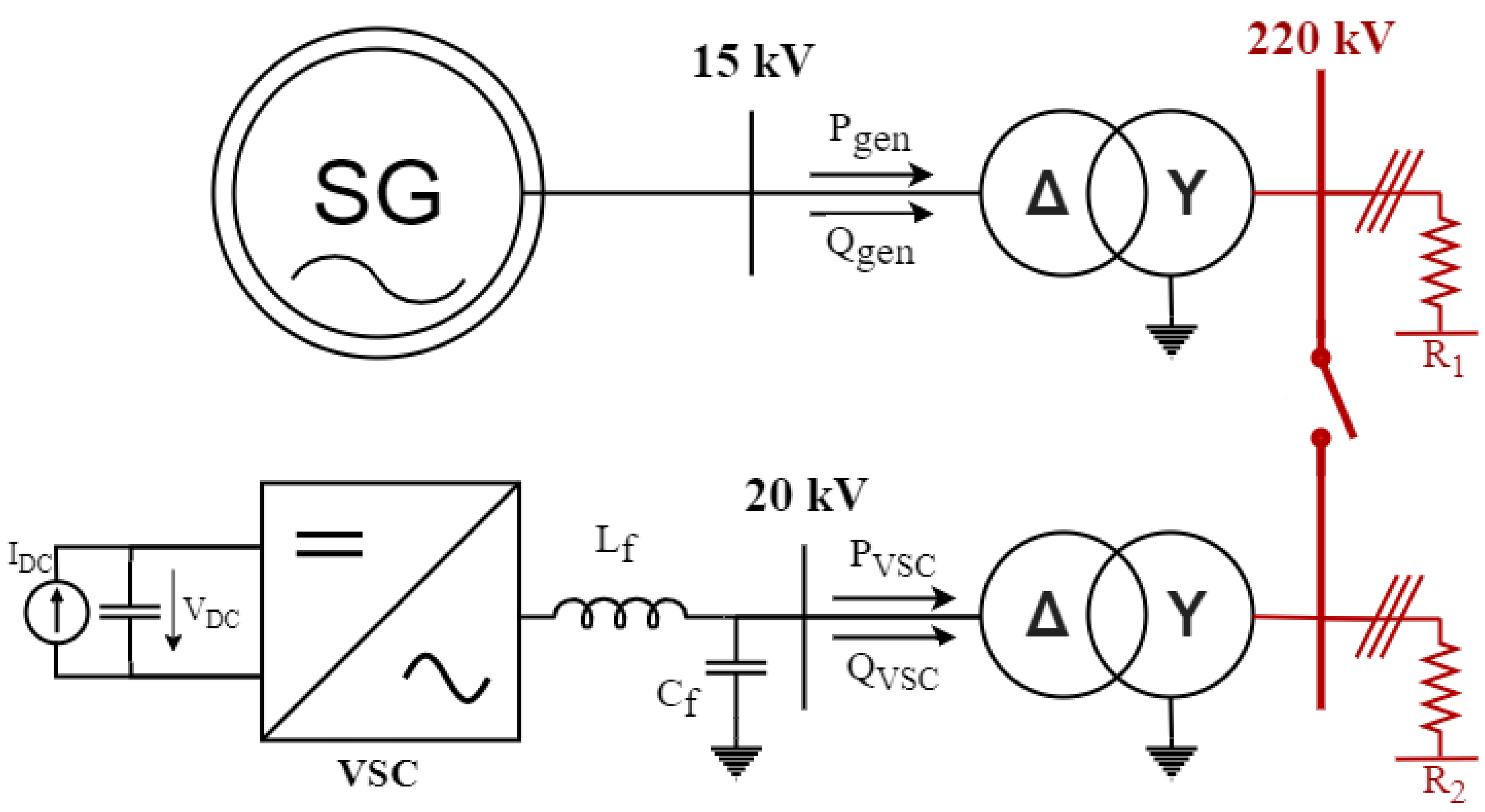

Figure 5: Description of the system implemented in case studies.

B. Case Study II: VSM feeding a local load

In this simulation two passive, purely resistive loads are connected to the 220 kV bus bar.
At the initial stationary state, the VSC is feeding partially its local load ($P_{VSC} = 100$) and the SG is supplying the rest of the total load ($P_{GEN} = 200$). At T=10 seconds, the switch at the 220 kV bus bar will open, so each generator will be left alone feeding a 150 MW load in an islanded system.

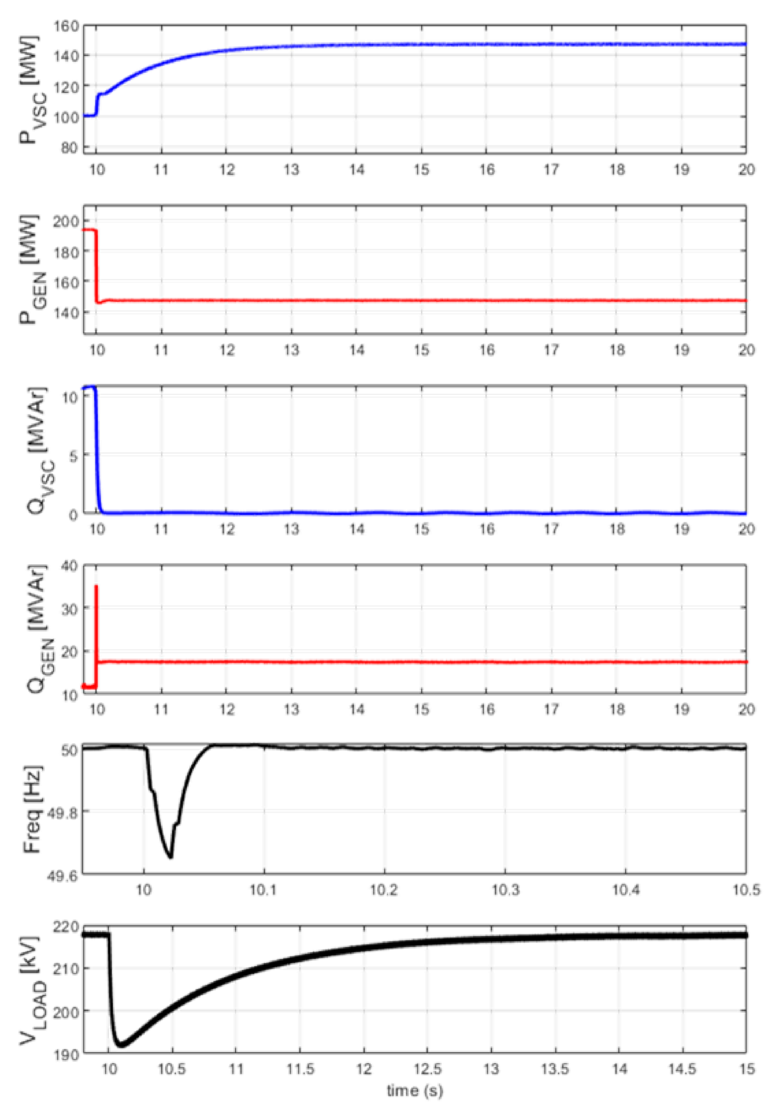

Figure 7: Results for the Case Study II.

Discussion of the results

- In both scenarios, one initially acting as a spinning reserve and the other one partially supplying a local load, the system shows a soft transition between grid supporting and grid forming mode, without changing its control strategy.
- While the frequency is driven back to its nominal value in a short period of time, the voltage level drops significantly (to 0.65pu in the first case and 0.85pu in the second scenario), caused by a sudden active power demand. However, the VSC can recover the stationary state.
- The reactive power behavior does not show any undesired transient behavior, reaching its nominal value right after the grid event. After the grid event the reactive power is fully controlled by the VSC and driven to its preset stationary value ($Q_s^{ref} = 0$ for all case studies).

CONCLUSIONS

- The converter recovers steady state conditions with a soft transition between grid-tied and grid forming modes without switching between control strategies.
- The VSC can maintain the nominal frequency in less than 100 ms, avoiding a black out in the system and acting as a spinning reserve with a virtual inertia.
- The VSM control strategy was proven to be stable operating in both grid-tied and grid forming modes.

Acknowledgement: This work has been supported by the Autonomous Community of Madrid under the PROMINT-CM project (P2018/EMT-4366).