Dynamic Performance of Voltage Oriented Control Method Applied in a Voltage Source Converter

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***Abstract*—The work focus the design of a Voltage Oriented Control method applied to a grid connected Voltage Source Converter. The laboratory implementation results show fast response time with small deviation under strong perturbations.**

***Index Terms*—Power Flow Control, AC/DC Power Source.**

I. INTRODUCTION

WIND is one of the most abundant renewable energy sources present in nature. Wind power systems solutions have been widely developed in recent years.

The most used power electronic solution to connect a wind turbine to the grid is composed by two Voltage Source Converters (VSC)in a back-to-back topology, sharing a common DC link, raising some challenges. The DC link voltage must be carefully regulated in order to have a robust and a high efficiency system in terms of operation.

Various VSC control methods have been proposed to balance the power flow from DC link to the Grid . The control methods can be classified as Voltage-based like Direct Power Control (DPC) and Voltage Oriented Control (VOC), as well as Flux-based algorithms, inspired by the motor control methods, like Virtual Flux Oriented Control (VFOC) and Virtual Flux-DPC (VF-DPC). The purpose of this paper is to model a VSC-VOC control method as well to experimentally study its dynamic performance.

II. VOLTAGE ORIENTED CONTROL USED IN THREE PHASE VOLTAGE SOURCE CONVERTER

A. Control method description

In VOC the VSC is modelled as a AC voltage controlled source (U_c). The principle of operation is explained by conecting the *VSC* to the grid via a line impedance (RL). If the voltage source is controlled either in amplitude or in phase, the active or reactive power flow to the grid is modified. Referring to figure 1, the converter voltage is fully defined by (1).

$$[u_{Cabc}] = R[i_{abc}] + L\frac{d[i_{abc}]}{dt} + [u_{Gabc}] \tag{1}$$

VOC for a grid-tied Pulse Width Modulation (PWM) converter is based on coordinate transformation between stationary three axis *abc* and synchronous rotating *dq* reference frames. The relationship (1) can be obtained in *dq* reference, by Clarke-Park transformation (2).

$$\begin{aligned} u_{Cd} &= Ri_d + L\frac{di_d}{dt} + u_{Gd} - \omega L i_q \\ u_{Cq} &= Ri_q + L\frac{di_q}{dt} + u_{Gq} + \omega L i_d \end{aligned} \tag{2}$$

The VOC scheme is shown in figure 1 and is characterized by having three control loops to control the grid power flow and the DC link voltage through the VSC.

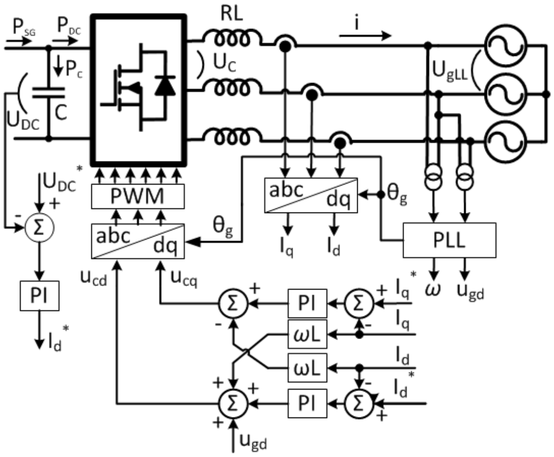

Fig. 1. Voltage Oriented Control scheme

Since the current control loops are decoupled, active (I_d) and reactive (I_q) component are independently managed [1]. In order to satisfy the current set points I_d^* and I_d^* imposed, the respective controllers change the *VSC* output voltage in order to reach the input reference.

The DC link voltage is regulated imposing a reference in the active current component (I_d^*). A voltage variation in the DC link is compensated by changing the AC line active currents, in such a way, that the DC link is kept at the established value. The analysed system is characterized by having lower power and so, is pretended to produce only active power. To accomplish this requirement the reactive current reference component (I_q^*) was imposed 0A.

B. Current Controller Design

As figure 1 shows, the voltage control loops are decoupled, meaning that variations in one component do not perturb the other. The transfer function between the applied voltage reference U_{Cj} and the respective $j \in (d, q)$ components were obtained by (2) and present in (3).

$$G(s) = \frac{I_j}{U_{Cj}} = \frac{1}{R + sL} \tag{3}$$

According to (3) a PI controller is an appropriate one to control i_d and i_q. The design of their parameters based on Internal Model Control (IMC) is presented in (5) [2].

$$G_{PI}(s) = k_p + \frac{k_i}{s} \tag{4}$$

$$\begin{aligned} k_i &= \alpha R \\ k_p &= \alpha L \end{aligned} \tag{5}$$

where α(rad/s) is the current controller bandwidth where the pole of G_{PI} is placed. The bandwidth α should be selected smaller than a decade below the sampling frequency.

C. DC Voltage Controller Design

The DC link must be modelled in order to design the parameters of the voltage control loop. The DC link, modelled as a pure capacitor, is presented in figure 1 as well as the DC input and output power flow.

The capacitor is an energy storage device modelled by (6) and the time derivative of the stored energy must be equal to the difference between the power from the wind generator and the one injected into the grid (7).

$$E_c = \tfrac{1}{2} C v_{DC}^2 \tag{6}$$

$$\begin{aligned} \frac{dE_c}{dt} &= P_{SG} - P_{DC} \\ \frac{1}{2} C \frac{dv_{DC}^2}{dt} &= P_{SG} - P_{DC} \end{aligned} \tag{7}$$

The dynamics of the DC voltage is nonlinear with respect to v_{DC}. For an accurate control model, it was made a linearization of (7), replacing v_{DC}^2 by W, resulting in the process model G_v presented in (8).

$$\begin{aligned} \frac{1}{2} C \frac{dW}{dt} &= \sqrt{3}.U_{gLL} i_d - P_{SG} \\ G_v(s) = \frac{W}{I_d} &= \frac{2\sqrt{3}U_{gLL}}{Cs} \end{aligned} \tag{8}$$

As before, a PI controller can accurately control the DC voltage. Their parameters were calculated in such a way that DC voltage compensation has a fastest response to the reference and perturbations (P_{SG}). In order to evaluate the dynamics in the DC-link voltage, were considered that the inductor value has a small value and so, neglect the variations in the reactive current component suffered by the DC voltage fluctuations.

III. IMPLEMENTATION RESULTS

The *VOC* method was implemented in laboratory using *Spartan-3E1600 Xilinx* FPGA. The system parameters used to design the controllers are presented in table I.

The presented control method allows the VSC to operate as a rectifier or in inverter mode, sharing the same dynamics [1]. The rectifier mode is more approachable to implement in laboratory, having been chosen. Since the DC link controller was dimensioned to have high immunity to DC current variations with an average voltage value of 400V DC, was performed a periodic 100ms variation of 0kW to 6.6kW and 0kW again of the DC power flow. The results are presented in figure 2.

TABLE I
SYSTEM PARAMETERS

Item	Symbol	Value	Unit
Rated Power	P_N	6.6	kW
Grid Line-Line voltage	U_{gLL}	200	V
Grid line inductance	L_g	3.8	mH
DC link reference voltage	U_{DC}	400	V
DC link capacitance	C	2	mF

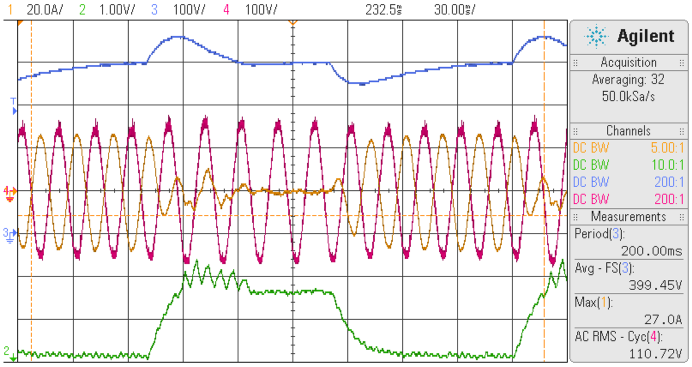

Fig. 2. DC link voltage regulation (blue) over a power flow variation. Electrical Grid Voltage (red) and Current (Yellow). i_d current dynamics (Green)

When the step variation in DC power flow is applied, the positive DC bus voltage error is amplified to reduce the impact of the introduced perturbation and the VSC starts to decrease/ increase its voltage in order to inject more power into the DC bus/grid to compensate the operation conditions.

From the resulted models and system parameters, applying a step change from no DC power flow to the nominal power flow, perturbs in $\pm 48.2V$ the 400V reference of the DC bus voltage. The maximum DC link error occurs around 10ms after the perturbation and takes around three grid cycles to restore the nominal DC level.

IV. CONCLUSION

The VSC-VOC method was carefully modelled to provide fast and robust results to manage the DC link voltage. After modelling, the system was implemented in laboratory to test the dynamic performance, under the worst operating conditions, with ideal step changes with the nominal power of the DC link. The control method is robust and keeps the system stable with fast response time to perturbations.

REFERENCES

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