# PMSGS AND DFIGS WIND FARMS EQUIVALENT MODEL CONSTRAINED TO GRID CODE FOR LOAD FLOW STUDIES

Ricardo Martínez Parrales and Claudio Rubén Fuerte Esquivel

Universidad Michoacana de San Nicolás de Hidalgo, ricardo.parrales@umich.mx, claudio.fuerte@umich.mx

## Introduction

The wind energy conversion to electric energy is one of the most popular and promising alternatives to reduce environmental pollution caused by classic electric generation machines that use fossil fuels. Among wind power plants, those located offshore have the best performance because the wind resource shows better conditions making this type of wind farms more desirable for large scale generation projects. To achieve high aerodynamic efficiencies, the permanent magnet synchronous generators (PMSG) and the doubly-fed induction generators (DFIG), uses voltage source converters (VSC) connected back-to-back (B2B) to be able to operate in a wide range of wind speeds.

In the past decades, the number of wind farms integrated into electric power systems has increased. These wind farms are integrated by a group of wind generators spatially distributed in a large area such that the impact of the different expected wind speeds at different locations of the wind park has to be taken into consideration in the load flow studies.

In this work, the load flow solution is constrained to the modulation index range, current capacity of the converters and the reactive power limits defined in the Mexican grid code by using the complementary theory. A reduced model for PMSGs and DFIGs wind farms based in clustering and circuits equivalents is presented. Each cluster is formed by a group of WTs with the same modulation index range, current capacity and control mode of operation.

## VSC model

The derivation of the mathematical model representing the VSC steady state operation is based on the concept of an ideal complex tap-changing transformer with the converter schematic representation shown in Figure 1. This permits the explicit consideration of the VSC reactive power injected (resp. absorbed) to (resp. from) the network together with the converter operational constraints.

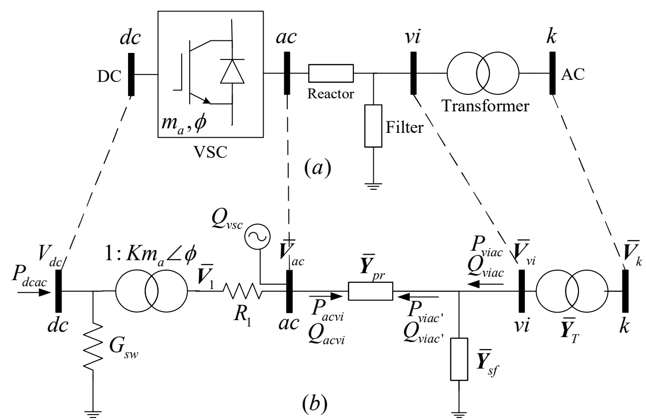


Figure 1. AC-DC converter station and transformer. (a) Schematic representation. (b) Positive sequence equivalent circuit model.

## VSC limits

To guarantee that the power flow solution corresponds to a feasible VSC steady state operation, three limiting factors must be considered in the formulation: i) the upper and lower DC capacitor charge limits; ii) the modulation index operational range; and iii) the maximum continuous current that the converter's switching elements can handle. The first two operating limits are considered by the inequality constraints $V_{dc}^{\min} \le V_{dc} \le V_{dc}^{\max}$ and $m_a^{\min} \le m_a \le m_a^{\max}$. On the other hand, the VSC protection against over currents is expressed in terms of the maximum apparent power $S_{acvi}^{\max} = I_{vsc}^{\max} V_{ac}$ at which the converter can operate. This power is decomposed to obtain the lower and upper limits $Q_{vsc}^{\min} \le Q_{vsc} \le Q_{vsc}^{\max}$ and $P_{dcac}^{\min} \le P_{dcac}(\mathbf{x}) \le P_{dcac}^{\max}$ based on the inner current limiter technique.

## Wind farm voltage regulation coordination method

The Mexican grid code requirements specify that the ratio between the wind farm reactive power $Q_{wf}^{PCC}$ injected/extracted at the PCC and the maximum active power $P_{wf}^{\max}$ of the wind farm should be inside the following limits (CRE 2016).

$$-0.5 \leq \frac{Q_{wf}^{PCC}}{P_{wf}^{\max}} \leq 0.5 \tag{1}$$

In this context, for each wind generator's grid side VSC, the reactive power set points $Q_{viac}^{sp,gs}$ limits are defined based on the corresponding active power wind generator capacity $P_{wg}^{\max}$ such that

$$-0.5 \leq \frac{Q_{viac}^{sp,gs}}{P_{wg}^{\max}} \leq 0.5 \tag{2}$$

In the case where the wind farm is participating in the voltage regulation at the PCC, the following coordination method is proposed. In this case, the PCC node is formulated as a PV node with the desired voltage magnitude. Then, at each NR iteration, the solved reactive power to be injected/extracted at this node is distributed between all the associated grid side VSC in the form of their corresponding reactive power set points $Q_{viac}^{sp,gs}$. This distribution is done proportional to each $P_{wg}^{\max}$ and constrained to (2) in order to fulfill the Mexican grid code requirements (CRE 2016).

## PMSG and DFIG models

The back-to-back converters of these two types of generators are represented using the constrained VSC model presented in Section 2. The proposed positive sequence representation of the complete PMSG is shown in Figure 2.

On the other hand, the complete DFIG's positive sequence representation proposed in this work is presented in Figure 3.

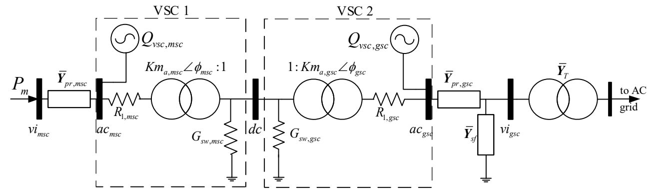


Figure 2. Positive sequence representation of PMSG.

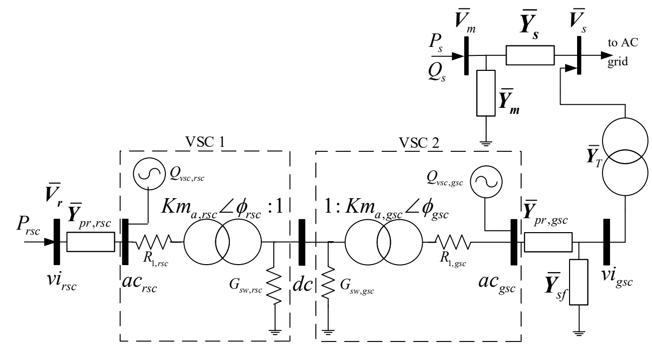


Figure 3. Positive sequence representation of DFIG.

## PMSG and DFIG equivalent wind farms model

The typical wind farm is formed by a large group of wind generators where only 1 o 2 different wind generator models are used such that an equivalent circuit can be obtained when a group of $N$ wind turbines with identical electric characteristics are connected in parallel.

The equivalent impedance values of the aggregated positive sequence circuit are obtained by dividing the impedance value of one wind generator by the number of identical wind generators whereas the equivalent admittances are computed by multiplying the admittance of one wind generator by the number of generators conforming the cluster based on the generators with the same expected wind speed, control modes and set points.

$$Z_{eq} = \frac{Z_{wg}}{N} \therefore Y_{eq} = NY_{wg} \tag{3}$$

## References

CRE, Comisión Reguladora de Energía. (2016). Código de red April 2016. Available: https://www.cenace.gob.mx/Docs/16_MARCOREGULATORIO/SENyMEM/(DOF%202016-04-08%20CRE)%20RES-151-2016%20DACG%20C%C3%B3digo%20de%20Red.pdf

1er Congreso Internacional
CEMIE-Océano

DOI: 10.26359/EPOMEX.CEMIE052021