Coordination between DFIG-based Wind Farms and LCC-HVDC Transmission Considering Limiting Factors

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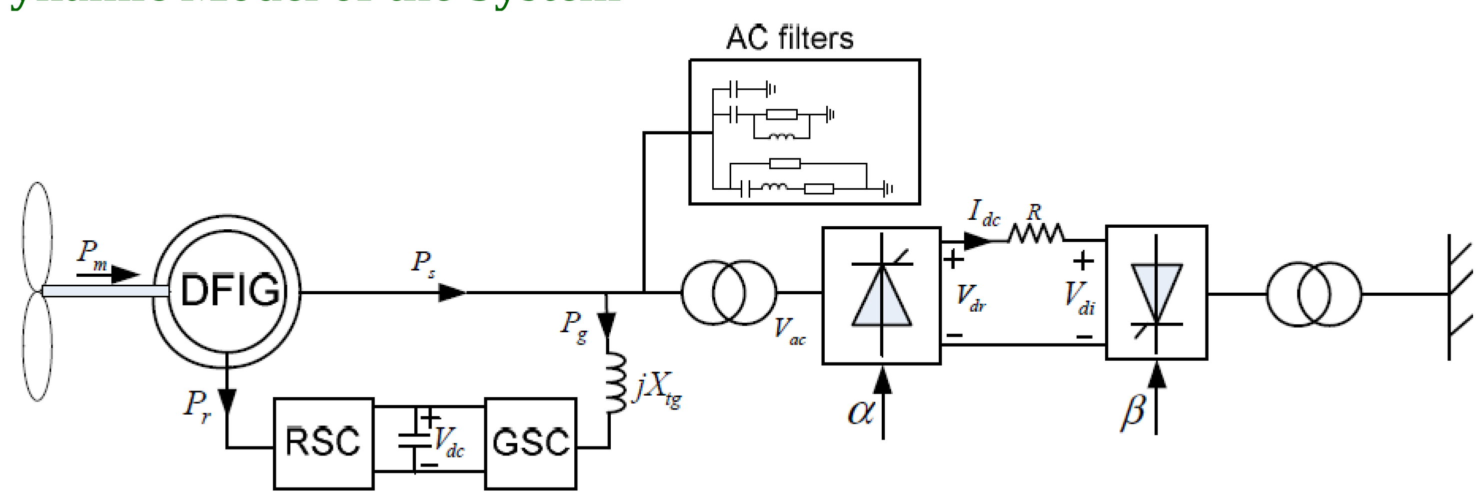
Abstract

For wind farms with thyristor-based line current commuting (LCC)-HVDC delivery systems, reactive power must be provided for the HVDC converters to ensure normal operation. When the wind speed increases, the capability to provide reactive power by a doubly-fed induction generator (DFIG) wind farm decreases. Meanwhile, there is an increase in reactive power loss in the transformer and ac lines. As a consequence, the reactive power transmitted to the LCC-HVDC could be reduced. Coordination of the DFIG wind farm terminal voltage and HVC rectifier voltage is necessary to make sure the required reactive power is supplied to the HVDC converters. The goal of this paper is to investigate the upper and lower limits for the rectifier ac bus voltage. An integrated DFIG-based 200 MW wind farm with a simplified HVDC-link connection is studied in Matlab/Simulink. Time-domain simulation results are given to confirm the analysis.

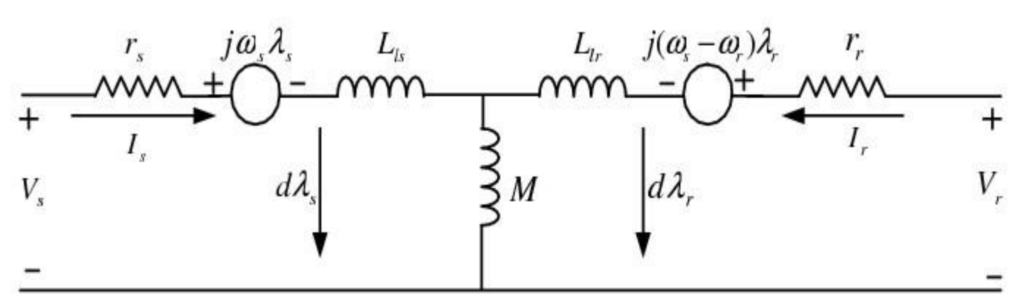
Dynamic Model of the System

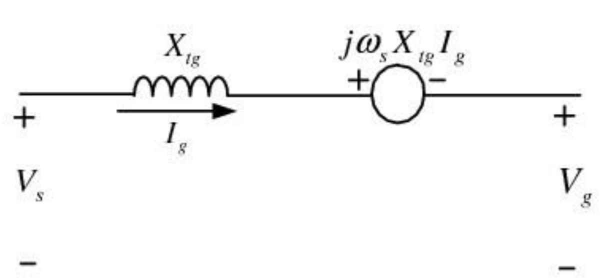


The configuration of the overall study system.

A. DFIG Model

The equivalent circuit of DFIG in qd reference frame is shown right.



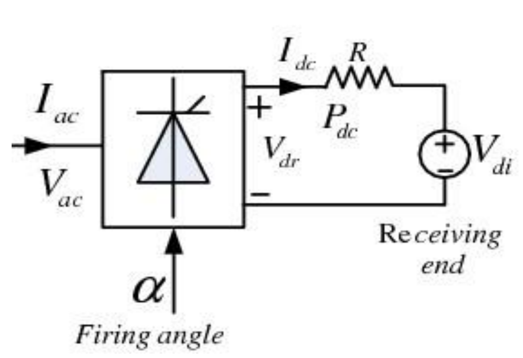


The dynamics of the dc-link between RSC and GSC can be expressed:

$$CV_{dc}\frac{dV_{dc}}{dt} = P_g - P_r$$

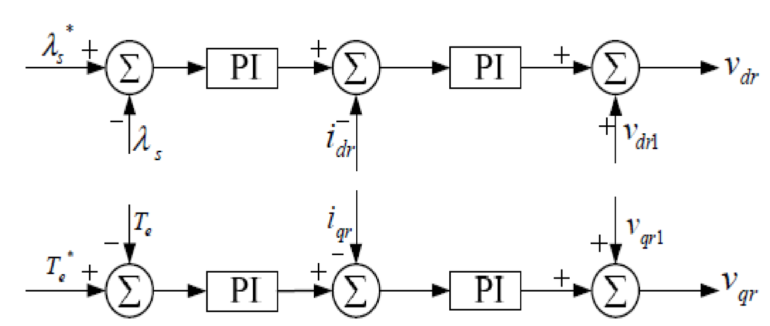
B. HVDC-link Model

$$\begin{cases} V_{dr} = \dfrac{3}{\pi}\sqrt{6}V_{ac}\cos\alpha \\ I_{dc} = \dfrac{I_{ac}}{\sqrt{2}\times 0.816} \\ P_{dc} = V_{dr}I_{dc} \end{cases}$$



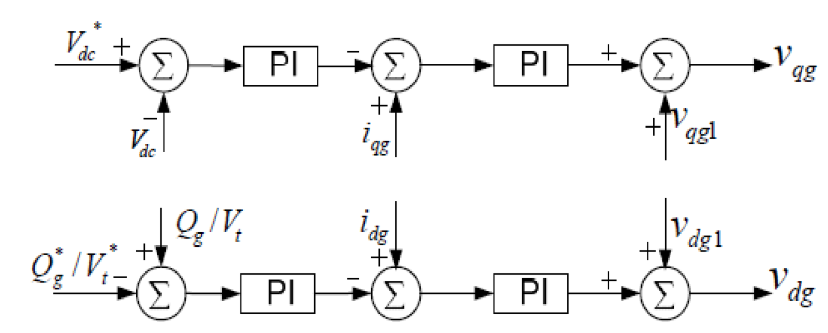
System Control Strategy

A. DFIG Control



Control scheme of RSC

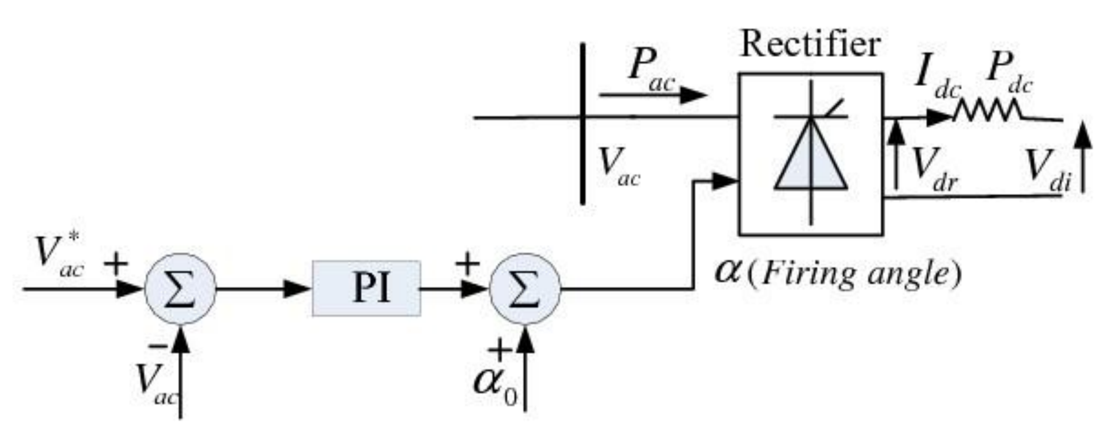
The stator flux linkage is well controlled through the d-axis, while q-axis control loop tracks the electromagnetic torque.



Control scheme of GSC

The voltage of dc-link V_{dc} is kept constant through GSC control

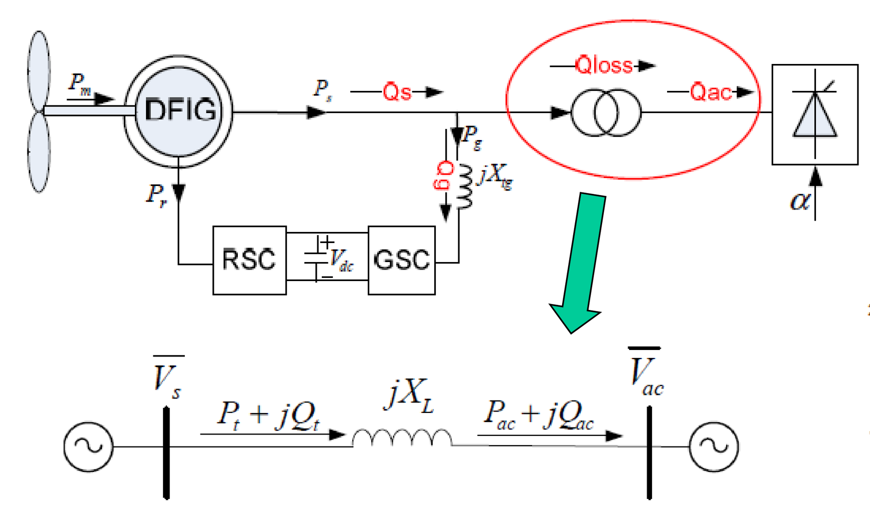
B. HVDC-link control



The control philosophy of HVDC-link is to ensure cooperation of the DFIG and the HVDC-link. As the wind speed changes, the dc voltage and dc current should increase or decrease accordingly. A constant ac voltage is similar as an infinite bus which can absorb varying power output from the wind farm..

Reactive Power Coordination Between DFIG and LCC-HVDC

A. Lower limit of the rectifier ac voltage

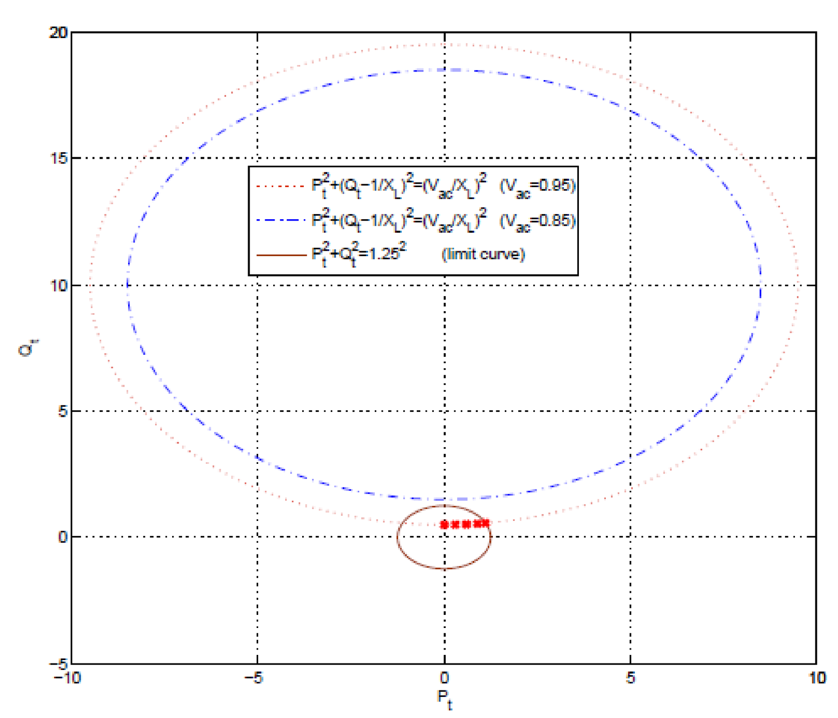


The total operation curve of DFIG:

$$P_t^2 + (Q_t - \frac{1}{X_L})^2 = (\frac{V_{ac}}{X_L})^2$$

Considering the 1 pu limit of the induction machine, the feasible region of DFIG is defined as 125% of the induction generator

$$P_t^2 + Q_t^2 \le 1.25^2$$

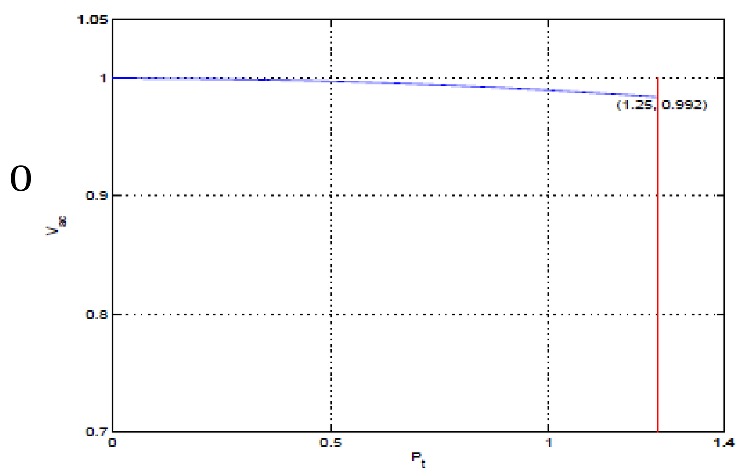


B. Upper limit of the rectifier ac voltage

To provide reactive power for LCC-HVDC:

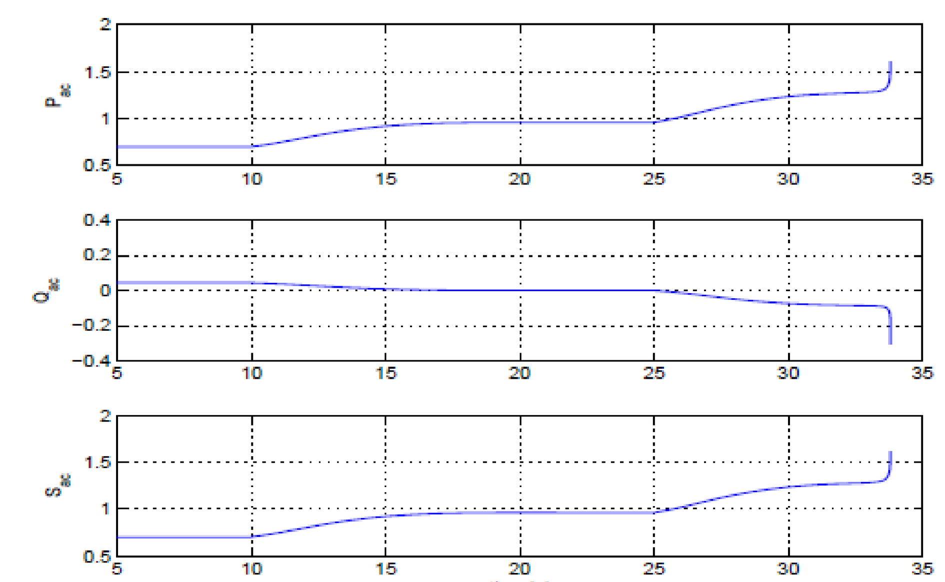
$$Q_{ac} = \frac{V_s V_{ac}\cos(\delta)}{X_L} - \frac{V_{ac}^2}{X_L} = \frac{V_{ac}(V_s\cos(\delta) - V_{ac})}{X_L} > 0$$

$$V_{ac} < \sqrt{1 - (\frac{P_t X_L}{V_{ac}})^2} \quad (P_t = P_{ac} = \frac{V_s V_{ac}}{X_L}\sin(\delta))$$



Case Studies

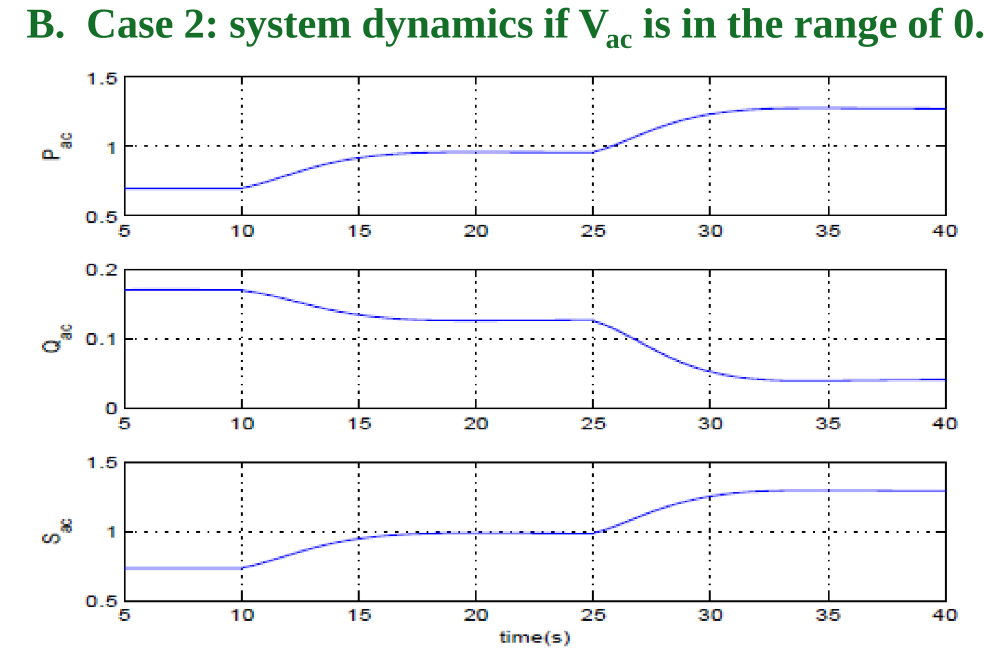
A. Case 1: system dynamics if V_{ac} is out of the range of 0.875-0.992



Dynamic responses of active power, reactive power, apparent power, wind speed increases from 9m/s to 10m/s at 10s, and increase from 10m/s to 11m/s at 25s. Vac = 0.993.

As the wind speed increases to 11m/s, the reactive power supply to HVDC is already less than zero, then the whole system will not work.

B. Case 2: system dynamics if V_{ac} is in the range of 0.875-0.992



Dynamic responses of active power, reactive power, apparent power, wind speed increases from 9m/s to 10m/s at 10s, and increase from 10m/s to 11m/s at 25s. Vac = 0.98.

The reactive power provided for HVDC is larger than 0 as wind speed increases.

Acknowledgement

This work was supported in part by the U.S. National Science Foundation under Award ECCS-1005277.