Reactive Power Management of a DFIG Wind System in Microgrids Based on Economics of the System

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Abstract

Due to significant line resistances in microgrids, active power variations produced by wind turbine can lead to significant fluctuations in voltage magnitudes and as a result economic of the grid. This project proposes a voltage sensitivity analysis-based scheme to achieve voltage regulation at a target bus in such microgrids. The method is local and can be implemented in the absence of widespread communication system or remote measurement. The economic performance of the method is illustrated on the IEEE-13 bus distribution network. Dynamic simulations (in PSCAD/EMTDC) are presented to assess the voltage regulation characteristics.

Introduction

While FERC 661-A requires operational at power factor greater than 0.95 for wind energy systems, many wind operators currently prefer unity power factor (UPF) operation. The method provides adjustments on reactive power based on the active power produced by the DFIG.

The primary objective of the VAR controller (proposed method) is to regulate the voltage at the target bus by modulation the DFIG reactive power in response to active power variations. This is based on sensitivity analysis.

The power flow equations for the system considering both inductive and resistive characteristics of the power lines are as follows:

$$\begin{cases} P_k = \sum_{n=1}^{N} |V_k|.|V_n|.|Y_{kn}|.\cos(\theta_{kn} + \delta_n - \delta_k) \\ Q_k = \sum_{n=1}^{N} |V_k|.|V_n|.|Y_{kn}|.\sin(\theta_{kn} + \delta_n - \delta_k) \end{cases}$$

The sensitivity of the bus voltages to deviations in active/reactive powers is obtain by computing the power flow Jacobian linearizing the power flow equations about a nominal operating point given by:

$$\begin{vmatrix} \mathbf{\Delta P} \\ \mathbf{\Delta Q} \end{vmatrix} = \begin{vmatrix} \frac{\partial P}{\partial \delta} & \frac{\partial P}{\partial V} \\ \frac{\partial Q}{\partial \delta} & \frac{\partial Q}{\partial V} \end{vmatrix} . \begin{vmatrix} \mathbf{\Delta \delta} \\ \mathbf{\Delta V} \end{vmatrix}$$

Provided the Jacobian is well conditioned, deviations in bus voltage magnitudes can be obtained from:

$$\begin{vmatrix} \mathbf{\Delta \delta} \\ \mathbf{\Delta V} \end{vmatrix} = \begin{vmatrix} [S_{\delta p}] & [S_{\delta q}] \\ [S_{vp}] & [S_{vq}] \end{vmatrix} . \begin{vmatrix} \mathbf{\Delta P} \\ \mathbf{\Delta Q} \end{vmatrix}$$

Denote the wind generator bus by “w” and the target bus by “v”. The voltage variations at the bus “v” due to active/reactive power variations at “w” are given by:

$$\Delta V_v = Svp_{vw}.\Delta P_w + Svq_{vw}.\Delta Q_w$$

For ideal voltage regulation, the reactive power must be modulated in response to variations in active power as given by:

$$\Delta V_v = 0 \Rightarrow \frac{\Delta Q_w}{\Delta P_w} = \frac{Q - Q_0}{P - P_0} = -\frac{Svp_{vw}}{Svq_{vw}}$$

Consequently, the required reactive power adjustment to compensate for voltage fluctuations due to active power variations is given by:

$$Q_w = -\frac{Svp_{vw}}{Svq_{vw}}(P_w - P_0) + Q_0$$

If the set point is chosen at P0=0, Q0=0, can be written as a constant power factor equation:

$$\mathrm{PF}_w = \frac{|Svq_{vw}|}{\sqrt{Svp_{vw}^2 + Svq_{vw}^2}}$$

Producing large amounts of reactive power by wind generators increases its winding currents and relevant losses. To minimize the operational losses, the set point is chosen at P0=Pave, Q0=0, where Pave is the average of the wind generator active power.

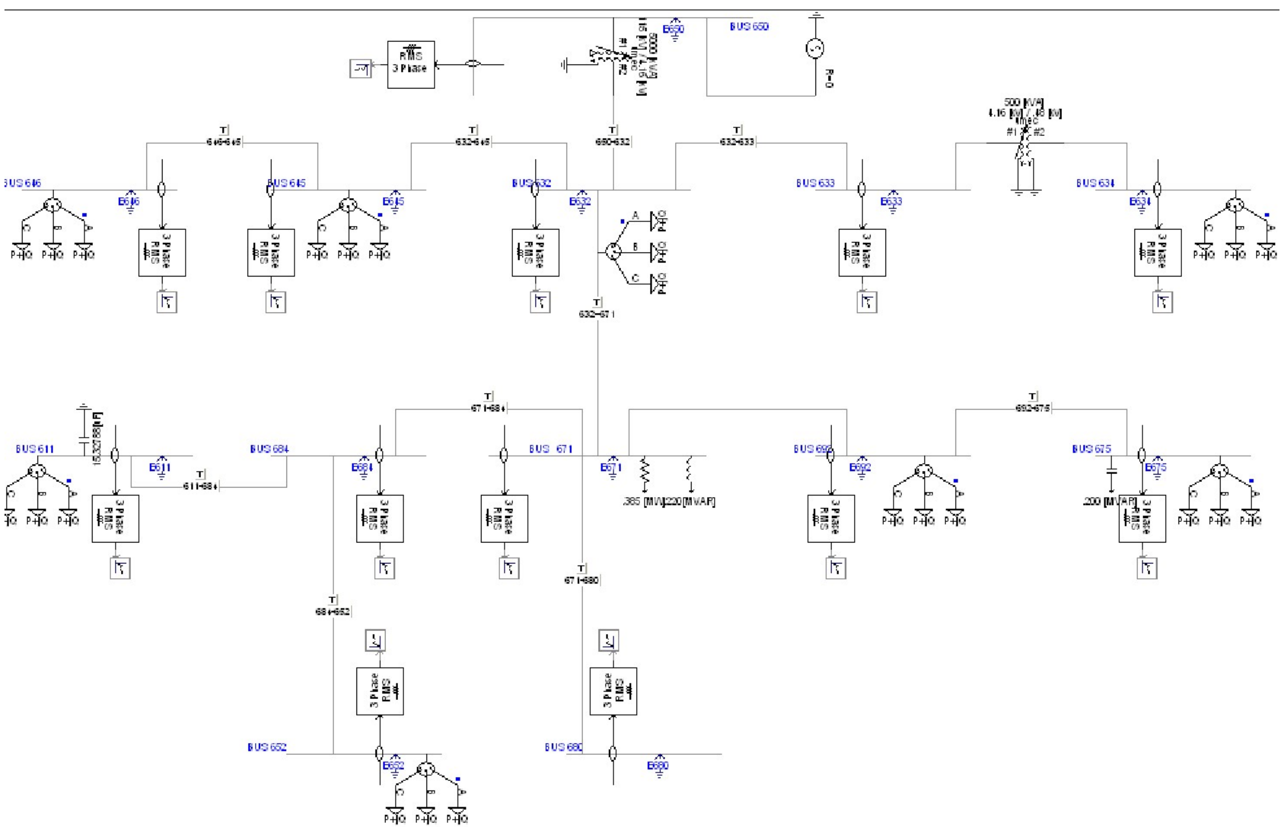
The proposed method achieves voltage regulation at a single target bus. This can be generalized so that the control is exercised to extend voltage regulation at multiple buses.

Methodology

Simulation of proposed method is classified to three classifications. The IEEE 13 node test system, The DFIG structure and control system and applies the proposed method.

IEEE 13 node test system

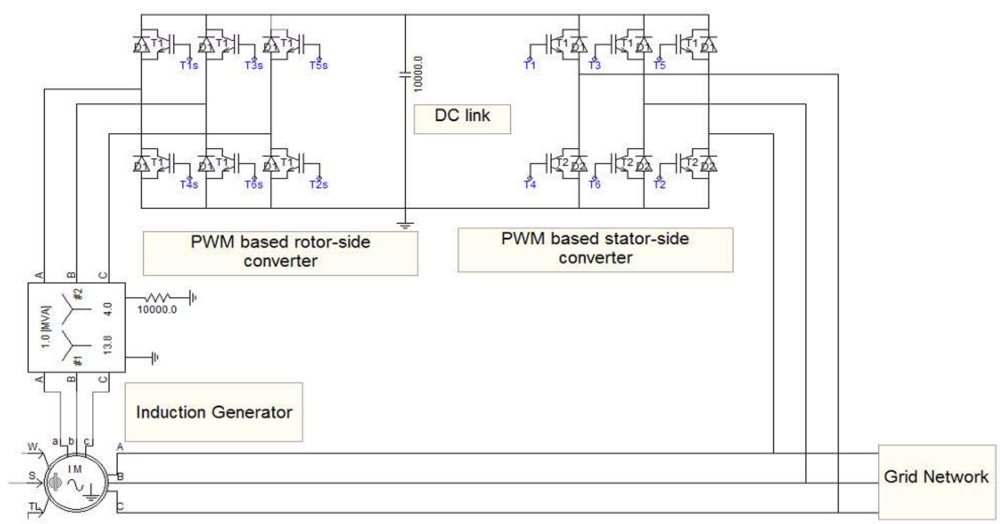
This distribution system contains 13 buses, unbalanced load, capacitor banks and etc. The loads of this system are from different types such as power constant (PQ), current constant (I) and Impedance constant (Z). The simulation of this system is shown below:



The simulation was run and the results compared with [1], [2]. Equivalent of voltage magnitudes derived from simulation with [5] illustrate the verity of simulation.

DFIG structure and control system

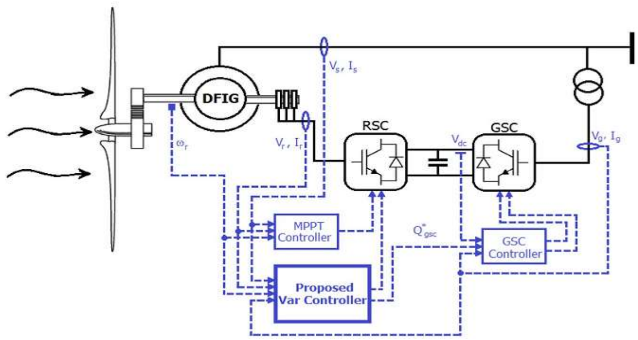
We can consider a DFIG structure as below:



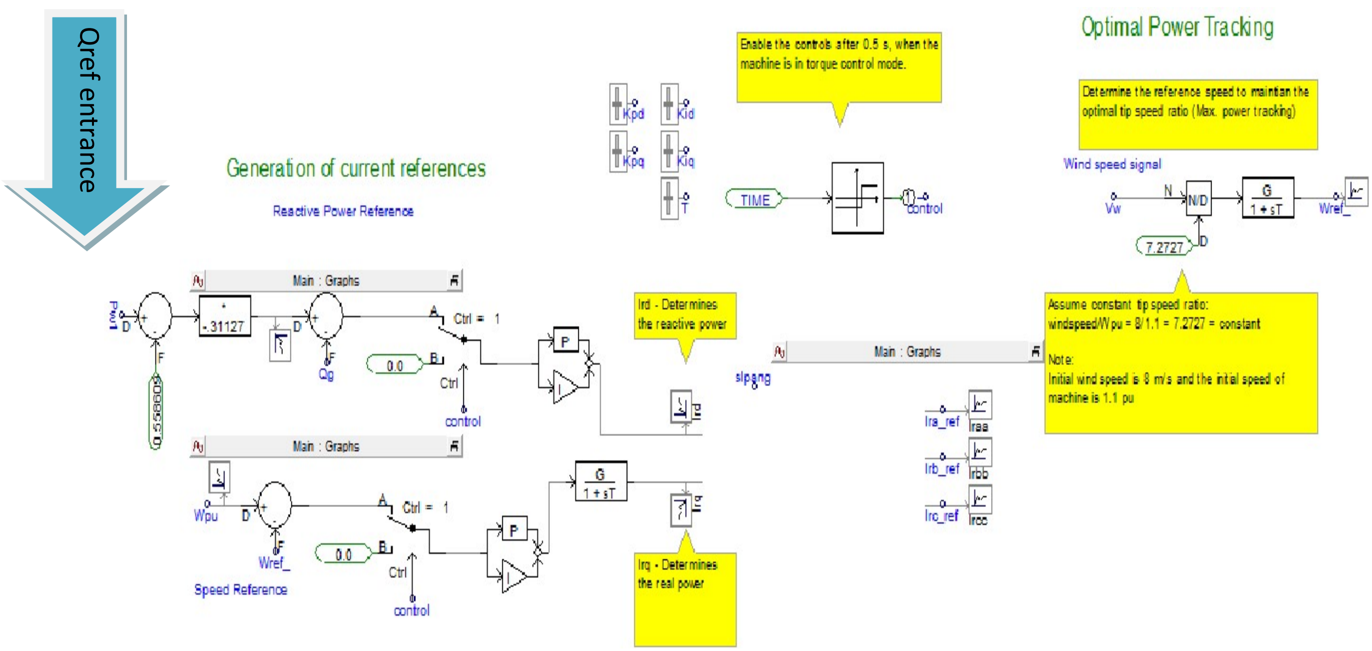
There are different methods for control DFIG system. In this simulation, vector control based on [7], [8] is done. The system employs two back to back converters: A rotor side converter (RSC) and a grid side converter (GSC) [1-8]. Typically, these converters are rated at about 25%-30% of the generator rating. While the RSC is used to adjust the rotor current, The GSC is responsible for adjusting the DC link voltage. The complete simulation procedure of control system is mentioned in [10].

Case Study

A schematic diagram of a DFIG and proposed VAR controller is shown below:



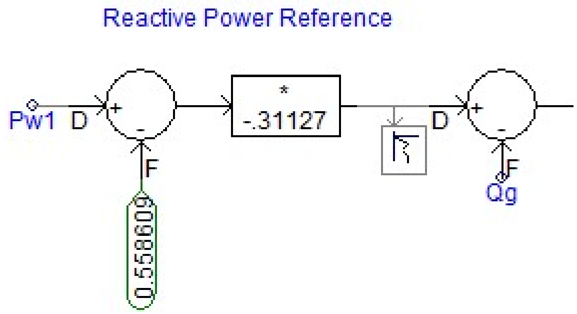
The DFIG system consist of four components namely: a) DFIG and converter units, b) maximum power point tracking (MPPT)/RSC controller, c) GSC controller, d)VAR coordinator[9-16]. One part of DFIG control system that receive ”Qref” and “Pref” for produce “Id” and “Iq” (two main control parameters) is shown below:



“Pref” input is used for MPPT (refer to last fig). Therefore, just one control parameter remains for VAR controller (Qref) [17-23].

Based on below equation and control part, the VAR control method was applied.

$$Q_w = -\frac{Svp_{vw}}{Svq_{vw}}(P_w - P_0) + Q_0$$

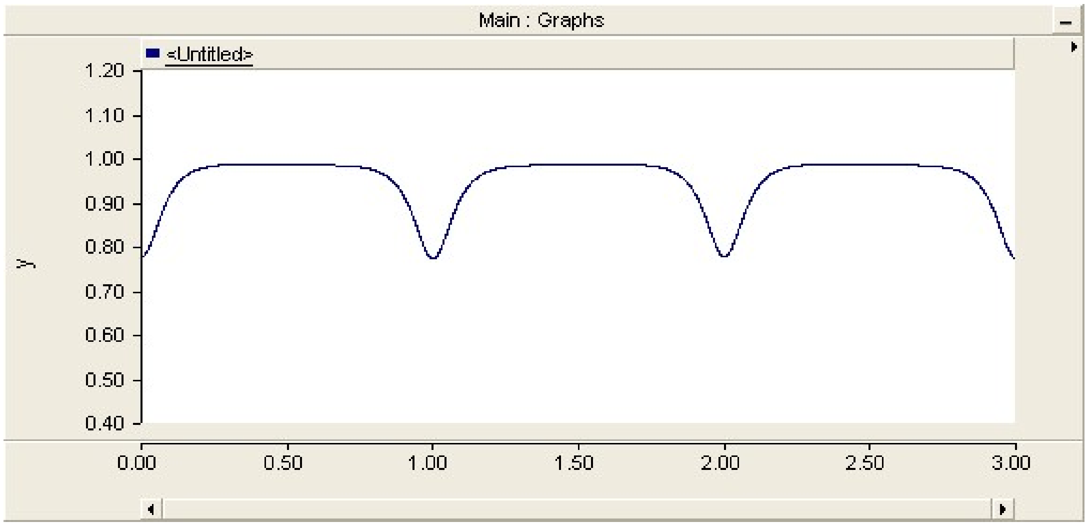


The quantity of sensitivity coefficient (-0.31127) is from sensitivity matrix that mentioned in [13], [14]. After apply this control part, the DFIG is connected to the bus 611 and the bus 652 chooses for target bus [17], [18]. For generate variations in input wind power, the tower shadow and wind shear effects are used as follows:

$$\begin{cases} T_{ae}(t,\theta) = \frac{1}{2}\rho A V^2 R \frac{C_\rho(\lambda)}{\lambda}\left[1 + \frac{2}{mV}\left(v_{ws} + v_{ts} + (1-m)V\right)\right] \\ v_{ts} = \frac{mV}{3R^2}\sum_{b=1}^{3}\left[\frac{a^2}{\sin^2\theta_b} ln\left(\frac{R^2\sin^2\theta_b}{x^2} + 1\right) - \frac{2a^2R^2}{R^2\sin^2\theta_b + x^2}\right] \\ v_{ws} = V\left[\frac{\alpha(\alpha-1)}{8}\left(\frac{R}{H}\right)^2 + \frac{\alpha(\alpha-1)(\alpha-2)}{60}\left(\frac{R}{H}\right)^3\cos(3\theta)\right] \\ C_p = \frac{1}{2}\left(\frac{RC_f}{\lambda} - 0.022\beta - 2\right)e^{-0.255\frac{RC_f}{\lambda}}, \lambda = \frac{\omega_t R}{V} \end{cases}$$

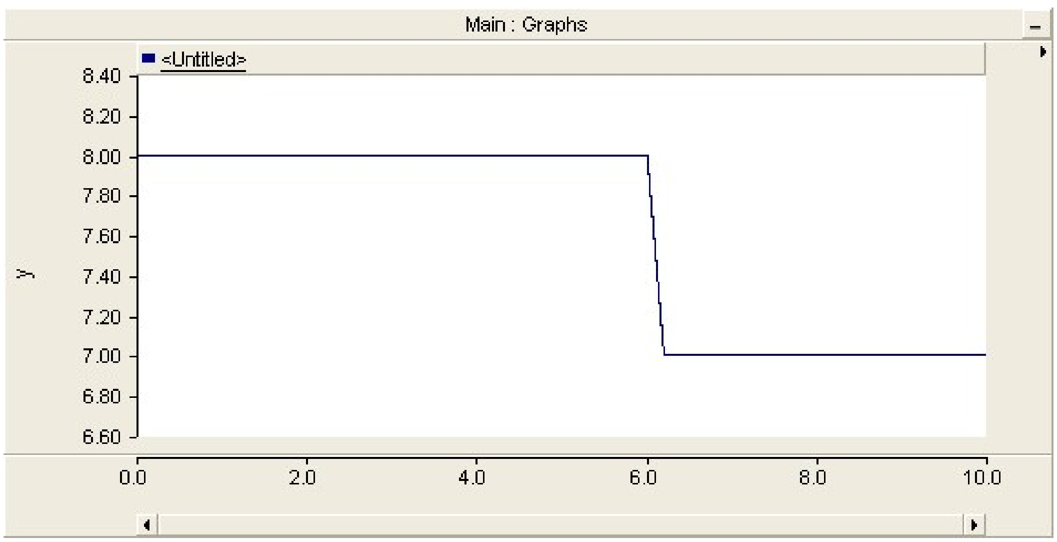
Names and quantities of parameters which are shown in upper equations are completely mentioned in [19], [20].

The output torque (simulation result) is shown below. It is obvious, that the output torque drops three times per each revolution.

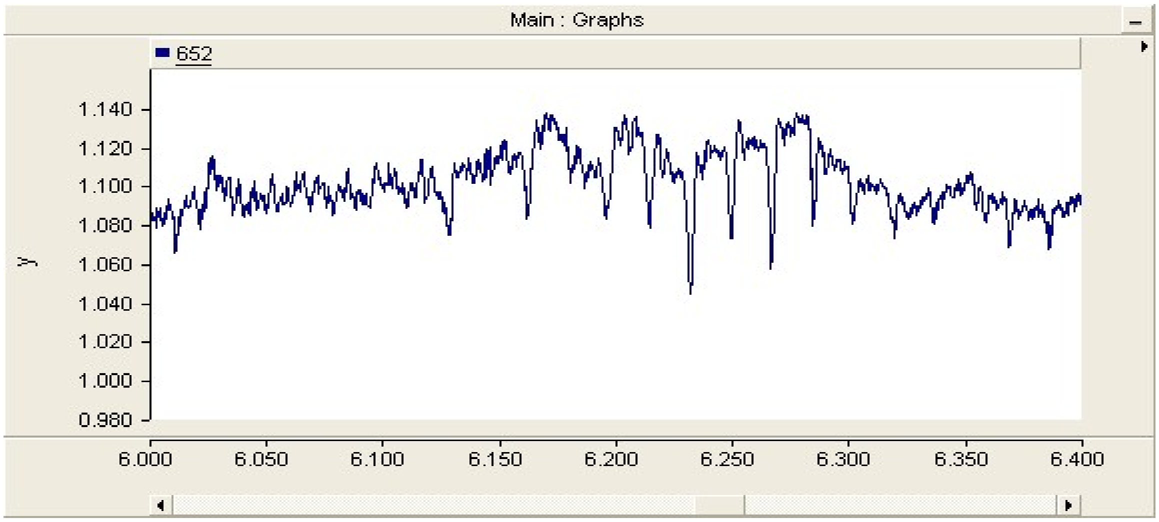


Simulation Results

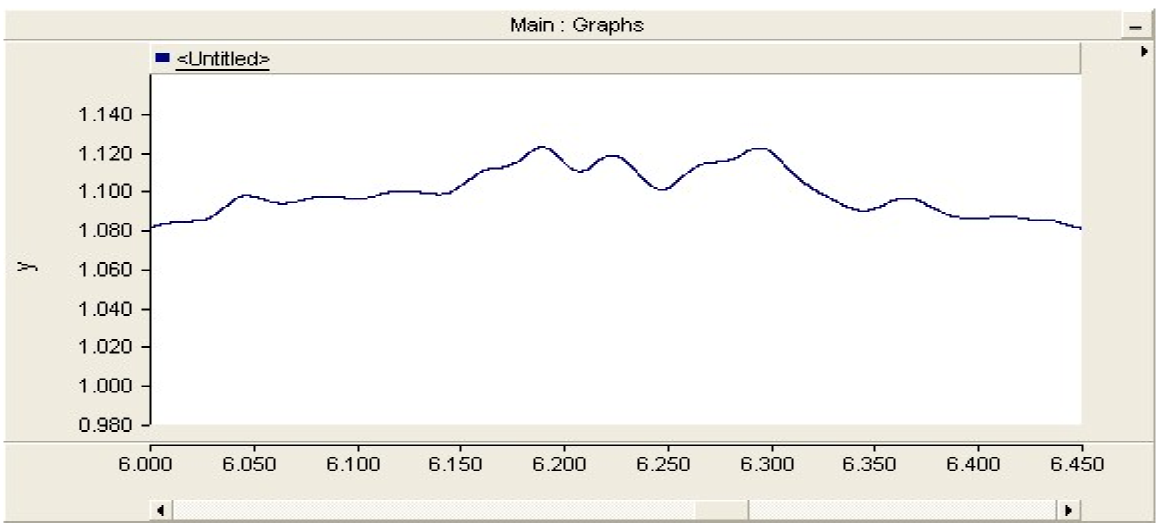
A ramp in wind speed exerted as follows:



The outputs (voltage diagram of bus 652) derived as follows:



Unity Power Factor Method



Proposed Method

It is obvious that proposed method had good effect on magnitude and frequency voltage variations of target bus [20].

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