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Engineering

PERFOMANCE OF SCIG AND DFIG WIND TURBINES UNDER DIFFERENT WIND SPEED

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ABSTRACT The power generated from renewable energy source is always fluctuating due to environmental condition. In the same way Wind power injection into an electric grid affects the power quality due to the fluctuation nature of the wind and the comparatively new types of its generators. Fixed speed wind turbine equipped with Squirrel cage induction generator has the advantages of being simple, robust and reliable. However, it also contains some disadvantages of uncontrollable reactive power output, mechanical stress and limited power quality control. Owing to its fixed speed operation, fluctuations in wind speed are further transmitted as fluctuations in the mechanical torque and then in the electrical power output. In order to overcome the above mentioned problems associated with fixed-speed wind turbine system and to maximize the wind energy capture, variable speed wind turbines based on Doubly fed induction generator are becoming employed.

KEYWORDS : Doubly fed induction generator (DFIG), Flicker, Power quality, Squirrel cage induction generator (SCIG), wind turbine

INTRODUCTION

The generated power from renewable energy source is always fluctuating due to environmental condition. In the same way Wind power injection into an electric grid affects the power quality due to the fluctuation nature of the wind and the comparatively new types of its generators [1]. One of the important power quality aspects is flicker. Flicker causes irritation to the consumer at the receiving end and results in a serious limitation for weak networks where the flicker effect can emerge.

There are numerous of factors that affect flicker emission of grid-connected wind turbines during continuous operation, such as wind characteristics (e.g. mean wind speed, turbulence intensity) and grid conditions (e.g. short circuit capacity, grid impedance angle, load type) [3]. The type of wind turbine also has influence on flicker emission. Fixed-speed wind turbine system use a multi-stage gearbox and a standard squirrel-cage induction generator (SCIG), directly connected to the grid. The speed is not controllable and variable only over a very narrow range, in which only speeds higher than the synchronous speed are possible for generator operation.

The variable-speed constant frequency system widely uses doubly fed induction generators (DFIGs) because of their many advantages. The rotor speeds of DFIGs can be controlled by the generators side, the active power and reactive power can be regulated independently by the rotor-side converter, and the voltage flicker is reduced [3]. In addition, their converters are only rated at about 25%-35% of the generator rating, and the rotor speeds can vary from 0.75pu to 1.25pu. So the DFIGs will be widely used in wind farms because of their good performance.

In this paper an investigation of the flicker emission is presented, considering different types of WT (fixed and variable speed), operating under a variable of wind conditions. First the network and WT modeling approach is outlined and subsequently the results of the investigation are presented and discussed, illustrating the effect of the wind on the flicker levels resulting from the operation of fixed speed and variable speed wind turbine.

WIND TURBINE MODELING

Wind turbines are designed to capture the kinetic energy present in wind and convert it to electrical energy [4]. The vast majority of wind turbines that are currently installed use one of the three main types of electromechanical conversion system. The first type uses a squirrel cage induction generator to convert the mechanical energy to electrical energy. Owing to different operating speeds of the wind turbine rotor and the generator, a gearbox is necessary to match these speeds. The second type uses a doubly fed induction generator instead of squirrel cage induction generator. The stator winding of the generator is coupled to the grid, and the rotor winding to a power electronics converter.

Modeling the Electric Generator of a WTGS

Induction Generator Model

Decoupling effect cannot be achieved in fixed-speed and rotor-resistance control based technologies. In a DFIG turbine, the decoupling of real and reactive power is achieved through the use of power electronics and flux-vector control [2]. In this subsection the considerations for modeling an induction machine and the concept of flux-vector control are introduced.

The electrical part of the machine is represented by a fourth-order state-space model and the mechanical part by a second-order system. All electrical variables and parameters are referred to the stator. All stator and rotor quantities are in the arbitrary two-axis reference frame (dq frame) as given in (1) – (4).

$$V_{qs} = r_s I_{qs} + \omega_e \lambda_{ds} + \frac{d}{dt}\lambda_{qs} \quad (1)$$

$$V_{ds} = r_s I_{ds} - \omega_e \lambda_{qs} + \frac{d}{dt}\lambda_{ds} \quad (2)$$

$$V_{qr} = r_r I_{qr} + (\omega_e - \omega_r)\lambda_{dr} + \frac{d}{dt}\lambda_{qr} \quad (3)$$

$$V_{dr} = r_r I_{dr} + (\omega_e - \omega_r)\lambda_{qr} + \frac{d}{dt}\lambda_{dr} \quad (4)$$

Where Vqs, Vds, Vqr, Vdr are the q and d-axis stator and rotor voltages, respectively. Iqs, Ids, Iqr, Idr are the q and d-axis stator and rotor currents, respectively. λqs, λds, λqr, λdr are the q and d-axis stator and rotor fluxes, respectively. ωe is the angular velocity of the synchronously rotating reference frame. ωr is rotor angular velocity; rs and rr are the stator and rotor resistances respectively. The flux linkage equations are given as;

$$\lambda_{qs} = L_s I_{qs} + L_m I_{qr} \quad (5)$$

$$\lambda_{ds} = L_s I_{ds} + L_m I_{dr} \quad (6)$$

$$\lambda_{qr} = L_m I_{qs} + L_r I_{qr} \quad (7)$$

$$\lambda_{dr} = L_m I_{ds} + L_r I_{dr} \quad (8)$$

Where Ls, Lr and Lm are the stator, rotor, and mutual inductances, respectively, with Ls= Lls+ Lm and Lr= Llr+ Lm; Lls being the self inductance of stator and Llr being the self inductance of rotor.
Solving (5) - (8) in terms of current equations:

$$I_{qs} = \frac{1}{\sigma L_s}\lambda_{qs} - \frac{L_m}{\sigma L_s L_r}\lambda_{qr} \quad (9)$$

$$I_{ds} = \frac{1}{\sigma L_s}\lambda_{ds} - \frac{L_m}{\sigma L_s L_r}\lambda_{dr} \quad (10)$$

$$I_{qr} = \frac{1}{\sigma L_r}\lambda_{qr} - \frac{L_m}{\sigma L_s L_r}\lambda_{qs} \quad (11)$$

$$I_{dr} = \frac{1}{\sigma L_r}\lambda_{dr} - \frac{L_m}{\sigma L_s L_r}\lambda_{ds} \quad (12)$$

Where leakage coefficient $\sigma = \frac{L_s L_r - L_m^2}{L_s L_r}$

DFIG WIND POWER SYSTEM

A double-Fed induction generator is as a standard wound rotor induction generator with its stator windings directly connected to the power grid and rotor connected to the power grid through a frequency converter [2]. In modern DFIG designs, the frequency converters are usually built by two, three phase self commutated back-to-back PWM converters with an intermediate capacitor link for DC bus voltage regularity. The converter that is connected to the rotor called „rotor side converter" and the other named 'grid side converter'. Vector control is one of the most common methods applied to DFIG to control the flow of active and reactive power between the stator and the grid. It can be applied on both rotor side converter (RSC) and grid side converter (GSC). The objective of the RSC is to govern both the stator-side active and reactive powers independently, while the objective of the GSC is to keep the dc-link voltage constant regardless of the magnitude and direction of the rotor power [3]. The GSC control scheme can also be designed to regulate the reactive power. By controlling the grid and rotor converters, the DFIG can be adjusted to achieve many.

PSCAD/EMTDC software package offers suitable models for evaluating DFIG wind turbine. Moreover, it includes a generic wind turbine governor and different wind resource patterns.

The unit transformer and grid are both modeled using in-built blocks supplied by PSCAD/EMTDC. The unit transformer is a wye-delta 2-MVA transformer with a primary voltage of 34.5 kV and a secondary voltage of 0.69 kV. During the development and testing phase, the grid is represented by a 34.5-kV voltage source. The Complete model implemented in PSCAD/EMTDC is shown in Figure 1.

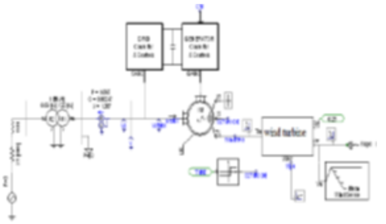

Figure 1: Schematic of DFIG for WECS in PSCAD/EMTDC

SIMULATION RESULTS

In this paper simulations were carried out for two cases of operating wind turbine:

Case 1: a wind turbine with SCIG
Case 2: a wind turbine with DFIG

In the real wind farm, the wind velocity is always fluctuating. To compare the dynamic response of each model, all the wind turbines experience identical wind with the mean velocity of 11 m/s, as shown in Fig. 2(a). Figure 2(b)-(d) compares the active power, reactive power, and voltage magnitude at the PCC by using the SCIG WTG equivalent model and the DFIG WTG model, respectively.

It has been observed that with random variation of wind speed, both the active power and reactive power fluctuate continuously as illustrated in Fig 3(b) and Fig. 3(c).The changes in generator voltage is shown in Fig 3(d). According to Fig.3 (d1) wind turbine with SCIG shows a voltage fluctuation of 4.5%. In the wind turbine with DFIG, active power output varies between 0.2 pu to 1.0 pu, and ultimately causes voltage variations between 0.99 pu and 1.01 pu. This represents a 2% variation compared to the nominal system voltage. It is clear that the voltage fluctuation is very small compared to SCIG wind turbine. Simulation results shown that, by the replacement of a fixed speed wind turbines with DFIG wind turbine can reduce the flicker emission. In this way, the DFIG wind turbine with its grid-side convertor behaves similarly to a STATCOM at the wind Turbine terminal. The difference is that the grid side converter is already there without any additional cost in the case of a doubly fed induction generator. With grid-side convertor of DFIG wind turbine alternative flicker mitigation is carried out to control measure directly controlling the voltage at the PCC, which can also be realized by regulating the reactive power of the PWM voltage source converters. The aim of the voltage controller is to keep the voltage at a constant value such that the voltage fluctuations as well as flicker are reduced.

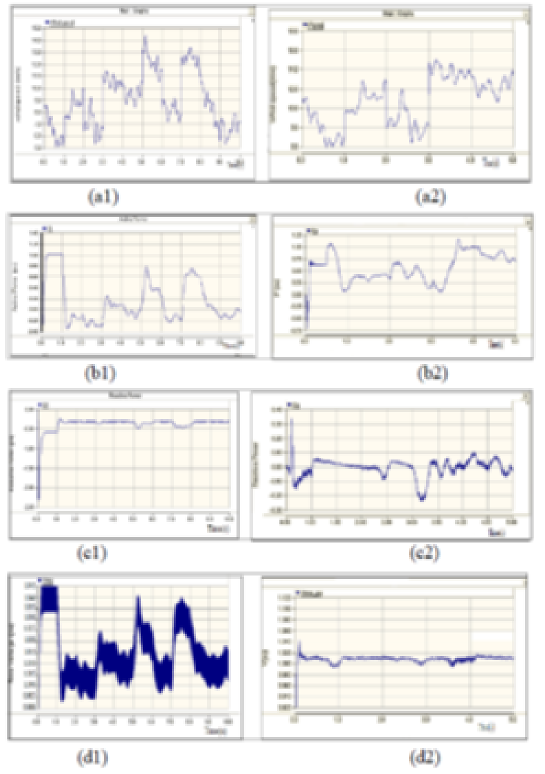

Figure 2. Wind speed, Active power, reactive power and voltage profile for SCIG and DFIG wind turbine model

CONCLUSIONS

A significant feature of wind power in contrast to conventional power is fluctuation of output power due to wind speeds and turbine locations. This fluctuation affects the voltage profile and system stability. The detailed model of the grid-connected wind turbine containing DFIGs and SCIGs is established in this paper. These models are compared by simulation studies in the PSCAD/EMTDC environment under different wind velocity and fluctuation conditions. For a fixed-speed wind turbine, there is no active control over the power output of the machine, once the rotor blade pitch angle is set. The DFIG technology allows extracting maximum energy from the wind for low wind speeds by optimizing the turbine speed, while minimizing mechanical stresses on the turbine during variable wind speed. Flicker mitigation can be realized by using the DFIG wind turbine in fixed speed wind farm which is significant in the flicker emission.

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