STABILITY ANALYSIS OF SCIG BASED WIND FARM CONNECTED WITH SERIES COMPENSATED TRANSMISSION LINE

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Abstract

Grid integration of wind farms in our country has many issues. The steady state and transient state stability must be maintained in wind farms to produce enormous power. We have to analyze the operation and performance analysis of single cage induction generator based wind farm connected to the grid. In this paper, the work has been done an analysis of the mathematical equations of the whole system, separating the mechanical system (turbine and gearbox) and the electrical (generator and converter). This idea aims to develop a dynamic model, of a generation system of electrical energy with a variable speed wind turbine using a squirrel cage induction generator which is connected to the grid and also the transient stability of wind generation system is evaluated in terms of sub synchronous resonance (SSR). The transient stability is analyzed by applying the three phase fault to the system and observed the operation of the generator. The transient stability analysis is done by using the MATLAB software.

Keywords: *SSR, SCIG, STABILITY, WIND FARM*

1. Introduction

Recently renewable energy sources are the main attention for providing a solution of energy security and also minimize the greenhouse effect by reducing gausses and also the huge scale research activities are carried out in this field [1]. Wind energy conversion system is becoming more famous for integrated with the grid on both large and small scale ratings. Transmission grids are generally facing the challenges of integrating these renewable systems because of their limited power transfer capacity [2]. To increase the available power transfer capacity of the existing lines, series compensation and FACTS devices are considered and in extreme condition, there is need to construct new lines which are at the very high expense [3, 4]. With the deployment of distributed wind systems increasing rapidly interconnection that high voltage conditions can occur on the distribution system, especially under conditions of high penetrations of wind when a large wind plant is connected to the end of a feeder [5]. In the United States, wind and PV is commonly connected to the output at unity power factor, which means the injection of active power can impact voltages around the wind and PV Point of Common Coupling (PCC) because of local reverse power flow [6]. To allow further DG connections, utilities need to install expensive voltage regulating devices (e.g., Static Var Compensator (SVC), Static Synchronous Compensator (STATCOM), voltage regulators, etc.). Voltage-source inverters are essential components of wind and PV solar farms (SFs), which provide wind power and solar power conversion during daytime (normal

operation). However, PV SFs are practically inactive during nighttime and do not produce any real power output [7, 8].
To improve power transfer capacity and also to control power flow, the line losses in transmission line has been reduced, so that it meets the required power demand. For controlling the voltage and the power flow, reactive power compensation is essential [9, 10]. Wherever and whenever there is a need to control power flow and voltage reactive power is injected at the particular location using the FACTS devices such as SVC, STATCOM, and STATCOM. Now a day FACTS devices are being increasingly considered for increasing the available transfer capacity (ATC) of existing lines [11, 12]. Wind turbine and PV generates real power during daytime and during night period they are wholly idle. These are very expensive properties which are maintained entirely unutilized during nighttime and not bringing any revenues for solar plant owner [13]. The main element of wind power plant and PV solar plant is a voltage source inverter or converter which is also a core part of Flexible AC Transmission System (FACTS) device- STATCOM [14]. So that it is possible to utilize solar inverter as STATCOM to reduce the use of FACTS device [15].
Various control strategies such as unity power factor control strategy, positive sequence control strategy, constantly active and reactive power control strategy, instantaneous active reactive control, adjustable power quality characteristic strategy can be implemented for PV solar farm. The conventional controllers of the SVC and the TCSC in order to damp the SSR in a series compensated wind farm [16, 17]. Furthermore, the damping controller of the SVC is a conventional lead-lag controller and the damping characteristic of the TCSC have been added through constant current control of the TCSC [18]. The Wind and PV as FACTS controller UPQC for performing voltage control, hence there is an improvement in the system performance and there is an increase in grid connectivity of neighboring wind farms [19]. Propose a power improvement by the power flow control on wind/PV system to act as UPFC the voltage control functionality with the hybrid system [20]. Source current harmonics mitigation and reactive power compensation. Although the damping methods can mitigate SSR, the protection system assures the safety of the network components under any condition.
This work aims to develop a dynamic model, of a generation system of electrical energy with a variable speed wind turbine using a squirrel cage induction generator which is connected to the grid .In the project has been done an analysis of the mathematical equations of the whole system, separating the mechanical system (turbine) and the electrical (generator).The proper functioning of the model is checked comparing the obtained results with some commonly known results. The system is operated for both fault and without fault to obtain the necessary changes in the system.

2. Modelling of study system

A Wind Turbine Generator is what makes your electricity by converting mechanical energy into electrical energy. In the case of a wind turbine generator the wind pushes directly against the blades of the turbine, which converts the linear motion of the wind into the rotary motion necessary to spin the generators rotor and the harder the wind pushes, the more electrical energy can be generated.
mostly used generator in the wind turbine is SCIG because it is less cost when compared to the other generator and it is very simple to operate. A mathematical modelling is the description of the system using mathematical equation and concepts. In mathematical modelling, we translate those beliefs into the language of mathematics. Mathematics is a very precise language. This helps us to formulate

ideas and identify underlying assumptions. Mathematics is a concise language, with well-defined rules for manipulations. All the results that mathematicians have proved over hundreds of years are at our disposal. Computers can be used to perform numerical calculations.

2.1 Transient analysis:

Transient analysis gives time domain waveforms which are plots of voltage or current versus time. AC analysis gives the voltage or current versus frequency in a linearized version of the circuit. DC analysis gives DC voltage or current, usually versus a stepped voltage or current. Systems can be analyzed using the system response to an input to the signal. The response of any system is the sum of the transient and the steady state response. Any system can either be in equilibrium or not in equilibrium (rise/decay). The transient response is the response of the system to a change in equilibrium and steady state is the response when the system is in equilibrium.

2.2 System modelling

The modelling of whole system includes modelling of each component connected to it. This includes Rotor, Gearbox, SCIG and Transmission line as shown in fig.1

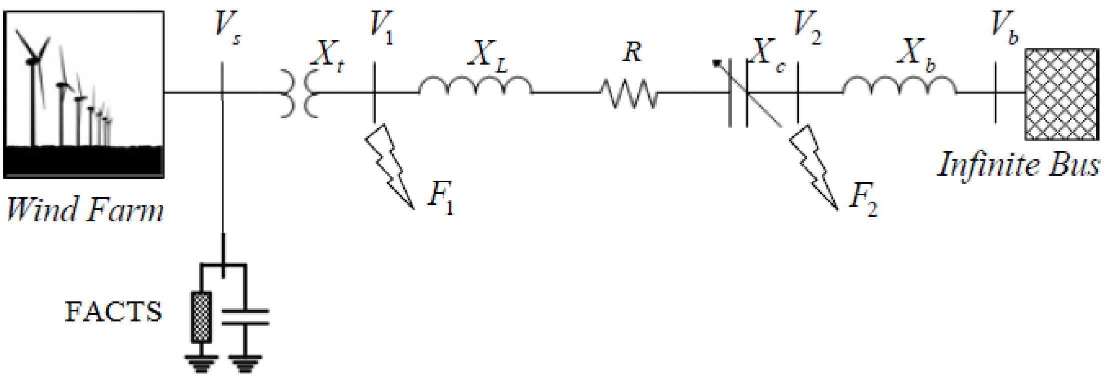

Fig. 1 Model of the system

The turbine is connected to the rotor of the generator through a gearbox. The gearbox is used to step up the low angular speeds of the turbine (normally about 25-30 rpm) to the high rotational speed of the generator (normally around 1800 rpm). Fig. 2.1 shows of the shaft and gearbox model, with all the torques acting on the system and the angular velocities of the various masses. The turbine torque Tm(produced by the wind), accelerates the turbine inertia and is counterbalanced by the shaft torque T (produced by the torsional action of the low speed shaft

2.3 Modelling of generator

Electrical equations of the SCIG in the PARK frame are written as follows

$$\begin{cases} v_{ds} = R_s i_{ds} + \dfrac{d\lambda_{ds}}{dt} - \omega_s \lambda_{qs} \\ v_{qs} = R_s i_{qs} + \dfrac{d\lambda_{qs}}{dt} - \omega_s \lambda_{ds} \\ v_{dr} = 0 = R_r i_{dr} + \dfrac{d\lambda_{dr}}{dt} - (\omega_s - \omega_r)\lambda_{qr} \\ v_{dr} = 0 = R_r i_{qr} + \dfrac{d\lambda_{qr}}{dt} - (\omega_s - \omega_r)\lambda_{dr} \end{cases} \tag{1}$$

where subscripts 's' and 'r' refer to the stator and rotor side respectively, subscripts 'd' and 'q' refer to the d-axis and q-axis respectively. The stator and rotor flux can be expressed as

$$\begin{cases} \lambda_{ds} = L_s i_{ds} + L_m i_{dr} \\ \lambda_{qs} = L_s i_{qs} + L_m i_{qr} \\ \lambda_{dr} = L_r i_{dr} + L_m i_{ds} \\ \lambda_{qr} = L_r i_{qr} + L_m i_{qs} \end{cases} \tag{2}$$

The electromagnetic torque can be calculated as

$$T_{em} = \lambda_{qs} i_{ds} - \lambda_{ds} i_{qs}$$

The voltage and flux equations can be supplemented by the mechanical equation for the drive train given to complete the model of SCIG used

$$J \frac{d\omega_m}{dt} = T_m - T_{em}$$

Where J is total inertia

The active and reactive power transmitted through the stator can be expressed as

$$\begin{cases} P_s = v_{ds} i_{ds} + v_{qs} i_{qs} \\ Q_s = v_{ds} i_{qs} - v_{qs} i_{ds} \end{cases} \tag{3}$$

2.4 Modelling of turbine

A windmill is a machine responsible for transforming the kinetic energy of the wind into the electrical energy. If the wind flow is known, the kinetic power could be expressed, as it is well known, by means the follow equation [21]-[24]:

$$P_{wind} = \frac{1}{2} m v_w^2 = \frac{1}{2} \rho A v_w^3 \tag{4}$$

where

$\dot{m}$ mass flow
V_w wind speed
ρ air density
A area where the air flow could pass through

The power described in (2.1) is just a mathematical description about kinetic power. However, this power could not be obtained by a wind turbine. The power that could be achieved in the best situation, is 0.593 times P_{wind}. This value is called as the Betz number. It is a power coefficient and the turbine efficiency limit, for more details how to obtain the Betz number. The power coefficient can be defined as the ratio between the mechanical power extracted by the converter and the power of the undisturbed air stream

$$C_p = \frac{P_{wind}}{P_{wind0}} = \frac{\frac{1}{4}\rho A(v^2{}_{w1} - v^2{}_{w2})(v_{w1} - v_{w2})}{\frac{1}{2}\rho A v^3{}_{w1}} = \frac{1}{2}\left(1 - \left(\frac{v_{w2}}{v_{w1}}\right)^2\right)\left(1 + \frac{v_{w2}}{v_{w1}}\right) \tag{5}$$

with

$vw1$	wind speed before the turbine
$vw2$	wind speed after the turbine
ρ	air density
A	area where the air flow could pass through. as could be seen in (2.3)
$Pwind$	mechanical power extracted by the converter
$Pwind0$	mechanical power that could be converted

It should be noted that the quotient between v_{w2} and v_{w1} never can overcome $\frac{1}{3}$ because of the betz number.

The kinetic power obtained by the turbine can be defined as:

$$P_{wind} = C_p P_{wind0} \tag{6}$$

where c_p is defined in (2). However, this coefficient depends directly on each turbine, on the tip speed ratio λ, which is defined below in (2.5) and, just in the case that the rotor is equipped with blade pitch control, on the θ_{pitch} called pitch. The coefficient's value can be found on tables for some specific turbines or determined by analytic function, as follows

$$c_p(\lambda, \theta_{pitch}) = c_1\left(c_2\frac{1}{\Lambda} - c_3\theta_{pitch} - c_4\theta^{c_5}{}_{pitch} - c_6\right)e^{-c_7\frac{1}{\Lambda}} \tag{7}$$

$$\lambda = \frac{\omega_t R}{v_{w1}} \tag{8}$$

$$\frac{1}{\Lambda} = \frac{1}{\lambda + c_8\theta_{pitch}} - \frac{1}{1 + \theta^3{}_{pitch}} \tag{9}$$

c_i set of values greater or equal than zero, these are known as turbine characteristic's coefficient.

ω_t turbine's spin speed.

R radius of the turbine, that means, the length of blades

2.5 Modelling of transmission lines

The transmission line parameters include series resistance and inductance and shunt capacitance. In this chapter we shall discuss the various models of the line. The line models are classified by their length. These models will be discussed in this chapter. However before that let us introduce the ABCD parameters that are used for relating the sending end voltage and current to the receiving end voltage and currents. We have used the transmission line up to 25km.Therefore only short line approximation is derived. The shunt capacitance for a short line is almost negligible. The series impedance is assumed to be lumped as shown in Fig.2. If the impedance per km for an l km long line is $z_0 = r + jx$, then the total impedance of the line is $Z = R + jX = lr + jlx$. The sending end voltage and current for this approximation are given by

$$V_S = V_R + ZI_R \qquad (10)$$

$I_S = I_R$

Therefore the ABCD parameters are given by

$A = D = 1$, $B = Z$ Ω and $C = 0$

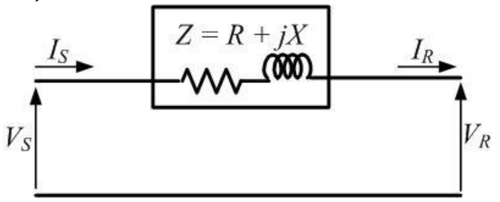

Fig 2. Short transmission line representation.

Modelling of SCIG is done using MATLAB which is an ODE solver and analyzed by varying parameters and the simulation model is given in the Fig.3 given below.

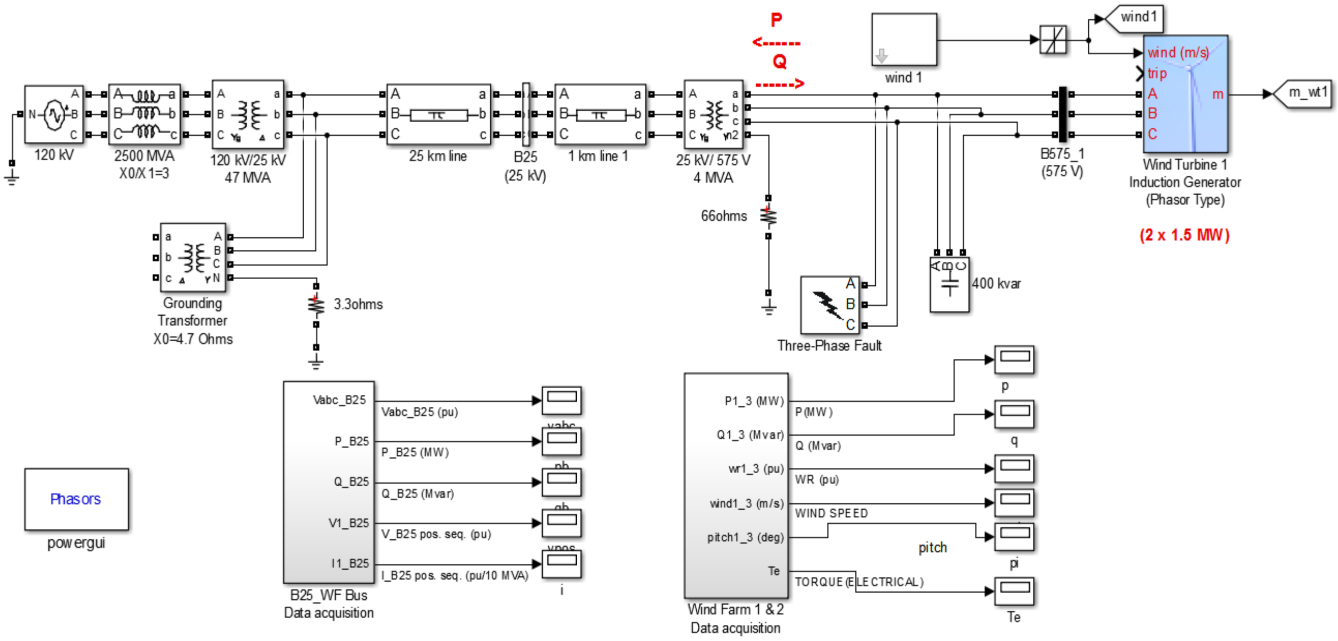

Fig 3. Simulation diagram

3. Result and discussion

3.1 Steady state and transient stability analysis

Simulink model has been analyzed with the necessary changes in the generator and turbine data to get the necessary result to meet our objectives. For changing power, the maximum loading current is obtained by keeping wind speed constant with changing MW rating of the turbine as shown in table.1. The steady state stability is reduced due to increase of wind speed as given in table.2. The electrical torque (T_e) measurement values are shown in table1&2.

Table 1. Changing MW rating and constant Wind Speed (Turbine)

Power(MW)	T_e(p.u)	W_r(p.u)	Wind(m/s)
3	-0.4	1.6	11m/s
6	-0.3	1.6	11m/s
9	-0.2	1.6	11m/s
12	-0.15	1.6	11m/s

Table 2. Changing Wind speed and constant MW rating (Turbine)

Power(MW)	Te(p.u)	Wr(p.u)	Wind(m/s)
3	-0.2	1.3	11
3	-0.25	1.3	14
3	-0.3	1.3	16
3	-0.35	1.3	18

In table.2 the power ratings are varied and wind speed kept constant for obtaining bus voltage and current at the terminal of wind farm. The system stability has been reduced enormously due to rise of line current.

Table 3. Changing MW rating and constant Wind Speed (Bus)

Power(MW)	Voltage(v)(pu)	Current(I)(pu)	Wind(m/s)
3	0.03	0.6	11m/s
6	0.025	0.7	11m/s
9	0.022	0.8	11m/s
12	0.02	0.85	11m/s

Table 4. Changing Wind speed and constant MW rating (Bus)

Powe(MW)	Voltage(V)(pu)	Current(I)(pu)	Wind(m/s)
3	0.42	3	11
3	0.44	3	14
3	0.45	3	16
3	0.46	3	18

The dynamic conditions of series compensated line current and capacitor voltage are obtained through differential equation. The combined state space vector is developed to perform Eigen value analysis. The real power transferred over transmission line depends on change of load angle corresponding to fluctuation of phase angle deflection w.r.t series reactance occurs due to sub-synchronous current entering from series compensated network in the form of oscillatory components. The sub synchronous resonance (SSR) analysis is performed for the study system with respect to degree of series compensation.

Table 5. Eigen values for 500MW system

Modes	Series compensation	
	70%	40%
Electrical	**1.812±85.376i**	**-1.198 ± 115.34i**
Rotor	-5.762±43.342i	-3.586 ± 38.30i
Turbine	-0.3564±3.3431i	-0.375 ± 3.533i

The stability analysis has been performed using Eigen value analysis based on mathematical equations derived. Three modes have been analyzed for stator voltage, rotor angle and turbine twisting angle. When series compensation is increased to 70% for 500MW system, the stability of the study system is decreased as shown in table.5. The steady state stability of the wind farm depends on the degree of series compensation. It is observed that SSR occurred at 70% series compensation in wind turbine.

CONCLUSION

In this paper, modelling equations for formulation of the dynamic model of a squirrel cage induction generator connected to the grid has been derived using ODE solver. The system has been tested with fault and the results are obtained. By analyzing the obtained results, the stability of the study system depends on location of fault and level of series compensation. The aggregated model of wind farm has been tested for two levels of series compensation. The dynamic stability of the study system is reduced while there is an increase of wind power penetration and wind speed.

Acknowledgments

This work has been completed in Indian Institute of Technology Delhi under research fellowship.

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Appendix

Generator:

components	Resistance(p.u)	Inductance(p.u)
Positive sequence	0.1	0.0153
Zero sequence	0.3	0.0458

Transformer:

Winding	Voltage (Vrms)	Resistance(p.u)	Inductance(p.u)
Winding 1	120KV	0.00267	0.08
Winding 2	25KV	0.00267	0.08

Transmission line:

Sequence	Resistance(Ω/km)	Inductance(H/km)	Capacitence(F/km)
Positive sequence	0.1153	1.05mH	11.33nF
Zero sequence	0.413	3.32mH	5.01nF

Turbine:

Type	Resistance(p.u)	Inductance(p.u)
Stator	0.004843	0.1248
Rotor	0.004377	0.1791