Impact of Variable Speed Wind Turbine driven Synchronous Generators in Transient Stability of Power Systems

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Abstract—**With the scenario of wind power constituting up to 20% of the electric grid capacity in the future, the need for systematic studies of the impact of wind power on transient stability of the grid has increased. This paper investigates possible improvements in grid transient stability while integrating the large-scale variable speed wind turbine driven synchronous generator. A dynamic modeling and simulation of a grid connected variable speed wind turbine (VSWT) driven synchronous generator with controllable power inverter strategies suitable for the study was developed, tested and verified. This dynamic model with its control scheme can regulate real power , maintain reactive power, generate voltage, and speed at different wind speeds. For this paper, studies were conducted on a standard IEEE 9 bus system augmented by a radially connected wind power plant (WPP) which contains 28 variable speed wind turbines with controllable power inverter strategies. Also it has the potential to control the rotor angle deviation and increase the critical clearing time during grid disturbance with the help of controllable power inverter strategy.**

Keywords: *Variable speed wind turbine, direct drive synchronous generator , rotor angle deviation and critical clearing time, transient stability, grid connected.*

I. INTRODUCTION

Installed wind power generation capacity is continuously increasing. Wind power is the most quickly growing electricity generation source with a 20% annual growth rate for the past five years. Variable speed operation yields 20 to 30 percent more energy than the fixed speed operation, reduces power fluctuations and improves reactive power supply [1]. Stable grid interface requires a reliable tool PSAT/Matlab for simulating and assessing the dynamics of a grid connected variable speed wind turbine driven synchronous generators [2].There are many papers dedicated to dynamic model development of variable speed wind turbine driven synchronous generators[3,7]. Taking an IEEE three-machine, nine-bus system [4], we attach the WPP system radially through a transmission system and transformers at bus 1 in Fig. 2.The equivalent WPP has a set of 28 turbines connected in daisy-chain fashion within the collector system. The direct driven synchronous generator is operated in a variable speed with capability to control the voltage at the regulated bus at constant power factor, or at constant reactive power. In this study, we set the wind turbines to have constant unity power factor. The 28 wind turbine generators have a combined rating of 100MW. The impact of wind-generation technology on power system transient stability is also shown in [5&6].

II. MODELING OF VSWT DRIVEN SYNCHRONOUS GENERATOR

Fig.1presents a schematic diagram of the proposed VSWT driven Synchronous generator connected to the grid.

A.Wind Turbine

The wind turbine is described by the following equations(1)(2) and (3)

$$\lambda = \frac{\omega_M R}{V_W} \qquad (1)$$

$$P_M = \frac{1}{2}\rho\pi R^2 C_P V_W \qquad (2)$$

$$T_M = \frac{P_M}{\omega_M} = \frac{1}{2}\rho\pi R^5 C_P \frac{\omega_M^2}{\lambda^3} \qquad (3)$$

where λ = tip speed ratio

$\omega_{M=}$Mechanical speed of wind turbine [rad/s]

R= Blade radius [m]

$V_{W=}$wind speed [m/s]

P_M =Mechanical power from wind turbine [kW]

ρ =Air density [kg/m^3]

C_P= Power coefficient

T_M= Mechanical torque from wind turbine [$N \cdot m$]

The mechanical torque obtained from equation (3) enters into the input torque to the synchronous generator, and is driving the generator. CP may be expressed as a function of the tip speed ratio (TSR) λ given by equation (2) .

$$C_P = (0.44 - 0.0167\beta)\sin\frac{\pi(\lambda-2)}{13-0.3\beta} - 0.00184(\lambda-2)\beta \qquad (4)$$

where β is the blade pitch angle. For a fixed pitch type the value of β is set to a constant value 4.5^0

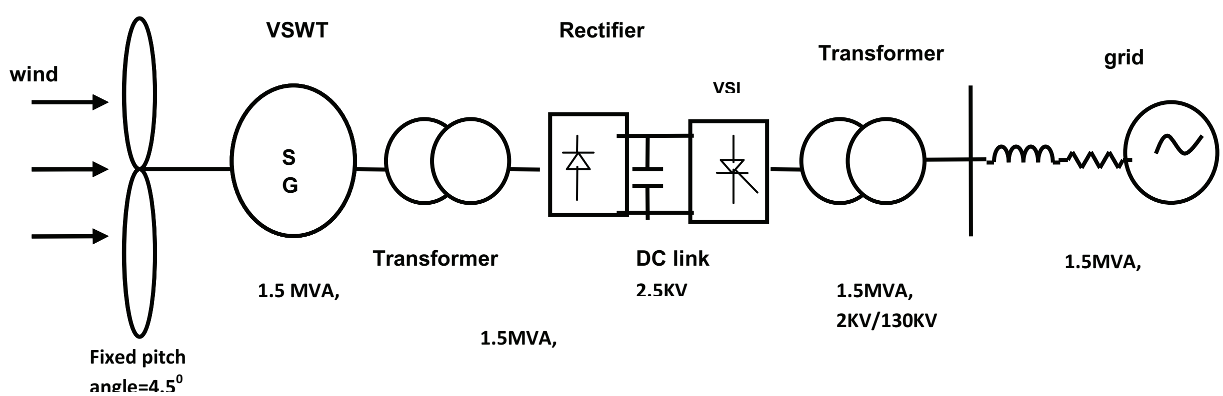

Figure1. Schematic diagram of the proposed VSWT driven Synchronous generator connected to the grid

B. Synchronous Generator

The synchronous generator is equipped with an exciter identical to IEEE type 1 model [8].The exciter plays a role of helping the dc link to meet the adequate level of inverter output voltage as given in (5) below

$$V_{dc} = \frac{2\sqrt{2} \cdot V_{AC\_RMS}}{D_{RMS}} \tag{5}$$

where V_{AC_RMS} is RMS line to neutral voltage of the inverter and D_{MAX} is maximum duty cycle. The exciter plays a role of meeting the dc link voltage requirement.

C. Power Electronics Control

The power conversion system composed of a six-diode rectifier and a six-MOSFET voltage source inverter, which is simple, cost-effective and widely used for industrial applications[9].The VSI includes a *LC* harmonic filter at its terminal to reduce harmonics it generates. The rectifier converts ac power generated by the wind generator into dc power in an uncontrollable way; therefore, power control has to be implemented by the VSI. A current-controlled VSI can transfer the desired real and reactive power by generating an ac current with a desired reference waveform.

The maximum power available from VSWT driven synchronous generator is given by(6

$$P_M^{MAX} = \frac{1}{2}\pi\rho R^5 \frac{C_P^{MAX}}{\lambda_{OPT}^3}\omega_M^3 \tag{6}$$

The desired real power reference Pref values are calculated by (7)

$$P_{ref} = \eta P_M^{MAX} \tag{7}$$

The desired reactive power reference Qref values are calculated by (8)

$$Q_{ref} = P_{ref} \cdot \frac{\sqrt{1-PF^2}}{PF} \tag{8}$$

By using proportional-integral-derivative (PID) control gains, errors between P_{ref} and P_{inv} (measured real power of inverter)and between *Q*ref and *Q*inv (measured reactive power of inverter) are processed into the *q*- and *d*-axis reference current *Iq* ref and *Id* ref , respectively, which are transformed into the *a*-, *b*- and *c*- axis reference current *Ia* ref*, Ib* ref and *Ic* ref by the *dq* to *abc* transformation block. When the desired currents on the *a*-*b*-*c* frame are set, a pulse

width modulation (PWM) technique is applied. The error signal is compared with a carrier signal and the switching signals are created for the 6-MOSFETs of the VSI.

III. ASSESSMENT OF TRANSIENT STABILITY

Analysis of transient stability of power systems involves the computation of their nonlinear dynamic response to large disturbances, usually a transmission network fault, followed by the isolation of the faulted element by protective relaying. In these studies, two methods are used for assessing dynamic performance of the power system following a large disturbance:

- Calculation of critical fault clearing times for faults on the power system; and
- Examination of the rotor angle deviation of generators following a large disturbance.

A. Critical Clearing Time

The critical clearing time (CCT) is the maximum time interval by which the fault must be cleared in order to preserve the system stability.

Generating units may lose synchronism with the power system following a large disturbance and be disconnected by their own protection systems if a fault persists on the power system beyond a critical period. The critical period will depend on number of factors. The nature of the fault (e.g. a solid three phase bus fault or a line to ground fault midway on a transmission circuit);

- The location of the fault with respect to the generation; and;

- The capability and characteristics of the generating unit.

The calculation of the critical clearing time for a generating unit for a particular fault is determined by carrying out a set of simulations in the time domain in which the fault is allowed to persist on the power system for increasing amounts of time before being removed.

B. Rotor angle deviation

Rotor angle deviation assessment of wind power generator is one of main issues in power system security and operation.

IV. SIMULATION RESULTS AND DISCUSSION

Fig.2represents the Power system network with fault near by bus-7 with only conventional synchronous generators.

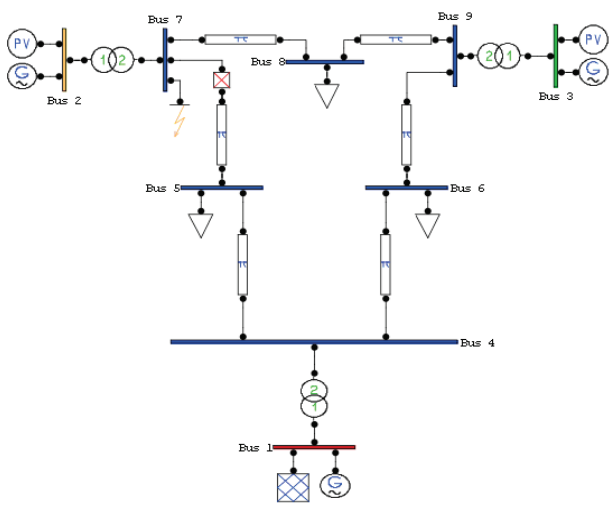

Figure 2. Power system network used in the study(IEEE 9 bus system with fault near by bus-7 with only conventional synchronous generators.

- Bus-1 - 100MVA, 16.5KV
- Bus-2 - 100MVA, 18KV
- Bus-3 -100MVA,13.8KV
- Tr-1-16.5KV/230/KV
- Tr-1-18KV/230/KV
- Tr-1-13.8KV/230/KV
- Load at bus5-125MW,50MVar
- Load at bus6-90MW,30MVar
- Load at bus8-100MW,30MVar

The capacity of the VSWT driven synchronous generator is chosen to be 1.5 MVA and real power 1.5 MW. The rated speed of the rotor is chosen to be 40 rpm. The rated wind speed is 15 m/s. the cut-in and cut-out speeds are 4 m/s and 23 m/s respectively. The switching frequency of the grid interface inverter is 1.040 kHz. The capacitor value of grid interface rectifier is 2500uF and d.c link voltage is 2.5 KV. The generated voltage of synchronous generator is 0.6KV. The transformer rating of grid connected side is 2KV/130KV. The p.u voltage magnitude of primary of the transformer is 0.99 p.u.. The grid voltage is 130KV. Figures[3-8] represents the Simulation waveform of the modeled VSWT driven synchronous generator.

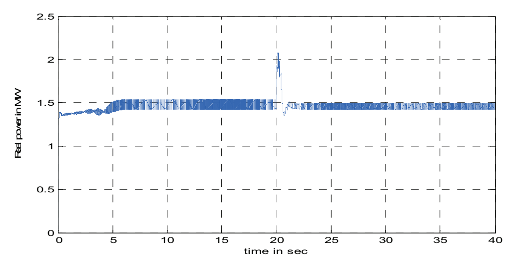

Figure 3. Simulation waveform of Real power of variable speed wind turbine

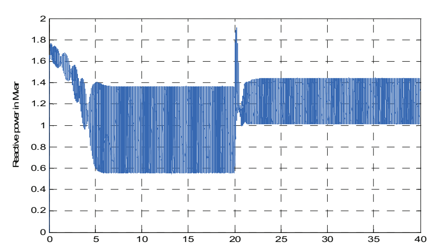

Figure 4. Simulation waveform of Reactive power of variable speed wind turbine

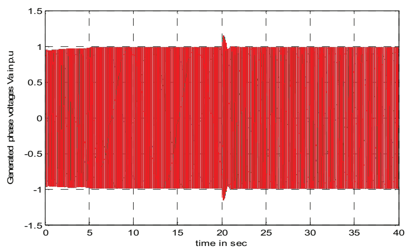

Figure 5. Simulation waveform of Generated phase voltage in p.u of variable speed wind turbine driven synchronous generator

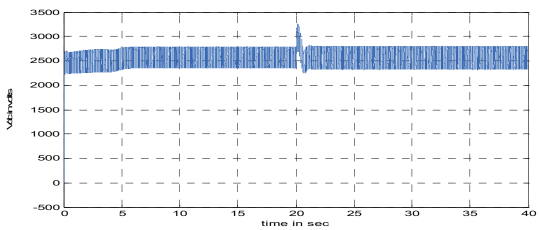

Figure 6. Simulation waveform of d.c link voltage 2.5 KV of variable speed wind turbine driven synchronous generator.

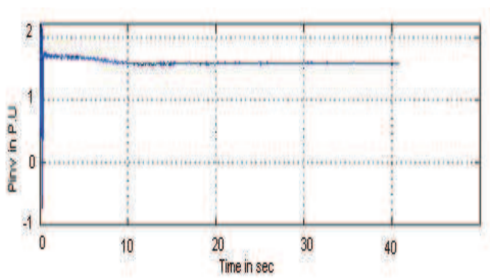

Figure 7. Simulation waveform of real power 1..5MW in grid side in p.u of variable speed wind turbine driven synchronous generator

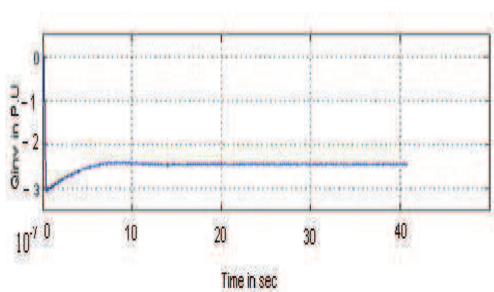

Figure 8. Simulation waveform of injected 0.25 MVAR reactive power in grid side in p.u of variable speed wind turbine driven synchronous generator

Figures[9-12] represents the voltage, real power, reactive power, rotor angle deviation for line fault near bus 7 with only conventional synchronous generators.

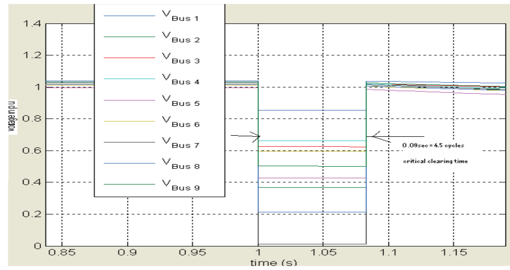

Figure 9. Voltages for line fault near bus 7 with only conventional

synchronous generators

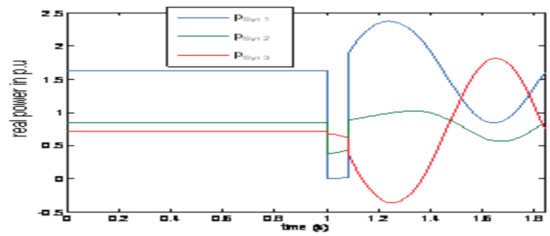

Figure 10. Real power for line fault near bus 7 with only conventional

synchronous generators

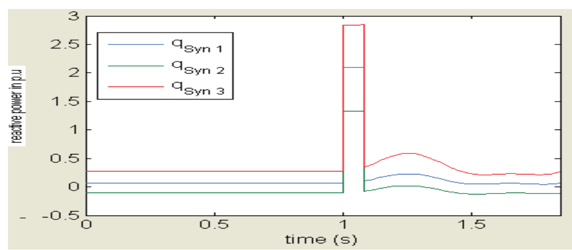

Figure 11. Reactive power for line fault near bus 7 with only conventional synchronous generators

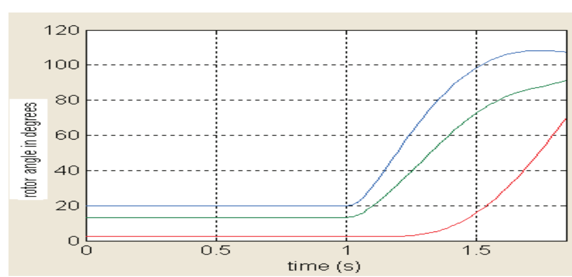

Figure 12. Rotor angle deviation for line fault near bus 7 with only conventional synchronous generators

WPP having 28 no. of wind turbine generators of capacity 1.5 MVA,600V ,50Hz is connected at bus-1. Figures[13-16] represents the voltage, real power, reactive power, rotor angle deviation for line fault near bus 7 with conventional synchronous generators replaced by the wind turbine generators.

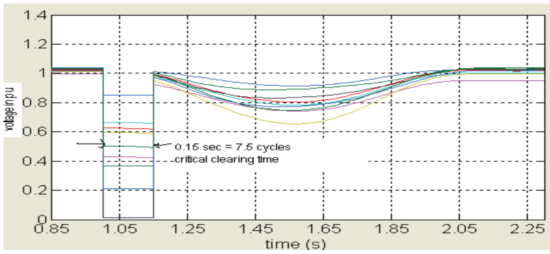

Figure 13. Voltages for line fault near bus 7 with a WPP at bus 1

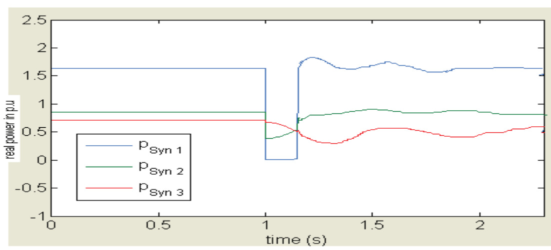

Figure 14. Real power for line fault near bus 7 with a WPP at bus 1

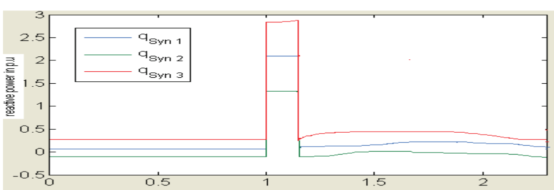

Figure 15. Reactive power for line fault near bus 7 with a WPP at bus 1

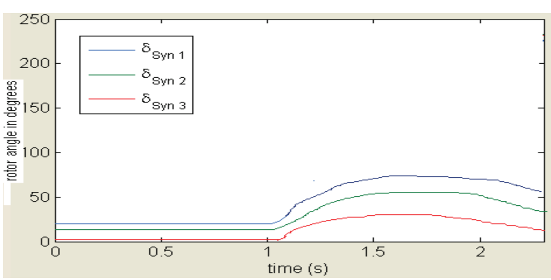

Figure 16. Rotor angle deviation for line fault near bus7 with a WPP at bus 1

Results obtained shows that for the investigated IEEE9 bus system considered in this paper, the critical fault clearing time of the generator was increased by three cycles, when the above modeled variable speed wind turbine driven synchronous generator was connected at one of the generation buses.

Rotor angle deviation was reduced nearly by 30^0 when the above modeled variable speed wind turbine driven synchronous generator was connected at one of the generation buses.

V. CONCLUSION

The dynamic model of a VSWT driven synchronous generator with power electronic interface was proposed for computer simulation study and was implemented in a reliable power system transient analysis program. This paper has mainly focused on the modeling, assessment of the rotor angular stability and critical clearing time (CCT). This was done by observing the behavior of the test system with only conventional synchronous generators and then by connecting the modeled VSWT driven synchronous generator with the test system, when a three phase fault is included. Comprehensive impact studies are necessary before adding wind turbines to real networks. In addition, users or system designers who have a plan to install or design wind turbines in networks must ensure that their systems have well performed while meeting the requirements for grid interface. The work illustrated in this study may provide a reliable tool for evaluating the performance of a VSWT driven synchronous generators and its impacts on power networks in terms of dynamic behaviors; therefore, serve as a preliminary analysis for actual applications. Fault tests carried out has proven that the integration of this model could enhance the transient stability.

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