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Stability Improvement of DFIG based WECS Connected Power System Using Custom Power Devices

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Abstracts

There is a continuously growing demand for wind power generation capacity. As the wind power generation, which depends on the weather, is integrated into the grid continuously and quickly, the influence of wind turbines on the grid power quality is becoming an important issue, especially the influence on voltage fluctuation and flicker. The system operators, who are responsible for maintaining power system stability and reliable power supply, have formulated specifications regarding grid integration of wind power generation. The reason is, when the wind power penetration level is high, the protective disconnection of a large amount of wind power will be an unacceptable consequence that may threaten the power system stability. In this paper we have have taken a test case of power system with and without custom devices which are main component of unified power quality conditioner (UPQC) or unified power flow controller(UPFC) and have shown effect of rating of these devices on stability of grid-connected doubly fed induction generator wind energy system(DFIG-WES).

Keywords: LVRT, Indian Electricity Grid code, UPFC, DFIG-WECS.

Introduction

Recently non conventional energy sources are becoming very popular and as they are infinite and clean source of electricity [1,2]. Wind energy is most popular dominant source among renewable sources of energy[3]. Among the wind turbine concepts, turbines using the doubly fed induction generator (DFIG) are dominant due to its variable-speed operation, its separately controllable active and reactive power, and its partially rated power converter. But the reaction of DFIGs to grid voltage disturbances is sensitive, for symmetrical and unsymmetrical voltage dips, and requires additional compensation support to keep the voltage within area bounded by the LVRT and HVRT margins of the electricity grid codes.

The detailed settings of the reactive power control system are provided by the respective system utility (SU). The wind farm must have adequate reactive power capacity to be able to operate with zero reactive exchange with the network measured at the connection point, when the voltage and the frequency are within normal operation limits. The following points are the standards being framed by the IEGC for reactive power exchange within the network:

- VAR drawn from the grid at voltages below 97 % of nominal will be penalized.
- VAR injection into the grid at voltages below 97 % of nominal will be given incentive.
- VAR drawl from the grid at voltages above 103 % of nominal will be given incentive.
- VAR injection into the grid at voltages above 103 % of nominal will be penalized [4].

Fault-ride through (FRT) requirement is imposed on a wind power generator so that it remains stable and connected to the network during the network faults. Disconnection from grid may worsen the situation and can threaten the security standards at high wind penetration. The wind farm must be able to operate satisfactorily during and after the disturbances in the distribution/ transmission network, and remain connected to the grid without tripping from the grid for a specified period of time during a voltage drop (LVRT) or voltage swell (HVRT) at the PCC[5].

Flexible AC transmission system (FACTS) devices have been used to maintain the WTGs penetration to the electricity grid during fault conditions and wind speed variation. This work investigates the application of unified power flow controller (UPFC) to improve the wind turbine FRT capability in compliance with Indian Electricity grid codes. FACTS devices are needed to which can either, compensate the voltage, phase shift, or both the

increase of voltage and phase shift, and real and reactive power enhancement. Among various FACTS devices we have analyzed the performance of grid connected DFIG-WES system without and with UPFC as this custom power device has unique capability of series as well shunt compensation [6].

System Under Study:- Fig.1 shows the system under study, which consists of 9 MW DFIG connected to a grid that is simulated as an ideal 3-phase voltage source of constant voltage and frequency through 21 km transmission line and two transformers.
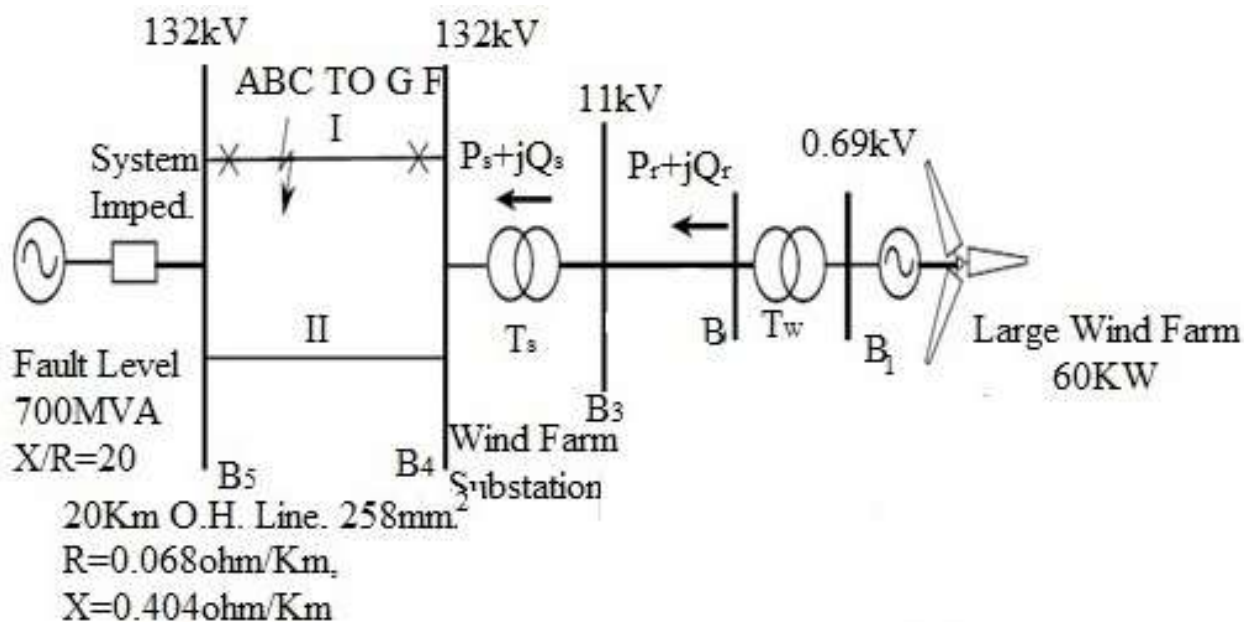
Fig. 1 Single line diagram of system under study.

The 9 MW wind farm consisting of six 1.5 MW wind turbines connected to a 25 kV distribution system exports power to a 120 kV grid through a 21 km, 25 kV feeder. A 500 kW resistive load and a 0.9 Mvar (Q=50) filter are connected at the 575 V generation bus. The turbine parameters specifying ratings of power components of the wind turbine are as follows: The wind turbine model is a phasor model that allows transient stability type studies with long simulation times. In this case study, the system is observed during 30 s. The 6-wind-turbine farm is simulated by a single wind-turbine block by multiplying the following three parameters by six, as follows:

- nominal wind turbine mechanical output power: 6*1.5e6 watts, specified in the Turbine data menu
- generator rated power: 6*1.5/0.9 MVA (6*1.5 MW at 0.9 PF).
- nominal DC bus capacitor: 6*10000 microfarads.

mode of operation is set to Voltage regulation in the Control Parameters dialog box. The terminal voltage is controlled to a value imposed by the reference

voltage (Vref=1 pu) and the voltage droop (Xs=0.02 pu). In this model the wind speed is maintained constant at 14 m/s. The control system uses a torque controller in order to maintain the speed at 1.09 pu. The reactive power produced by the wind turbine is regulated at 0 Mvar. For a wind speed of 14 m/s, the maximum turbine output is 0.55 pu of its rated power (0.55*9MW=4.95 MW) at a speed of 1.09 pu of generator synchronous.

Figure 3 show the test system for our study. It consists of a grid connected DFIG wind farm. The system is modeled with the help of Matlab Simulink and operated without any compensation and with step change in wind speed. Than the system is operated with STATCOM for various ratings and voltage is observed at various buses in both the conditions. Configuration Details of the Fig. 1 are as under,

1. One sources with a 120 KV and
2. Second sources as a DIFG wind farms sources.
3. The system impedances 2500 MVA
4. Transformer rating is 120kv/25kv and 25kv/575v with load of 500kw.

5. Grounding transformer 25kv and X/R=4.7 ohm
6. STATCOM with variable ratings ranging from 100 MVA to 10 MVA.

Simulation of Fig 1 without facts devices was done and following are the wave forms obtained. In the "Wind Speed" step block specifying the wind speed. Initially, wind speed is set at 8 m/s, then at t = 5s, wind speed increases suddenly at 14 m/s. Start simulation and observe the signals on the "Wind Turbine" scope monitoring the wind turbine voltage, current, generated active and Reactive powers, DC bus voltage and turbine speed.
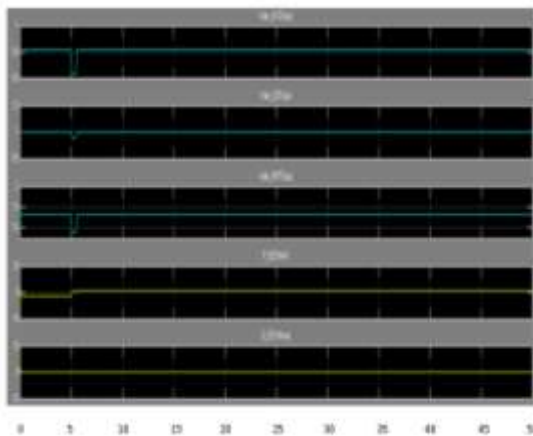
*Fig. 2 Output voltage at various buses in uncompensated system.*

At t = 5 s, the generated active power starts increasing smoothly (together with the turbine speed) to reach its rated value of 9 MW in approximately 20 s. Over that time frame the turbine speed will have increased from 0.8 PU to 1.21 PU. Initially, the pitch angle of the turbine blades is zero degree and the turbine operating point follows the yellow curve of the turbine power characteristics. Fig 5.8 shows voltage at bus 120, bus 25, bus 575 and active power and reactive power at bus 25. Waveforms shows bus B120 voltage is a 0.9 p.u., bus B25 at 1 p.u and bus B575p.u at 1.7p .u while the active and reactive power at bus 25 is 0. Initially, the pitch angle of the turbine blades is zero degree and the turbine operating point follows the yellow curve of the turbine power characteristics. Then the pitch angle is increased from 0 deg to 0.76 deg in order to limit

Fig. 3 Simulink model of uncompensated system

the mechanical power. We also observed the voltage and the generated reactive power. The reactive power is controlled to maintain a 1 PU voltage.

Simulink Model With Facts (Statcom 100 Mva) Devices On A System At B575
In this section flicker mitigation using STATCOM during continuous operation of the grid-connected wind turbine with DFIG is studied. The

studied system, the generator parameters and the base case are the same as introduced in section 5.4. The STATCOM is connected. in shunt to bus 2 (PCC) to mitigate the flicker levels. With the vector-control scheme, the DC link voltage and the reactive power generated or absorbed by the Simulation of case syatem with FACTS (STATCOM 100MVA) device of is shown in Fig 4 was done and waveforms obtained are shown in fig. 5.

In these, waveform as shown in 5 we can see that voltage at bus B120 is 0.9 p.u, at bus B25 is 1p.u, and at B575 is 1 p.u. Real power at bus B25 is 9 p.u and reactive power at B25 is a 7 p.u. Initially when wind speed was 8 m/s even the voltage at bus 575 was maintained to 1 p.u. As after 5 s wind speed changes by step to 14 m/s the real and reactive power generated by wind generated increased, at this the reactive power generated by STATCOM reduces and voltage again maintained to 1 p.u. at bus 575 after a flicker.
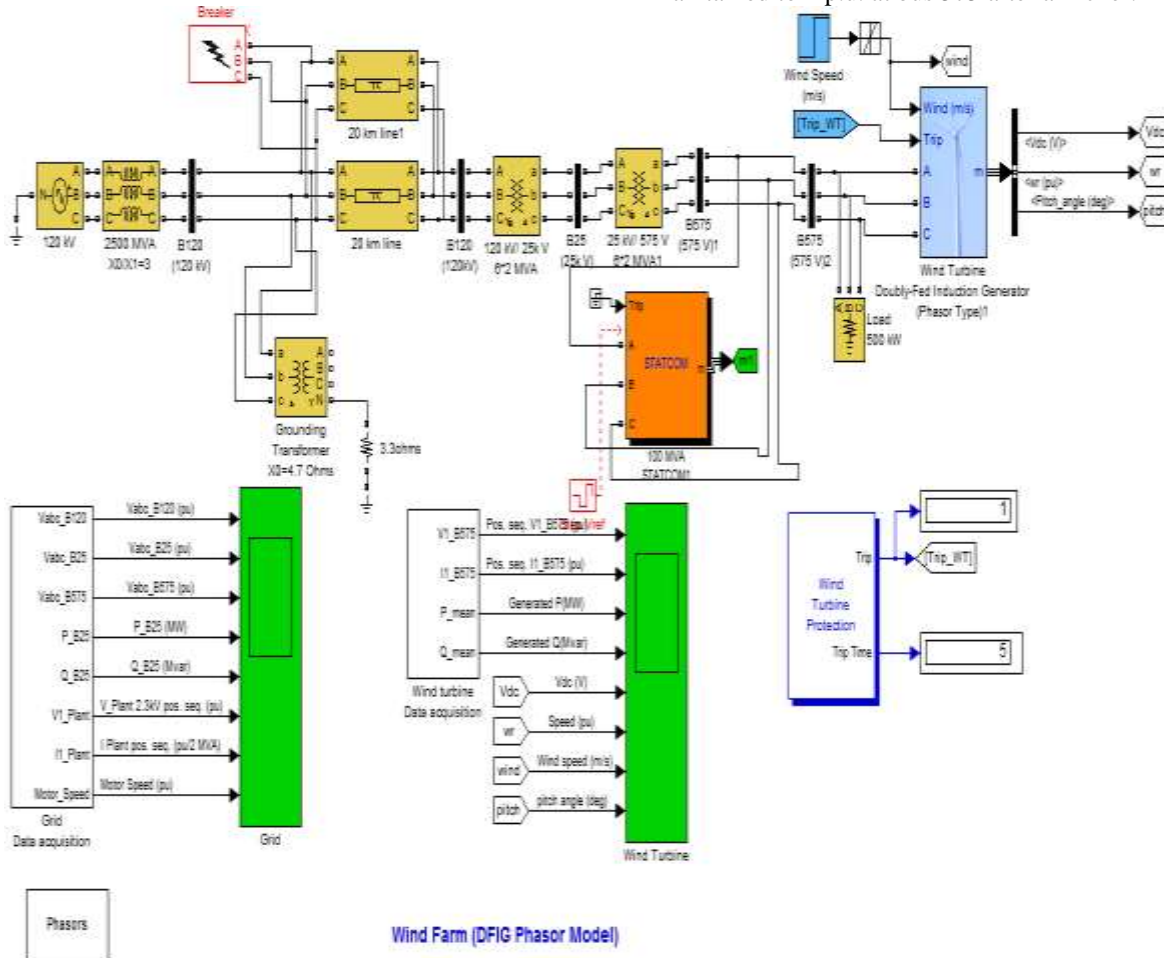
*Fig. 4 Test case model with STATCOM*
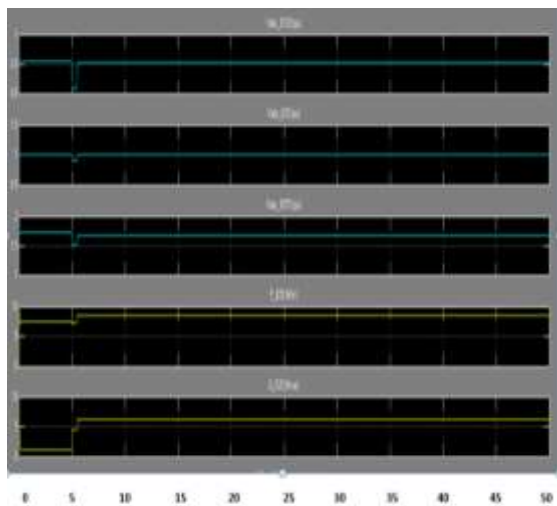
***Fig..5 Simulink result with STATCOM 100MVA
FACTS devices on a system***

In these, waveform as shown in 5 we can see that voltage at bus B120 is 0.9 p.u, at bus B25 is 1p.u, and at B575 is 1 p.u. Real power at bus B25 is 9 p.u and reactive power at B25 is a 7 p.u. Initially when wind speed was 8 m/s even the voltage at bus 575 was maintained to 1 p.u. As after 5 s wind speed changes by step to 14 m/s the real and reactive power generated by wind generated increased, at this the reactive power generated by STATCOM reduces and voltage again maintained to 1 p.u. at bus 575 after a flicker.

Simulink with FACTS (STATCOM 30MVA) devices on a system at B575

We have connected a UPFC to the PCC bus to increase the WTG damping and to provide support to the system during fault conditions. The model of the power system scheme for case study is illustrated in Fig.2, including the controllers with the control strategy, is implemented using Matlab/Simulink software. During normal operation, the reactive power produced by the wind turbines is regulated at 0 Mvar to achieve unity power factor operation. For an average wind speed of 14 m/s, which is used in this study, the turbine output active power is 1.0 pu and the generator speed is 1.0 pu. The UPFC is used to improve the FRT of the WTGs, by controlling the active and reactive power at the bus it is connected. Numerical simulations are performed to determine and then compensate voltage fluctuation due to wind power variation, and voltage regulation problems due to a sudden load connection.. Simulation of the with FACTS (STATCOM) devices was done and Following are the waveforms obtained
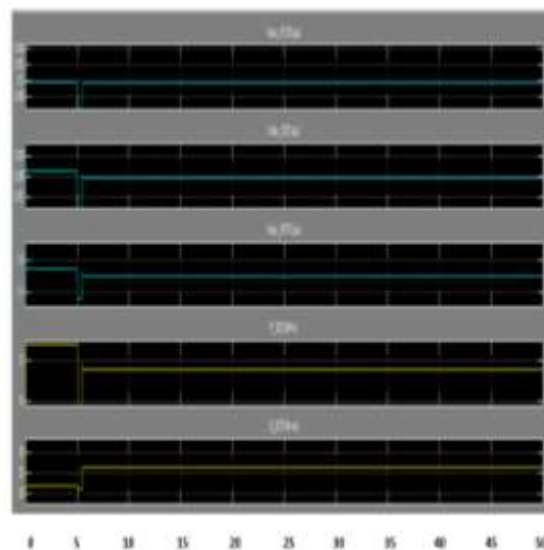

***Fig. 6 Simulink result with FACTS (STATCOM 30MVA)
devices on a system at B575.***

Fig 6 shows that bus B120 is 0.9p.u, bus B25 is 0.98 and bus B575 is a 1.2.u. Active power at bus B25 is 11p.u. and reactive power at bus B25 is a 26p.u. Since the STATCOM is not of sufficient capacity so the voltage at bus B575 is not maintained at unity. Also voltage flicker is of high magnitude at step change in wind speed.

Simulink model with FACTS (STATCOM 10MVA) devices on a system at B575

Simulation of the power system shown in Fig.1 with FACTS (STATCOM 10 MVA) devices was done and Following are the waveforms obtained
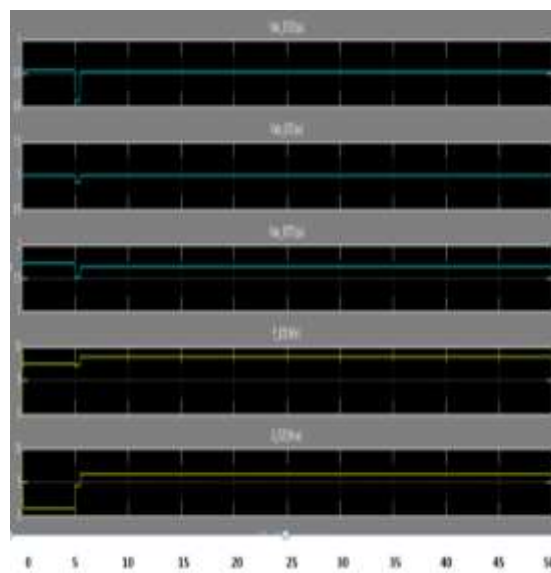
***Fig.. 7 Simulink circuit with FACTS (STATCOM
10MVA) Devices on a system at B575.***

Fig 7 shows the voltage at bus B120 is 0.9 p.u , at B25 is a 1p.u, and at bus B575 is 1.5 and active power at bus B25 is 6 p.u, reactive power is at bus B25 is 9 p.u. Based on the principle, flicker mitigation is realized by controlling the wind turbine output reactive power and using STATCOM during the continuous operation of grid-connected wind turbines with DFIG. Simulation results demonstrate that these two measures are effective for flicker mitigation regardless of mean wind speed. Also STATCOM must be of sufficient MVA rating to absorb or deliver required amount of reactive power to maintained voltage at various buses of system

Table 5.1
Comparison of voltages at various bus under variable compensation by STATCOM.

Bus. No.	Uncompensated system	Compensated with STATCOM		
		100 MVA	30MVA	10 MVA
B575	1.7	1	1.2	1.5
B25	1	1	1	1
B120	0.9	0.9	0.9	0.9

From table we can conclude that when system was operating without STATCOM , on step change in speed of wind the steady state voltage rises to 1.7 p.u. at bus B575, a much higher voltage than rated. Now with STATCOM compensation voltage is maintained nearby 1 p.u., so effect of rise in speed in wind is nullified and voltage is maintained at unity with sufficient capacity of STATCOM.

Conclusion
In this paper, a new compensation strategy implemented using an UPQC type compensator was presented, to connect SCIG based wind farms to weak distribution power grid. The proposed compensation scheme enhances the system power quality, exploiting fully DC–bus energy storage and active power sharing between UPQC converters, features not present in DVR and STATCOM compensators. The simulation results show a good performance in the rejection of power fluctuation due to power shadow effect and the regulation of voltage due to a sudden load connection. So, the effectiveness of the proposed compensation approach is demonstrated in the study case.
Based on the principle, flicker mitigation is realized by controlling the wind turbine output reactive power and using STATCOM during the continuous operation of grid-connected wind turbines with DFIG. Simulation

results demonstrate that these two measures are effective for flicker mitigation regardless of mean wind speed. Also STATCOM must be of sufficient MVA rating to absorb or deliver required amount of reactive power to maintained voltage at various buses of system.

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