

Simulation, Analysis and Mitigation of DFIG Oscillatory behavior Related to FIDVR Problem

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ABSTRACT: the use of renewable source to produce electric power is increasing day by day. Among such various sources wind energy has taken place to contribute towards massive energy requirement due to its abundant availability and economical aspects. Use of DFIG technology in wind farms is gaining popularity due to new developments in power electronic devices. To make better use of such renewable sources there is trend to integrate them with existing distribution system or local systems. With such integration there are new problems arising in the system such as Fault Ride Through, Sub-Synchronous Resonance, harmonics etc. this project deals with one of such problem where it can be seen than DFIGs in a wind farm connected to Distribution system shows oscillatory behavior due to Fault Induced Delayed Voltage Recovery (FIDVR). In first part paper symptom of FIDVR Problem and oscillatory behavior of DFIG is simulated and analyzed. In second part a control scheme using FACTS Controllers is implemented to minimize the FIDVR Problem and Oscillations in DFIG.

KEY WORDS: DFIG, FIDVR, DSTATCOM, DVR

I. INTRODUCTION

There is continuous increase in electricity demand worldwide. Hence there is a need of boosting the electric power generation to assure minimum contingencies and efficient operation of the transmission and distribution networks. A simple method to do this is the use of non conventional energy sources such as Solar Photo-Voltaic Plant and wind power plants reinforced in existing power grid. In this project a 9MW wind farm connected to Distribution-system is focus of the analysis and simulation

Power system transient behaviour and its dynamics are highly affected by the kind of Load present in the system. Load characteristic of low inertia components such as induction motor is a point of worry in present era as it contributes to large part of electric load worldwide due to its industrial applications and household use.

In the event of fault or disturbance it has been found that induction motor show stall behaviour i.e. Locked Rotor Effect which affect the recovery bus voltage at which motor is connected where in bus voltage take extra cycles to recover to its equilibrium value, commonly called as "Fault Induced Delayed Voltage Recovery" (FIDVR) also in severe condition this may result in voltage collapse [1].

FIDVR results in voltage dip for tens of second reducing the power quality. There may be unnecessary operation of distribution fuses and automatic recloses (ARs) due to high currents during FIDVR. It also degrades the performance of transmission circuits and other device present in system such as generators, transformers etc.

In this project stability problem occurring in the DFIG due to FIDVR problem in the system is simulated and analysed. This paper is organized as follows: Section I is the introduction, in Section II FIDVR problem is presented, Section III gives the details of modelled system, and in Section IV simulation results and Discussion are presented. Finally conclusion is presented in Section V.

II. PROBLEM STATEMENT

FIDVR phenomenon occurs when there is large concentration of induction motor load. These motors shows locked rotor tendency in the event of fault or in major disturbance in the distribution and/or transmission system due to which voltage takes several seconds to recover its equilibrium point even after fault has been cleared. This event is also characterized by conditions [7].

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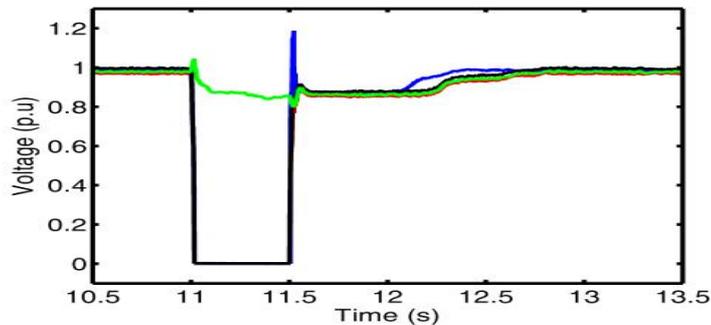


Fig. 1 Typical FIDVR problem

- Stalling of induction motor.
- Excessive consumption of active and reactive power by motor.
- Motor speed is significantly low for several seconds sometimes motor may decelerate to a value which blocks its rotor.
- Motor torque takes longer time to reach equilibrium point.

This phenomena also affect the performance of other components in system such as generators, transformers and protective relays, in this project it can be seen that DFIGs in wind farm shows oscillatory behavior with oscillation lasting up to 10 seconds having considerably high amplitude which has to be controlled to avoid damage to generators in wind farm.

III. SYSTEM MODELLING

Single line diagram of typical 9-MW wind farm is as shown in Fig. 2, wind farm is an equivalent model of six 1.5MW DFIGs and wind turbines. This wind farm feeds to a 25000MVA grid at 120kV through a 25kV distribution system. Distribution system contain a 2MVA plant working at 2300V, it contain a 1.68 MW squirrel Cage induction motor with 0.93 PF and a resistive load of 200kW. Another 500kW resistive load is present near to wind farm at B575 bus. A 575V/25kV, 12MVA transformer connects wind farm and Distribution system and 25kV/120kV, 47MVA transformer is used to connect distribution system and grid.

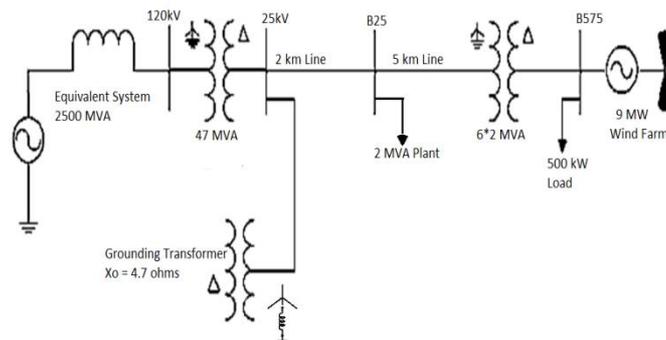


Fig. 2 Layout of typical wind farm connected to a Distribution System

Wind farm employs doubly fed induction generator (DFIG) technology in which there is a wound rotor induction generator and an AC/DC/AC PWM converter. Stator winding of generator is directly connected to grid operating at 60Hz frequency while rotor is fed through the AC/DC/AC Converter which provides various frequency voltage and current

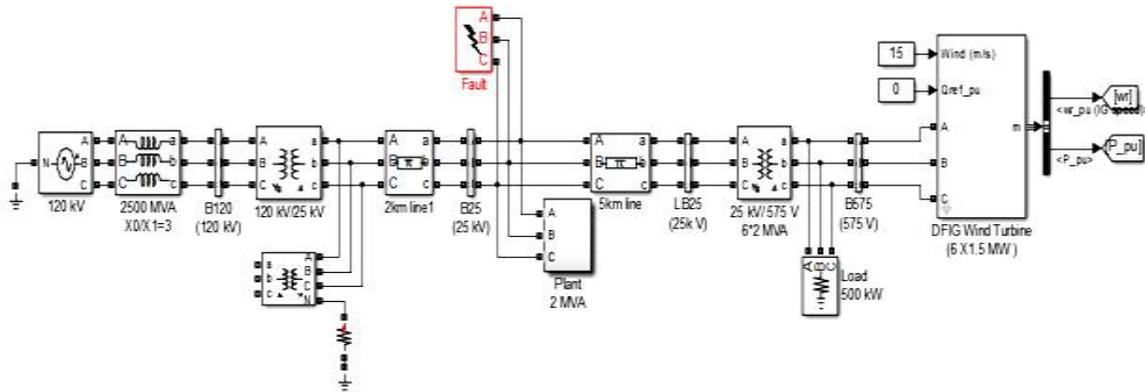


Figure 3 MATLAB Simulink model of SLD shown in Figure 2

Converter uses the IGBT switches which are simple to control and have high current capacity. In this simulation wind speed is considered to be constant at 15 m/s and the speed of generator is 1.2 pu during its normal operation. The turbine is modelled to regulate its reactive power output to 0 Mvar.

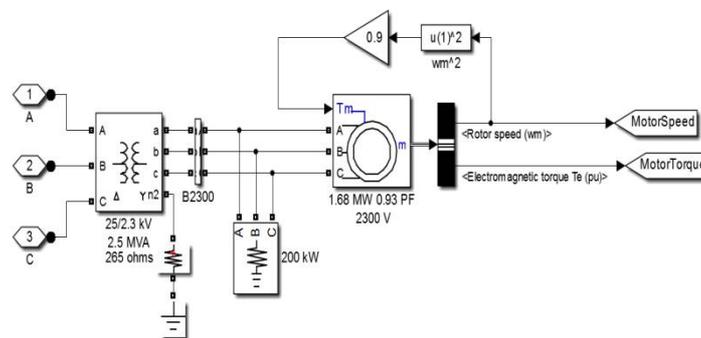


Fig. 4 MATLAB Model of 2 MVA plant

IV. RESULTS AND DISCUSSION

Typical wind farm on which simulations are carried out is shown in Fig. 2. Here system is modelled in 3- ϕ configuration, the simulations are carried out in MATLAB Simulink software and all the results are plotted in time domain.

To analyse FIDVR problem and its effects in system, an L-L short-circuit is applied in phases A and B at the bus V25. The fault details are as given below.

1. Fault resistance $R_f = 1\text{m}\Omega$
2. Fault application time = 10 second
3. Fault cleared time = 10.5 seconds

Results of simulation are as shown below

A. Case 1: Simulation, Analysis of FIDVR and Oscillatory behaviour of DFIG

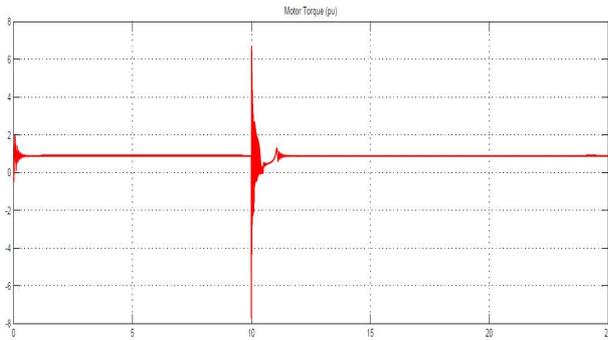


Fig. 5 Electromagnetic torque of the motor

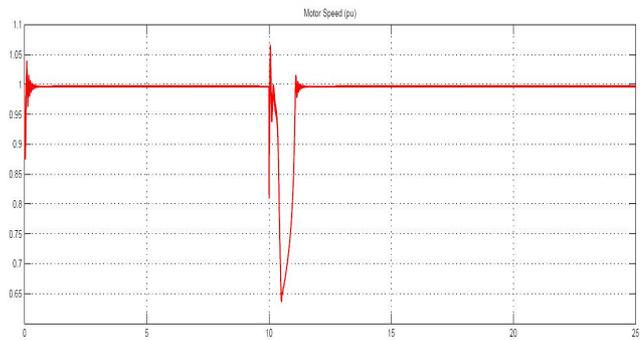


Fig. 6 Motor Speed

The Fig. 5 is the behavior of the electromagnetic torque of the induction motor. It can be seen that transient period of torque lasts about one second where as fault has ended 0.5 second later its application. In Fig. 6 it can be seen that speed takes more than 0.5sec to recover to its rated speed and speed drops to a value less than 0.65 pu i.e. speed drops to value less than 1170 rpm where as steady state speed is 1800 rpm.

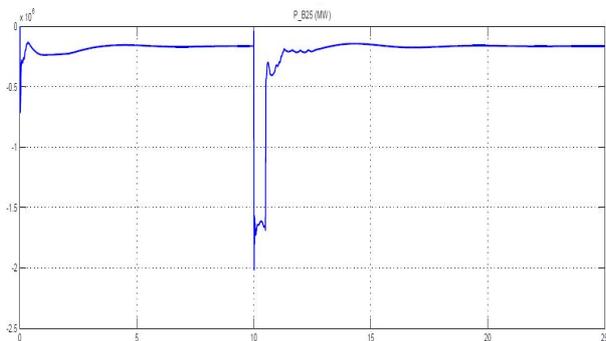


Fig. 7 Consumption of active power at bus B25

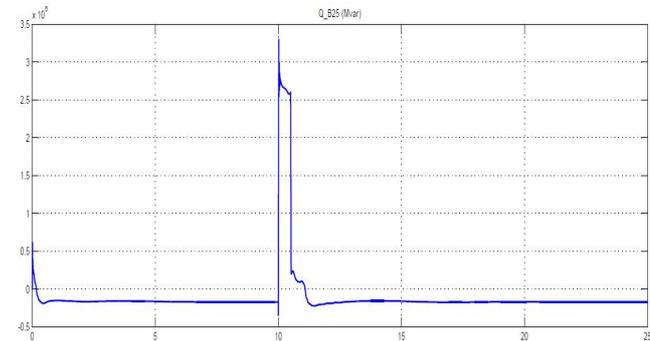


Fig. 8 Consumption of reactive power at bus B25

In response to get rid of this low speed condition the motors accelerates and consumes extra active and reactive power more than 2 times compared to pre-fault condition it can be seen in Figs.7 and 8

Results shown in figs. 5, 6, 7 and 8 are the characteristic symptoms of Fault Induced Delayed Voltage Recovery and Fig. 9 shows the actual FIDVR simulated in the system.

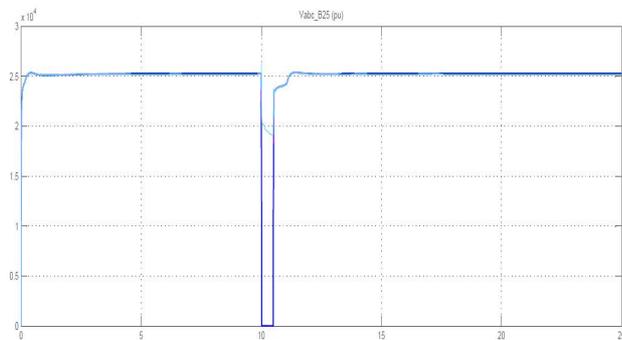


Fig. 9 Voltage measured at bus B25

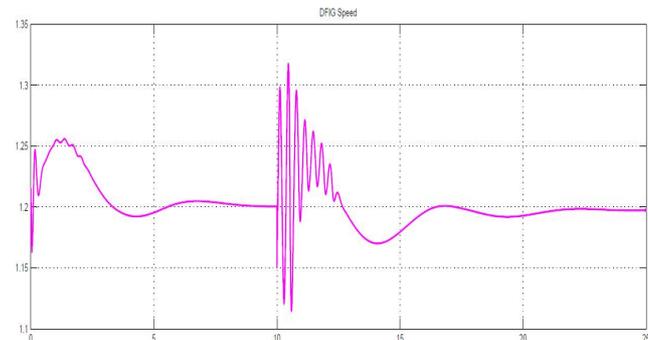


Fig. 10 DFIG Speed

In Fig. 9 it can be seen that with increased consumption of reactive power by the motors, the rms L-L voltage at bus B25 i.e. bus at which fault has occurred has a delay of more than 0.5 second in its recovery

Fig. 10 shows the effect of FIDVR on speed of DFIG generator. It can be seen that due to the negative sequence component of torque there are oscillation in DFIG speed which lasts more than 5 seconds also amplitude of oscillations exceeds the amplitude of 1.3 pu, which is harmful to the generator. These oscillations are successfully mitigated using FACTS Devices which can see in case 2 results.

B. Case 2: Mitigation of FIDVR and Oscillatory Behaviour of DFIG

A 3Mvar DSTATCOM and a DVR is used to control the problem of Delayed voltage recovery and minimize the electromechanical oscillations in the DFIG. Implemented control scheme is as shown in fig.11 Specifications of these FACTS devices are as given below

Specifications of DSTATCOM

- Coupling transformer of rating 25kV/1.25kV, it couples PWM inverter of D-STSTCOM with line to be compensated
- A PWM Voltage-Sourced Inverter with switching frequency 1.68 kHz
- LC damped filters with $L=0.8\text{mH}$ and $C=100\mu\text{F}$ is connected at the inverter output and the Q-factor of this filter is 40
- A 10000 μF Capacitor which acts as a DC voltage source for the inverter
- Anti-aliasing filters which provides acquisition of voltage and current

Specifications of DVR

- Three single phase 25kV/360V transformer units which acts as boosting transformer
- A IGBT based Voltage Source Inverter which is used to convert DC power stored into AC output
- A 700V battery unit to provide power to device Passive Filter unit with $R=1\Omega$ and $C=100\mu\text{F}$
- A controller unit which uses Fourier analysis to generate switching signals for IGBT's of VSI

Results for proposed control scheme are as shown below.

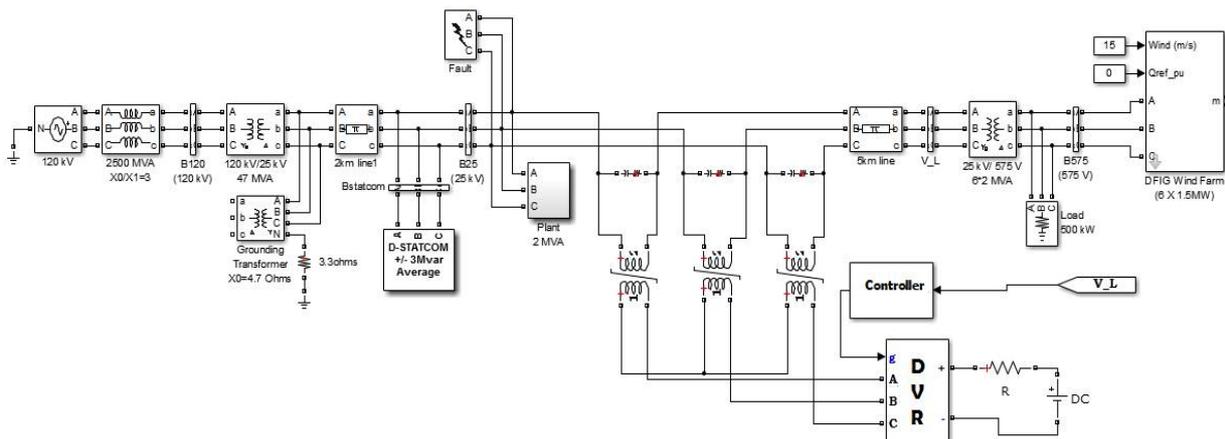


Fig. 11 implemented control scheme

In this control scheme a 3Mvar DSTATCOM is used to compensate for extra reactive power consumed by motor. A DVR is used to counteract Voltage imbalance and to provide voltage regulation.

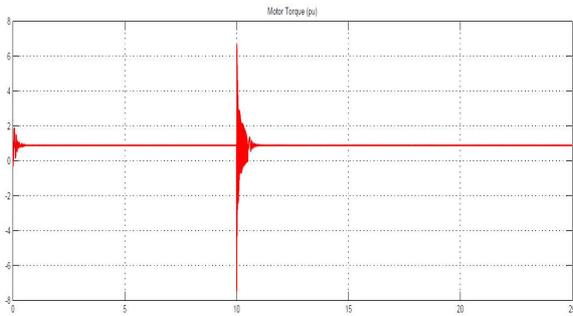


Fig. 12 Electromagnetic torque of the motor after mitigation of FIDVR

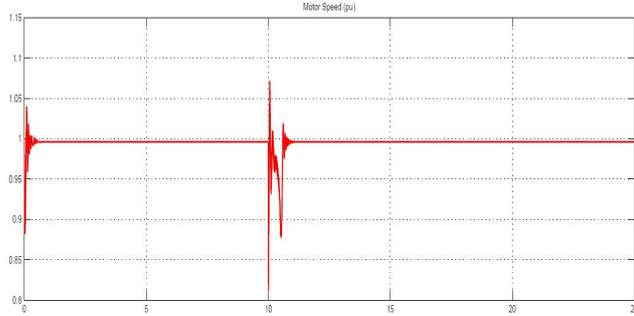


Fig. 13 Motor Speed after mitigation of FIDVR

In Fig. 14 it can be seen that excessive active power consumed seen in previous case has been reduced also in Fig. 15 it can be seen that reactive power consumption at bus B25 is almost at 0 Mvar due to injection of reactive power by DSTATCOM

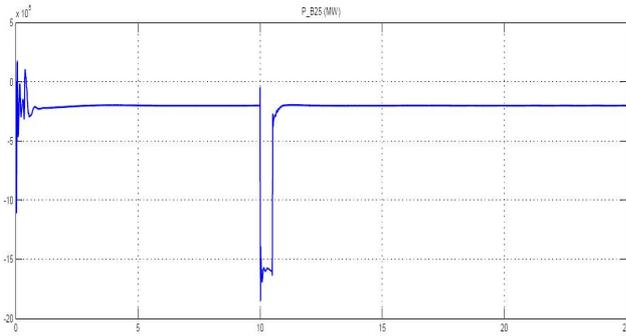


Fig. 14 Consumption of active power at bus B25 after mitigation of FIDVR

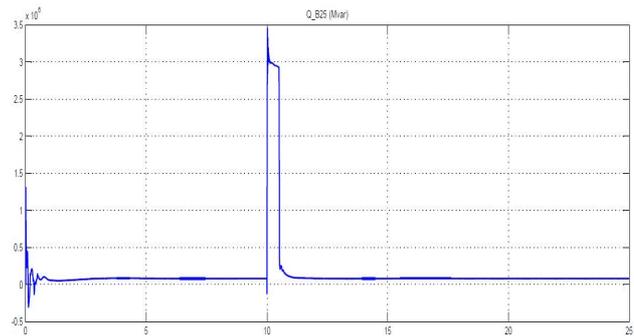


Fig. 15 Consumption of Reactive power at bus B25 after mitigation of FIDVR

Due to compensation of Reactive power we can see that electromagnetic torque of motor reaches steady state quickly as compared with case1 as seen in Fig.12 which imparts less stress on motor. It can be seen in Fig. 13 that speed of motor also reaches steady state earlier than seen in case1 and speed drop during transient period is very less i.e. speed does not drops below 0.85 pu which prevents damage of motor. As result we can see that voltage at bus B25 recovers almost instantaneously after fault has been removed as shown in Fig. 16

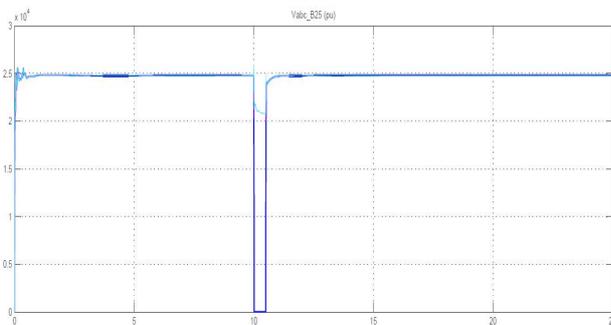


Fig. 16 Voltage measured at bus B25 after mitigation of FIDVR

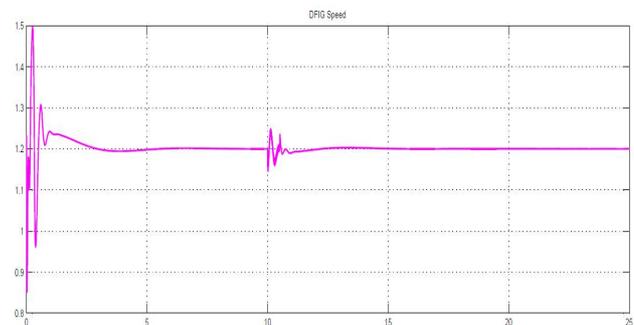


Fig. 17 DFIG Speed after mitigation of FIDVR

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In Fig. 17 it can see that speed of DFIG has negligible electro mechanical oscillations also their amplitude is very less as compared with Fig. 10 in case1. It can be seen that in case1 oscillations in DFIG lasts more than 5 seconds but in case2 DFIG speed is recovered almost instantly as fault is removed.

V. CONCLUSION

In first part of this paper simulation of the FIDVR problem is carried out in a typical wind farm and its effect on performance of DFIG are analysed. It is found that negative sequence component of electromagnetic torque directly affects the speed of DFIG. This negative sequence torque cause motor to take longer time to reach steady state, consuming extra active and reactive power and eventually causing delayed in voltage recovery of bus where induction motor is connected which results in oscillation in speed of DFIG.

In second part of simulation a DSTATCOM and DVR is used in the system which compensates for the extra reactive power consumed by the motor and also eliminates the voltage dip and imbalance in bus voltage resulting motor to reach its steady state quickly. This quick recovery of motor reduces the FIDVR problem also helps to eliminate the oscillations in DFIG speed.

VI. APPENDIX

Table 1 Parameters of Induction Motor in 2MVA Plant.

Parameter	Description	Value
P_{motor}	Nominal power of motor	1.68MW
R_s	Stator Resistance	0.0092 p.u.
L_{1s}	Stator Leakage Reactance	0.0711 p.u.
R_r'	Rotor Resistance	0.007 p.u.
L_{1r}'	Rotor leakage reactance	0.0717 p.u.
L_m	Mutual Inductance	4.12 p.u.
H_m	Inertial constant of motor	0.1 seconds
P	Motor pole pairs	2
V_n (rms)	Voltage (L-L)	2300 V
F	Frequency	60 Hz

Table 2 System Parameters of DFIG's in win farm.

Parameter	Description	Value
P_n	Power output of generator	1.67MVA
V_{s_nom} (rms)	Nominal stator voltage (L-L)	575V
R_s	Stator Resistance	0.023 p.u.
L_{1s}	Stator Leakage Inductance	0.18 p.u.
R_r'	Rotor Resistance	0.016 p.u.
L_{1r}'	Stator Leakage Inductance	0.16 p.u.
L_m	Mutual Inductance	2.9 p.u.
P	No. of pole pairs of generator	3
H_g	Inertia constant of Generator	0.1 p.u.
H_t	Wind turbine Inertia constant	3 sec.
K_{sh}	Shaft Spring Constant	0.579 sec.
D_{sh}	Shaft Mutual Damping	0.01 torque/p.u.
C_{dc}	DC Bus Capacitance	10000 μ F
$V_{C_{ref}}$	Nominal DC Bus Voltage	1150 V
P_r	Mechanical output of Turbine	1.5MW

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