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Reactive Power Control of DFIG Wind Turbine Integrated with Grid Under Symmetrical and Unsymmetrical Fault Conditions

Sarika Shrivastava[1], K.S. Verma[2] and Anurag Tripathi[3]

[1]Department of Electrical Engineering, Kamla Nehru Institute of Technology, Sultanpur, U.P, India
[2]Department of Electrical Engineering, Kamla Nehru Institute of Technology, Sultanpur, U.P, India
[3]Department of Electrical Engineering, Institute of Engineering & Technology, Lucknow, U.P., India
(sarikashri@yahoo.com, ksv211@rediffmail.com, anurag.tripathi.aparna@gmail.com,)
Corresponding Author, First Author email: sarikashri@yahoo.com
contact no.: +919335225157

Abstract

Variable-speed Wind Energy Conversion Systems based on doubly fed induction generators have a strong and substantial presence in today's wind power segment. Variable-speed operation of wind turbines offer to reduce stresses of the mechanical structure, noise reduction and the possibility to control active and reactive power. Presence of reactive power is mandatory for the stable and reliable operation of the power system. Doubly fed induction generator based wind turbines are capable of supplying both active and reactive power. For accurate assessment of the stability of the system and to control the voltage, the availability of reactive power in the system is a must. The shortage of reactive power is compensated by VAR regulators in power system. The situation worsens at the advent of various types of power system faults. The present paper explains the response of the reactive power in doubly fed induction generator wind turbine system to grid disturbances under normal, symmetrical fault & unsymmetrical fault conditions with and without VAR regulator.

Keywords-wind energy conversion system, doubly fed induction generator, symmetrical fault, unsymmetrical fault, reactive power, stability

I. INTRODUCTION

There is an augmented emphasis on the exploitation of renewable energy sources for supplementing electrical power generation from conventional sources worldwide. Amongst these renewable sources, wind energy based conversion systems are found to be most viable in contributing substantial amount of electric power. With increased penetration level, the characteristics of the different types of wind generating systems used in wind turbines start to affect the behavior of the power system differently. Growing penetration of wind energy conversion system (WECS) in the conventional power system has put tremendous challenge to the power system operators as well as planners to ensure reliable and secure grid operation [1]. Most of the wind turbine manufactures are developing new larger wind turbines in the range of 3 to 5 MW. Such wind turbines are all based on variable-speed operation with pitch control using a direct-driven synchronous generator (without gearbox) or a doubly-fed induction generator (DFIG). The characteristics of DFIG are high efficiency, flexible control and low investment. Due to reduced power rating requirements for the power electronic converters and ease of control, DFIG are increasingly employed for supplying the power either straight to the grid or for isolated loads from wind energy. Due to bi-directional power flow capability of the converters, DFIG can be operated in sub-synchronous or super-synchronous speed. The stator winding of DFIG is directly coupled to the power grid while the rotor is connected to the grid through a back-to-back converter, which only takes about 20–30% of the DFIG rated capacity for the reason that the converter only supplies the exciting current of the DFIG. The back-to-back converter consists of machine-side converter (MSC), DC Link capacitor and grid side converter (GSC). The regulators of the converters have significant effect on the stability of grid-connected DFIG [2].

II REACTIVE POWER CAPABILITY OF DFIG

Reactive power is mandatory for the stable and reliable operation of the power system. It is essential for the flow of active power from generator to the load centers and maintains bus voltage within the desired limits. Grid utilities require extended reactive power supply capability not only during fault condition but also in steady-state operation [2].Availability of adequate reactive power is essential for the stable operation of electrical power system. Conventional SCIG based wind turbines are not able to provide reactive power support themselves and equipped with static sources like capacitor banks or dynamic reactive power sources like SVCs. While DFIG based wind turbines are capable of supplying active and reactive power both. They are faster acting reactive power sources compared to synchronous generator directly connected to the grid [3]. This results in better voltage control.

III. MODELING OF DFIG WIND TURBINE SYSTEM

Fig 1 shows the static model of DFIG.

Fig 2 depicts the simulation model of DFIG based wind farm under study. DFIG which is essentially a wound rotor induction generator is fed by drive train system. The drive train system consists of low speed shaft, gearbox and high speed shaft which is directly coupled to the rotor of the DFIG. The three phase stator winding is directly connected to the grid whereas rotor wind is connected to the grid via machine-side converter, dc-link and rotor-side converters. The converters are three phase back-to-back converter insulated gate bipolar transistor (IGBT) based pulse width modulation (PWM). Their control system of DFIG also includes three parts: machine-side converter controller, grid-side converter controller and wind-turbine controller. The function of these controllers are to inject smooth electrical power at constant voltage and frequency to the power grid whether the wind system is working at sub-synchronous speed or super-synchronous speed, depending on the speed of the wind[4].

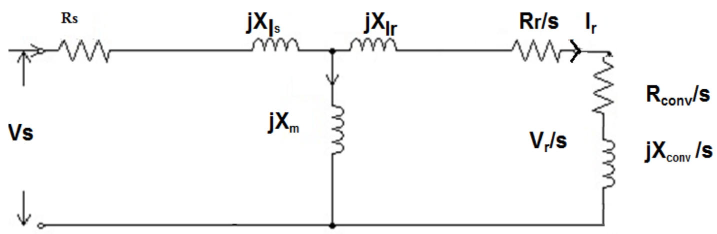

Fig.1 Static model of DFIG

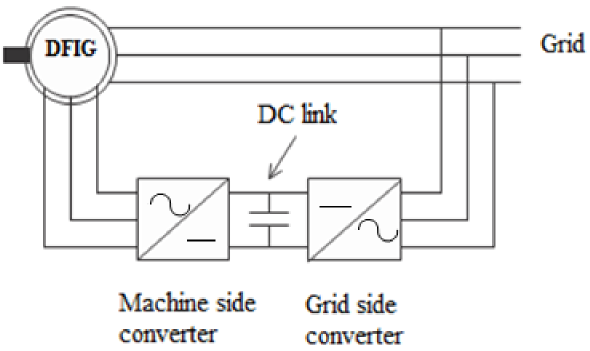

Fig.2 Simulation Model of Doubly-fed induction generator connected with grid

The maximum power coefficient may be achieved by controlling the WT speed in order to track the maximum power from wind. The tracking strategy for the DFIG is achieved by driving the generator speed along the optimum power speed characteristic curve, which corresponds to the maximum energy capture from the wind.

The DFIG can operate in both sub- and super-synchronous speed. Availability of consistent wind is required for the reliable operation of the wind energy conversion system connected to grid. To extract the power available in wind at variable wind speeds, the variable speed operation of DFIG is satisfactory where the speed range requirements are small e.g. ±30% [5].

Fig. 2 depicts a configuration of DFIG based energy conversion system. The stator is integrated with LV distribution grid whereas rotor is linked with grid via MSC, GSC and harmonic filter. The converters, MSC and GSC are connected back-to-back via a common dc- link coupling capacitor. Proposed VAR regulator is included in MSC controls to control the reactive power at wind turbine output. It regulates the reactive power Q under normal and symmetrical and unsymmetrical fault conditions to ensure stable operation of power system[6, 7].

IV. DFIG SYSTEM DESCRIPTION

A DFIG-based wind turbine of 1.5 MW is coupled to a 25 kV bus via 575/25 kV transformer. 25 kV bus is integrated with 120 kV grid via 5 km feeder and 25kV/120kV transformer. In the Fig. 3 the doubly-fed induction generator (DFIG) which is essentially of a wound rotor induction generator is integrated with grid, there is a direct coupling of stator with grid and IGBT based PWM converters in the rotor circuit establish the connection between rotor and grid. Both the PWM converters are coupled by dc-link capacitor of 10pF.

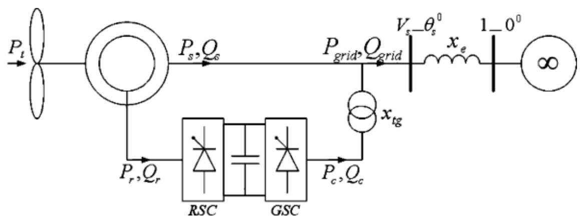

Fig. 3 Active & Reactive Power Flow in DFIG wind turbine connected to grid

Due to variable speed operation, the DFIG based wind energy conversion systems are capable of capturing maximum energy from the wind for lower wind speeds by optimizing the turbine speed. During gust of wind there are severe mechanical stresses and vibrations in the low speed and high speed shaft of the turbine and there effect can be minimized by adjustable speed of DFIG.

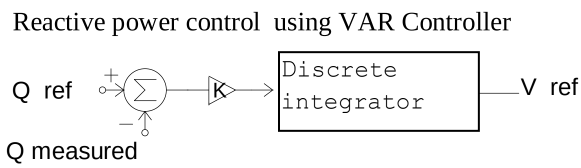

Fig.4 VAR Controller

With the help of VAR regulator of proportional gain Kp of 0.04, the reactive power at DFIG terminal is regulated around zero value. The system is simulated under various conditions and corresponding results were obtained *using MATLAB/Simulink.*

V. DFIG RESPONSE TO VARYING OPERATING CONDITIONS

A 9 MW doubly fed induction generator based wind farm generating voltage at 575 V is connected to 25 kV bus via step-up transformer of 575V /25kV. The 25 kV bus is linked to the 120 kV grid through a line of 5 km length as shown in fig. 3. The reactive power at the 575 V bus is measured under normal and fault condition. Different types of symmetrical and unsymmetrical faultsoccurnear 25 kV grid at 1/60 sec and is cleared at 5/60 sec and corresponding simulation results are obtained.The simulation results with and without VAR regulator are as follows:

Case I: DFIG connected to grid under normal condition with & without control of Reactive power Qgrid at 575 V bus:

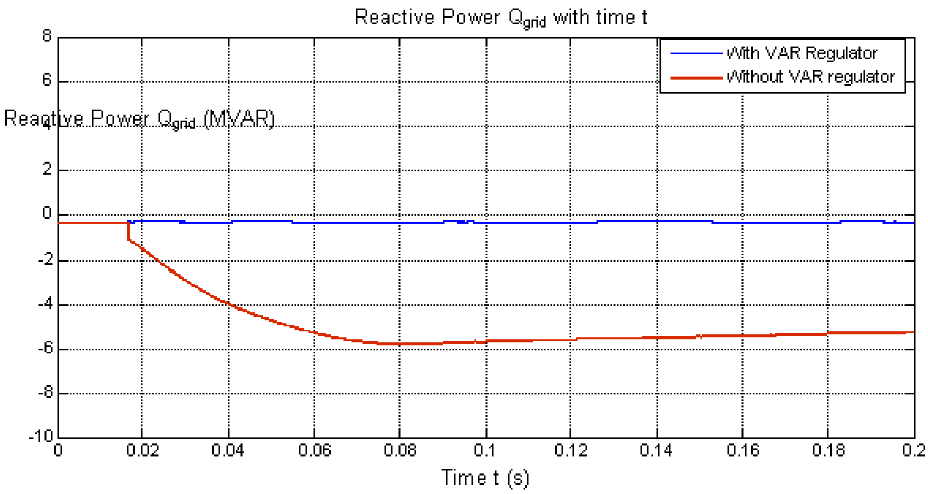

Fig. 5 Simulation result for normal operation with & without control of Q_{grid}

The simulation results shown in fig 5 depict large variation in reactive power Q without using VAR regulator. When VAR regulator is connected in machine-side converter the reactive power at the grid is regulated at reference value. The reference reactive power is 0 VAR.

Case II: DFIG connected to grid under the condition of symmetrical fault LLLG with & without control of Reactive power Q:

A three phase symmetrical fault LLLG has been included at 25kV grid.

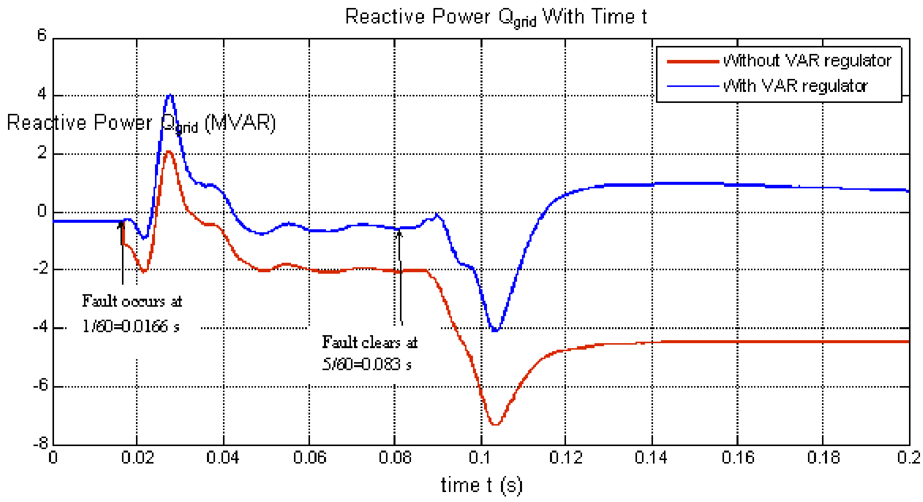

Fig. 6 Simulation result for symmetrical fault(LLLG) with and without control of Reactive Power Q_{grid}

Under the condition of symmetrical LLLG fault at the grid, there are large variations in Q with time. With the inclusion of VAR regulator the variation in VAR has been reduced considerably as shown in fig. 6.

Case III: DFIG connected to grid under the condition of LLG with & without control of Reactive power Q

When an unsymmetrical LLG fault occurs on the bus, there are large variations in reactive power with time without VARregulator as shown in Fig.7. Byusing VAR regulator the reactive power is regulated around reference value.

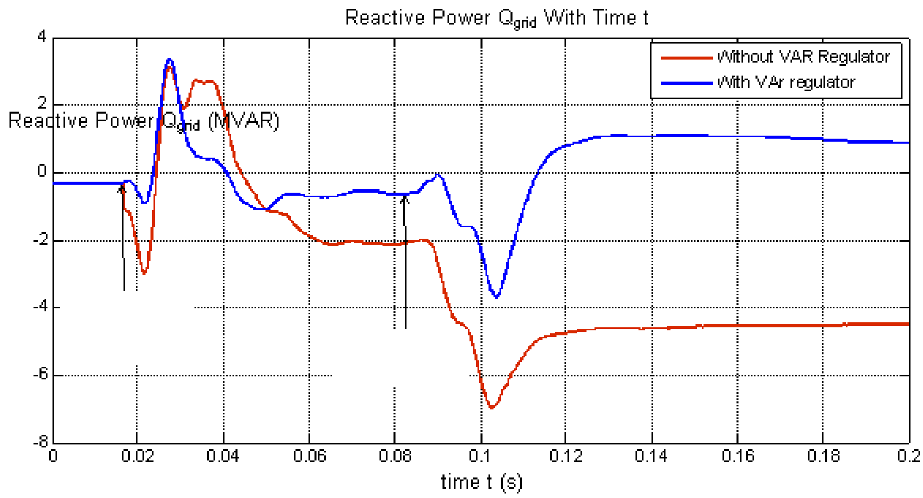

Fig. 7 Simulation result for unsymmetrical fault (LLG) with and without control of Reactive Power Qgrid

Case IV: DFIG connected to grid under the condition of LG fault with& without control of Reactive power Q:

With VAR regulator, the variations in reactive power are reduced and restricted around reference value of 0 VARas shown in fig.8.

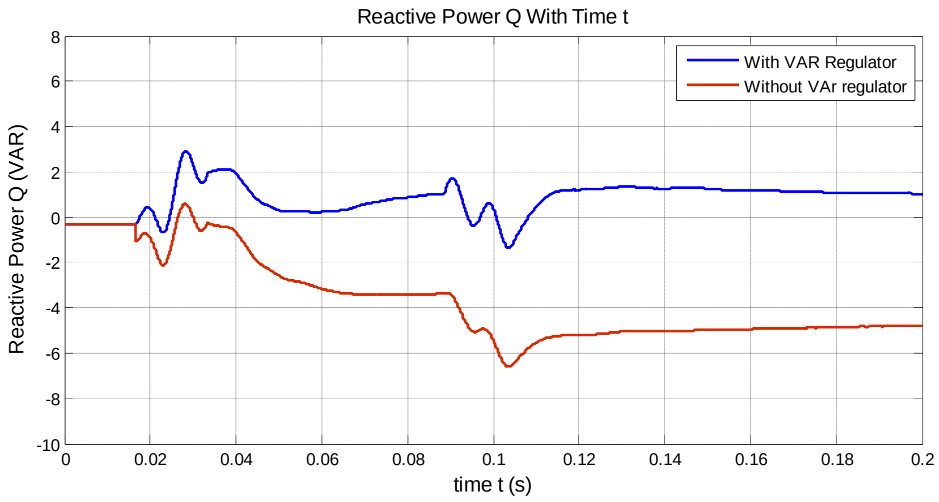

Fig. 8Simulation result for unsymmetrical fault (LG) with and without control of Reactive power Q

TABLE I Summary of simulation results with and without control of Reactive power using VAR Regulator

S.No.	Operating Condition	Range of MVAR	
		Without VARRegulator	With VAR Regulator
1	Normal	-5.785 to 0.3223 **(6.1073)**	-0.3313 to-0.2649 (**0.0664**)
2	Symmetrical Fault (LLLG)	-7.084 to 2.163 **(9.247)**	-4.803 to 3.627 **(8.430)**
3	Unsymmetrical fault(LLG)	-7.208 to 1.495 **(8.579)**	-3.674 to 3.369 (**7.043)**
4	Unsymmetrical fault(LG)	-6.599 to 0.5884 **(7.043)**	-1.374 to 2.916 **(4.290)**

VI. CONCLUSIONS

Grid code requires wind farms connected to grid to ride-through grid faults and provide active & reactive power support for grid-voltage recovery. Proposed VAR regulatorincluded in MSC reduces the fluctuation in reactive power under normal operation as well under the condition of various grid faults as shown in Table-1. The variation in reactive power without VAR regulator is found to be 6.1073, while with the regulator the variation has been reduced to 0.00664 MVAR. Further in case of LLLG fault the variation has been reduced from 9.247 to 8.430 MVAR. Under the case of LLG fault the variation has reduced to 7.043 from 8.579 MVAR. During LG fault with the inclusion of regulator fluctuation in reactive power has been changed from 7.043 MVAR to 4.290 MVAR. So it can be conclude that the reduction in variation of reactive power is facilitated by the proposed control scheme. The simulation results show satisfactory operation of VAR regulator for symmetrical as well as unsymmetrical fault at grid.

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