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A Novel Approach for Reactive Power Copensation in Wind Farms using GSC & RSC Control Alogrithms

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***Abstract*—In this paper, we proposed a working and operation of Doubly fed induction generator (DFIG) based wind energy conversion systems. Here the energy conversion system is having capabilities of integration of active power with grid-side converter (GSC). Here the objective of rotor side converter is to attain maximum power withdrawal that is required to supply reactive power to Doubly fed induction motor. In the paper a good control of Grid side converter is obtained, in addition to its slip power transfer, harmonics has to be supplied. A static compensator is used for mitigating those harmonics in case of the wind turbine is in shutdown situation. Here we are using Matlab and simulink software for simulating the proposed Doubly fed induction generator (DFIG) based wind energy conversion systems using both GSC and RSC (Rotor Side Converter) control algorithms and check its performance. These simulation results are validated with developed DFIG system for various practical conditions, such as variable wind speed and unbalanced loads or single-phase loads.**

I. Introduction

The energy demand has increased drastically with the increase in population and industrialization. On the other hand, the conventional energy sources such as coal, oil, and gas etc., are restricted in nature and harmful to the environment. Nowadays, there is a need for non-conventional energy sources for the upcoming energy demand. The major advantages of these non-conventional energy sources are eco-friendliness and indefinite in nature.

Harmonics are introduced from the RSC into the rotor windings. This generates losses and noise in the machine. Thus, the harmonics are not passing through machine windings in every of these cases. In this effort, a new control algorithm for GSC is projected for compensating harmonics created by nonlinear loads by means of an indirect current control. RSC is worn for controlling the reactive power of DFIG. The additional main advantage of proposed DFC is that it works as an active power filter even after the wind turbine is in shutdown situation. Hence, it compensates load reactive power and harmonics at wind turbine stalling case. The proposed DFIG-based WECS is simulated using MATLAB/Simulink software to check its performance. These simulation results are validated with developed DFIG system for various practical conditions, such as variable wind speed and unbalanced loads or single-phase loads.

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II. Direct-In-Line ASG System

One possible implementation scheme of ASGs is shown in Fig. 1. A synchronous generator is used to produce variable- frequency ac power. A power converter connected in series with the ASG transforms this variable-frequency ac power into fixed-frequency ac power.

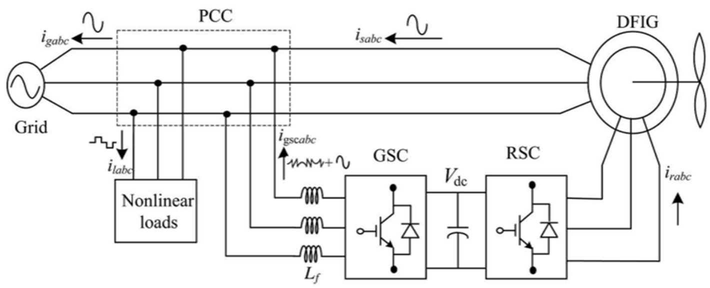

Fig. 1 Proposed system configuration

Although these direct- in-line systems have been built up to 1.5 MW, several disadvantages are apparent.

- The power converter, which has to be rated at 1 P.U. total system power, is expensive.
- Inverter output filters and EMI filters are rated for 1 P.U. output power, making filter design difficult and costly.
- Converter efficiency plays an important factor in total system efficiency over the entire operating range.

A. Doubly Fed Induction Generator ASG System

Recent developments seek to avoid most disadvantages of direct-in-line converter based ASGs. Fig. 2 shows an alternative ASG concept that consists of a doubly fed induction generator (DFIG) with a four-quadrant ac-to-ac converter based on insulated gate bipolar transistors (IGBTs) connected to the rotor windings.

B. Dynamic Model of A Doubly Fed Induction Generator

To develop decoupled control of active and reactive power, a DFIG dynamic model is needed. The construction of a DFIG is similar to a wound rotor induction machine (IM) and comprises a three-phase stator winding and a three-phase rotor winding. The latter is fed via slip rings. In these equations, all quantities are referred to the stator, i.e., transformed rotor quantities (superscript) are used. Transforming these equations from three-phase to two-phase components and subsequently rotating all variables into a synchronous reference frame (DQ) according to

$$V_{sj=r_s}.i_{sj} + \frac{\partial\varphi}{\partial t}s_j \quad {}_{j=\{1,2,3\}} \text{ and } \quad V'_{Rj=r'_R}.i'_{Rj} + \frac{\partial\varphi}{\partial t}R_j \quad {}_{j=\{1,2,3\}}$$

DFIG Vector Control

To guarantee stable operation and enable independent control of active and reactive power of the DFIG, a model-based feed-forward controller is developed using the dynamic model equations mentioned above. A block diagram is shown in Fig. 2. Fundamentally, the proposed controller is a vector controller, because the synchronous reference frame in which the machine equations are described is linked to the stator voltage space vector v s and not to the stator or rotor flux vector, as is common in field-oriented controllers for drives.

C. System Configuration And Operating Principle

Fig. 2 shows a schematic diagram of the proposed DFIG based WECS with integrated active filter capabilities. In DFIG, the stator is directly connected to the grid as shown in Fig. 2. Two back-to-back connected voltage source converters (VSCs) are placed between the rotor and the grid. Nonlinear loads are connected at PCC as shown in Fig. 2. The proposed DFIG works as an active filter in addition to the active power generation similar to normal DFIG. Harmonics generated by the nonlinear load connected at the PCC distort the PCC voltage. RSC is controlled for achieving maximum power point tracking (MPPT) and also for making unity power factor at the stator side using voltage-oriented reference frame. Synchronous reference frame (SRF) control method is used for extracting the fundamental component of load currents for the GSC control.

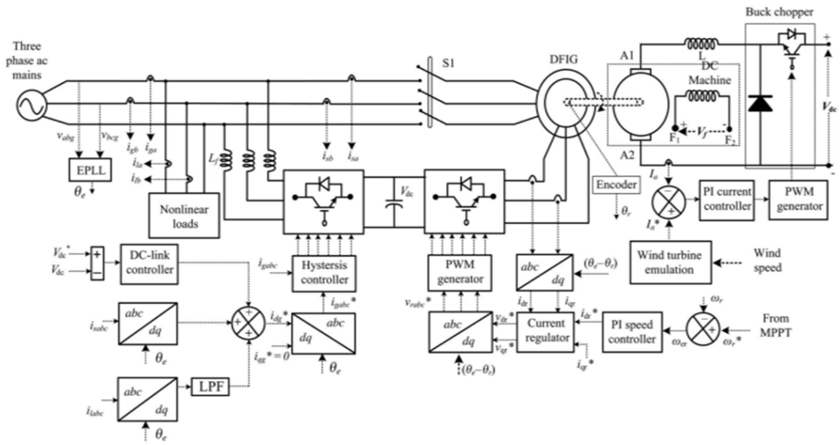

Fig. 2 Proposed DFIG based WECS with integrated active filter capabilities

D. Design of DFIG-Based WECS

Selection of ratings of VSCs and dc-link voltage is very much important for the successful operation of WECS.

E. Selection of DC-Link Voltage

Normally, the dc-link voltage of VSC must be greater than twice the peak of maximum phase voltage. The selection of dc link voltage depends on both rotor voltage and PCC voltage. While considering from the rotor side, the rotor voltage is slip times the stator voltage. DFIG used in this prototype has stator to rotor turns ratio as 2:1.While considering from the GSC side, the PCC line voltage (V_{ab}) is 230 V, as the machine is connected in delta mode. Therefore, the dc-link voltage is estimated as

$$V_{dc} \geq \frac{\sqrt[2]{2}}{\sqrt{3} * m} V_{ab}$$

F. Selection of VSC Rating

The DFIG draws a lagging volt-ampere reactive (VAR) for its excitation to build the rated air gap voltage. It is calculated from the machine parameters that the lagging VAR of 2kVAR is needed when it is running as a motor. In DFIG case, the operating speed range is 0.7 to 1.3 P.U. Therefore, the maximum slip (S_{max}) is 0.3. For making unity power factor at the stator side, reactive power of 600 VAR ($S_{max} *$ *Q*s= 0.3 ∗2 kVAR) is needed from the rotor side (Q_{rmax}). The maximum rotor active power is ($S_{max} * P$). The power rating of the DFIG is 5 kW. Therefore, the maximum rotor active power (P_{rmax}) is 1.5 kW (0.3 ∗5 kW = 1.5 kW). So, the rating of the VSC used as RSC S_{rated} is given as

$$S_{rated} = \sqrt{P_{r\,max}^2 + Q_{r\,max}^2}$$

GSC is responsible for both the controlling of the power flow between the GSC and the grid and the adjusting of DC-bus voltage for the RSC

$$i_{gsc}^* = i_{gsc}^*(k-1) + k_{pdc}\{V_{dce}(k) - V_{dce}(k-1)\} + ki_{dc}v_{dce}(k)$$

The dynamic model of the GSC with L filter is rewritten as follows:

vgd = −L digd/dt − Rigd + *ω*sLigq + vd   vgq = −L digq/dt − Rigq − *ω*sLigd + vq

The active power and reactive power from the grid to the GSC are described by

Pg = −3/ 2 (vgd*igd + vgq*igq)   Qg = −3/2 (vgq*igd – vgd*igq)

Quadrature axis component of reference grid current $\left(i_{gq}^*\right)$ is selected as zero for not to draw any reactive power from grid. Reference grid currents $\left(i_{ga}^*, i_{gb}^* and\ i_{gc}^*\right)$ are calculated from the direct and quadrature axis grid currents$\left(i_{gd}^*,\ i_{gq}^*\right)$.

III. Simulation Model and Results

To guarantee stable operation and enable independent control of active and reactive power of the DFIG, a model-based feed-forward controller is developed using the dynamic model equations mentioned above. Fundamentally, the proposed controller is a vector controller, because the synchronous reference frame in which the machine equations are described is linked to the stator voltage space vector $v\ s$ and not to the stator or rotor flux vector, as is common in field-oriented controllers for drives.

All measured quantities, i.e., stator and rotor current $i_S$and i_R, are transformed into the synchronous reference frame. A decoupling circuit calculates from the desired active and reactive power signals the rotor voltage command $v_{Rd}$and v_{Rq}. A reverse vector rotation computes magnitude and phase of the rotor voltage command in a stationary reference frame. Furthermore, the measured rotor current signals are used for rotor current regulation to minimize the effects of parameter detuning and inverter gain errors (Figs. 3-8).

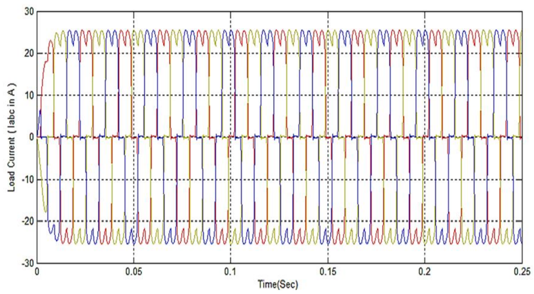

Fig. 3 Load Current

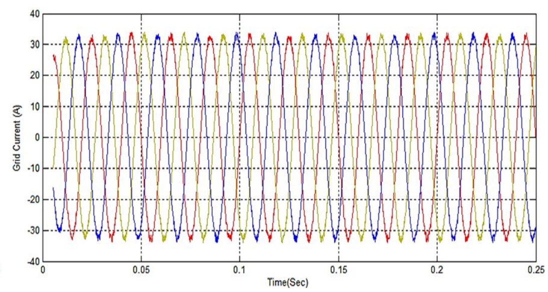

Fig. 4 Stator Current

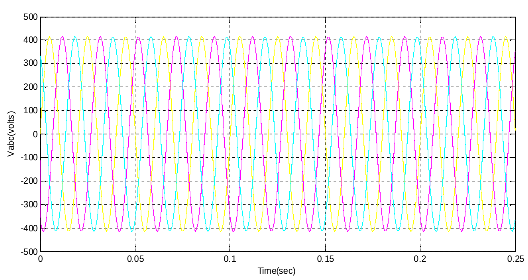

Fig. 5 Grid Voltage

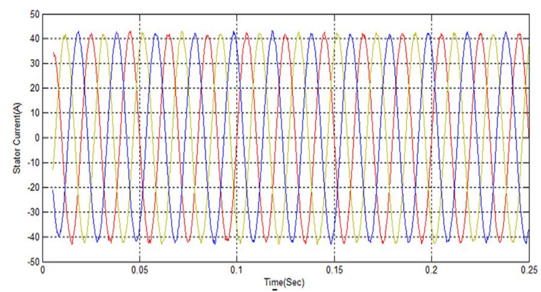

Fig. 6 Grid Current

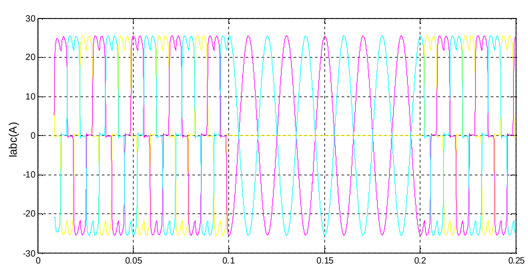

Fig. 7 Load Current

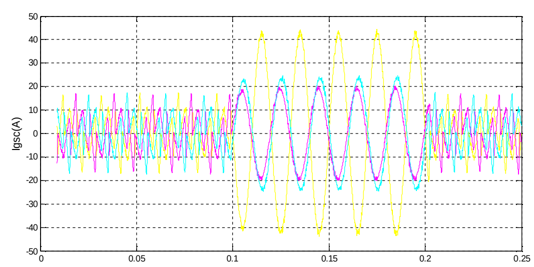

Fig. 8 Filter Curre

IV. Conclusions

In this paper, we proposed a working and operation of Doubly fed induction generator (DFIG) based wind energy conversion systems. Here the energy conversion system is having capabilities of integration of active power with grid-side converter (GSC). A good control of GSC is obtained for slip power transferring and rotor side converter achieves maximum power withdrawal, which has to be supply reactive power to doubly fed induction generator (DFIG).

Hence, during wind turbine shutdown situation also static compensator (WECS) suppresses the harmonics. The controllers in this paper that is grid side converter and rotor side converter are discussed clearly. By using MATLAB and SIMULINK software the proposed block diagram of doubly fed induction generator, based WECS has been simulated and verified the performance with practical values. The results are verified with variable wind speed and unbalanced loads and single-phase loads of practical conditions.

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