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Integrated Active Filter Capabilities for Wind Energy Conversion Systems with Doubly Fed Induction Generator Using Fuzzy

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ABSTRACT

The main contribution of this work lies in the control of GSC for supplying harmonics in addition to its s lip power transfer. The rotor-side converter (RSC) is used for attaining maximum power extraction and to supply required reactive power to DFIG. This wind energy conversion system (WECS) works as a static compensator (STATCOM) for supplying harmonics even when the wind turbine is in shutdown condition. Control algorithms of both GSC and RSC are presented in detail. The proposed DFIG-based WECS is simulated using MATLAB/Simulink. Simulated results are validated with test results of the developed DFIG for different practical conditions, such as variable wind speed and unbalanced/single phase loads. A fuzzy logic-based controller is developed to control the voltage of the DC Capacitor. This work presents and compares the performance of the fuzzy-adaptive controller with a conventional fuzzy and PI controller under constant load. The total Harmonic Distortion, Individual harmonic content with respect to % of fundamental in Supply current, source voltage have been analyzed.

I.INTRODUCTION

With the increase in population and industrialization, the energy demand has increased significantly. However, the conventional energy sources such as coal, oil, and gas are limited in nature. Now, there is a need for renewable energy sources for the future energy demand [1]. The other main advantages of this renewable source are eco-friendliness and unlimited in nature [2]. Due to technical advancements, the cost of the wind power produced is comparable to that of conventional power plants. Therefore, the wind energy is the most preferred out of all renewable energy sources [3]. In the initial days, wind turbines have been used as fixed speed wind turbines with squirrel cage induction generator and capacitor banks. Most of the wind turbines are fixed speed because of their simplicity and low cost [4]. By observing wind turbine characteristics, one can clearly identify that for extracting maximum power, the machine should run at varying rotor speeds at different wind speeds.

TABLE 1
CURRENT DISTORTION LIMITS FOR GENERAL DISTRIBUTIONS YSTEMS IN TERMS OF INDIVIDUAL HARMONICS ORDER (ODD HARMONICS)

I_{sc}/I_L	<11	$11 \le h \le 17$	$17 \le h \le 23$	$23 \le h \le 35$	$35 \le h$	TDD
< 20	4.0	2.0	1.5	0.6	0.3	5.0
$20 < 50$	7.0	3.5	2.5	1.0	0.5	8.0
$50 < 100$	10	4.5	4.0	1.5	0.7	12
$100 < 1000$	12	5.5	5.0	2.0	1.0	15.0
> 1000	15.0	7.0	6.0	2.5	1.4	20.0

Double Fed Induction Generator (DFIG):

DFIG is an abbreviation for Double Fed Induction Generator, a generating principle widely used in wind turbines. It is based on an induction generator with a multiphase wound rotor and a multiphase slip ring assembly with brushes for access to the rotor windings. It is possible to avoid the multiphase slip ring assembly (see brushless doubly-fed electric machines), but there are problems with efficiency, cost and size. A better alternative is a brushless wound-rotor doubly-fed electric machine.

Principle of a Double Fed Induction Generator Connected To a Wind Turbine

The principle of the DFIG is that rotor windings are connected to the grid via slip rings and back-to-back voltage source converter that controls both the rotor and the grid currents. Thus rotorfrequency can freely differ from the grid frequency (50 or 60 Hz). By using the converter to control the rotor currents, it is possible to adjust the active and reactive power fed to the grid from the stator independently of the generator's turning speed. The control principle used is either the two-axis current vector control or direct torque control (DTC). DTC has turned out to have better stability than current vector control especially when high reactive currents are required from the generator.

II. ACTIVE FILTER

Active filters have three main advantages over passive filters

- Inductors can be avoided. Passive filters without inductors cannot obtain a high Q (low damping), but with them are often large and expensive (at low frequencies), may have significant internal resistance, and may pick up surrounding electromagnetic signals.
- The shape of the response, the Q (Quality factor), and the tuned frequency can often be set easily by varying resistors, in some filters one parameter can be adjusted without affecting the others. Variable inductances for low frequency filters are not practical.
- The amplifier powering the filter can be used to buffer the filter from the electronic components it drives or is fed from, variations in which could otherwise significantly affect the shape of the frequency response.

Active filter circuit configurations (electronic filter topology) include:

- Sallen and Key, and VCVS filters (low dependency on accuracy of the components)
- State variable and biquadratic filters
- Twin T filter (fully passive)
- Dual Amplifier Bandpass (DABP)
- Wien notch
- Multiple Feedback Filter
- Fliege (lowest component count for 2 opamp but with good controllability over frequency and type)
- Akerberg Mossberg (one of the topologies that offer complete and independent control over gain, frequency, and type)

All the varieties of passive filters can also be found in active filters. Some of them are:

- High-pass filters – attenuation of frequencies below their cut-off points.
- Low-pass filters – attenuation of frequencies above their cut-off points.
- Band-pass filters – attenuation of frequencies both above and below those they allow to pass.
- Notch filters – attenuation of certain frequencies while allowing all others to pass.
  Combinations are possible, such as notch and high-pass (for example, in a rumble filter where most of the offending rumble comes from a particular frequency), e.g.Elliptic filters.

III. SYSTEM CONFIGURATION AND OPERATING PRINCIPLE

Fig. 1 shows a schematic diagram of the proposed DFIGbased WECS with integrated active filter capabilities. In DFIG, the stator is directly connected to the grid as shown in Fig. 1. 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. 1. 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. These nonlinear load harmonic currents are mitigated by GSC control, so that the stator and grid currents are harmonic-free. 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)

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control method is used for extracting the fundamental component of load currents for the GSC control.

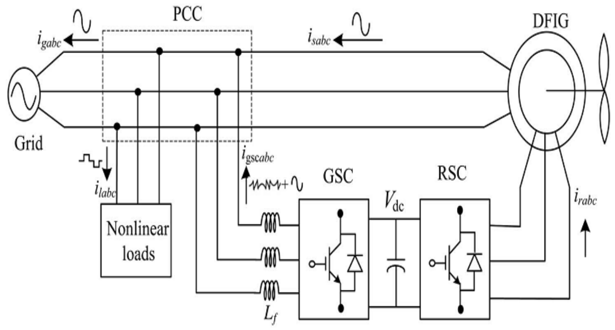


Fig. 1: Proposed system configuration.

IV. CONTROL S TRATEGY

Control algorithms for both GSC and RSC are presented in this section. Complete control schematic is given in Fig. 2. The control algorithm for emulating wind turbine characteristics using dc machine and Type a chopper is also shown in Fig. 2.

Control of RSC

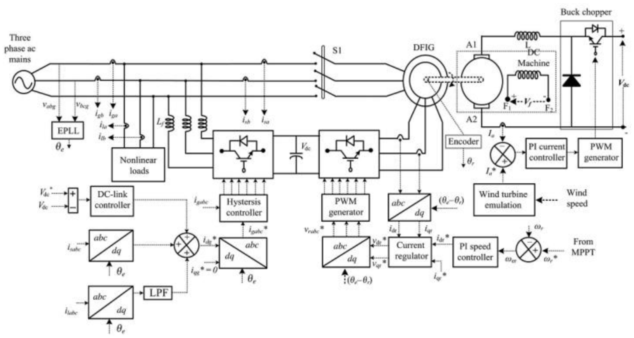
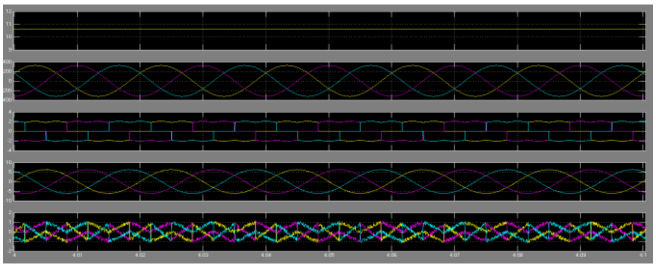


Fig 2: Control algorithm of the proposed WECS.

Control of GSC

The novelty of this work lies in the control of this GSC for mitigating the harmonics produced by the nonlinear loads.



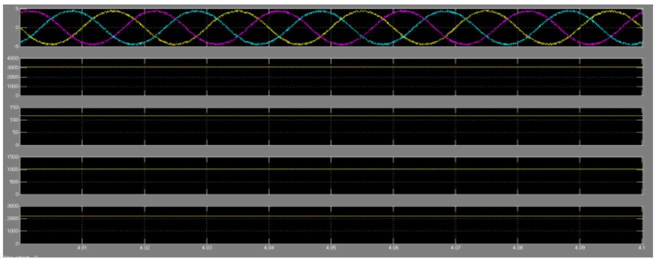
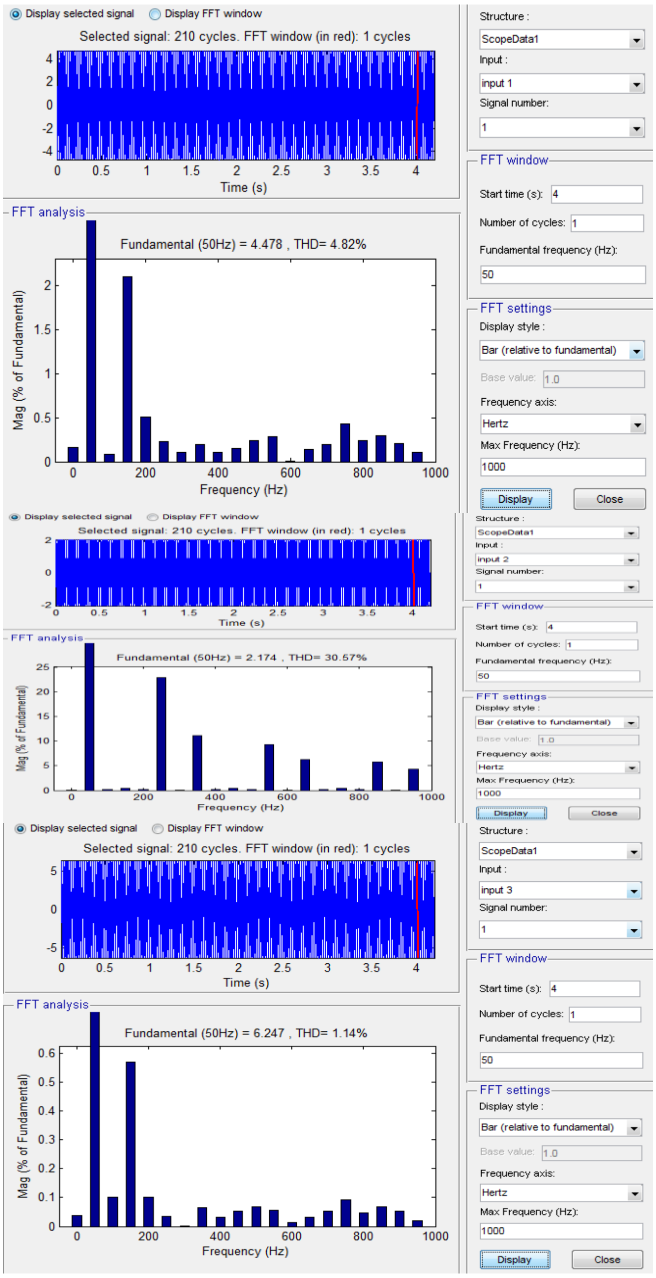


Fig 3: Simulated performance of the proposed DFIG-based W ECS at fixed



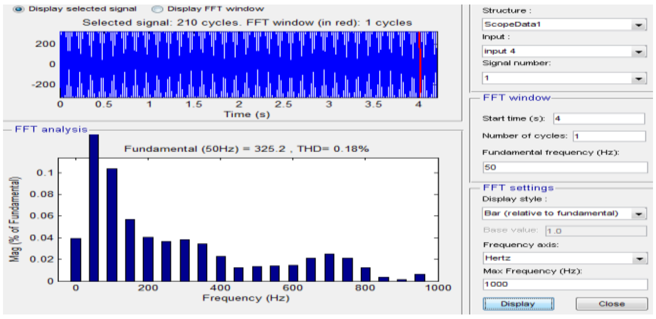


Fig 4. Simulated waveform and harmonic spectra of (a) grid current (i g a), (b) load current (i l a), (c) stator current (i s a), and (d) grid voltage for phase "a" (v g a) at fixed wind speed of 10.6 m/s (rotor speed of 1750 rpm)

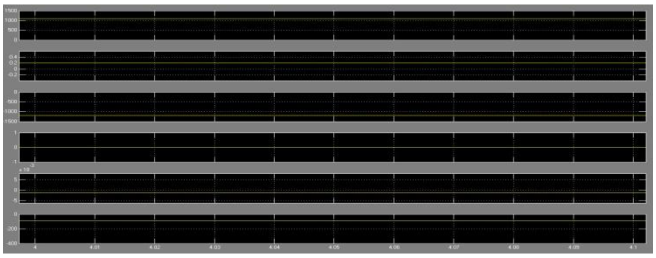


Fig 5: Simulated performance of the proposed DFIG-based WECS working as a STATCOM at zero wind speed

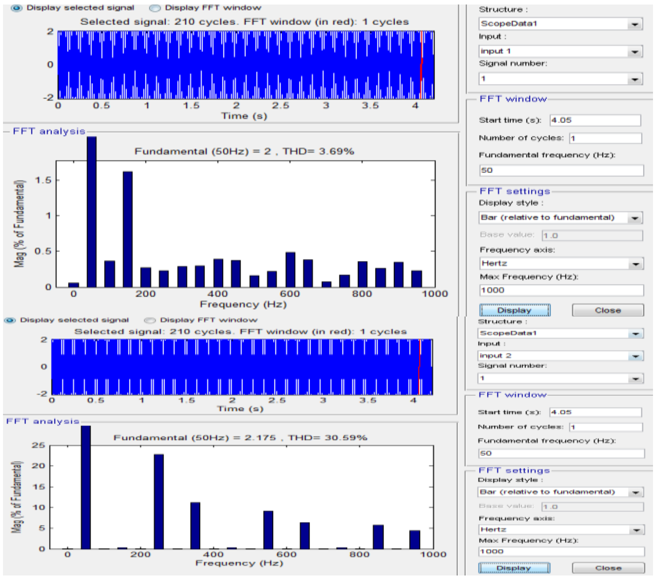


Fig 6: Simulated waveforms and harmonic spectra of (a) load current (i l a) and (b) grid current (i g a) working as a STATCOM at wind turbine shut down condition.

Fundamental active load current (ild) is obtained using SRF theory [33]. Instantaneous load currents (ilabc) and the value of phase angle from EPLL are used for converting the load currents in to synchronously rotating dqframe (ild). In synchronously rotating frames, fundamental frequency currents areconverted into dc quantities and all other harmonics are converted into non-dc quantities with a frequency shift of 50 Hz. DC values of load currents in synchronously rotating dqframe (ild) are extracted using low-pass filter (LPF).

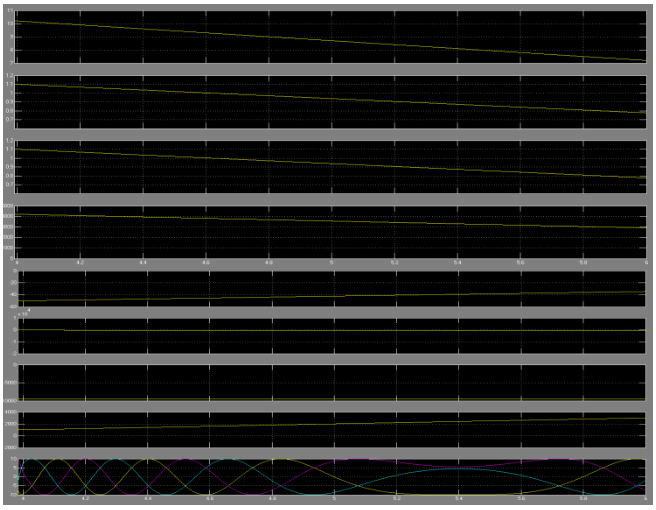


Fig 7: Simulated performance of proposed DFIG for fall in wind speed.load current (ild) in synchronously rotating frame and the loss component of GSC current (i*gsc)

V. RESULTS AND DISCUSSION

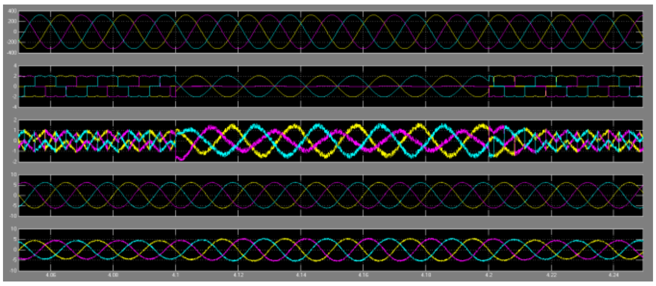


Fig 8: Dynamic performance of DFIG-based WECS for the sudden removal and application of local loads

VI.CONCLUSION

The GSC control algorithm of the proposed DFIG has been modified for supplying the harmonics and reactive power of the local loads. In this proposed DFIG, the reactive power for the induction machine has been supplied from the RSC and the load reactive power has been supplied from the GSC. The decoupled control of both active and reactive powers has been achieved by RSC control. The proposed DFIG has also been verified at wind turbine stalling condition for compensating harmonics and reactive power of local loads. This proposed DFIG-based WECS with an integrated active filter has been simulated using MATLAB/Simulink environment, and the simulated results are verified with test results of the developed prototype of this WECS. Steady-state performance of the proposed DFIG has been demonstrated for a wind speed. Dynamic performance of this proposed GSC control algorithm has also been verified for the variation in the wind speeds and for local nonlinear load.

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