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PERFORMANCE OF GRID INTERACTIVE DFIG BASED WECS FOR CONTROLLED POWER FLOW BY USING FRACTIONAL ORDER SMC

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Abstract

In this paper, the sharing of reactive power between two converters of a Doubly Fed Induction Generator (DFIG) based wind energy conversion system interacting with the grid. The Rotor Side Converter (RSC) control of DFIG is designed for sharing of reactive power at below rated wind speeds, which essentially reduces the amount of rotor winding copper loss. However, at rated wind speed, the RSC control is designed to maintain the unity power factor at stator terminals and to extract rated power without exceeding its rating. Further, the reduction in rotor winding copper loss due to reactive power distribution is demonstrated with an example. Moreover, the Grid Side Converter (GSC) control is designed to feed regulated power flow to the grid along with reactive power support to DFIG and to the load connected at point of common coupling. Moreover, the GSC control is designed to compensate load unbalance and load harmonics. The battery energy storage connected at DC link of back-to-back converters, is used for maintaining the regulated grid power flow regardless of wind speed variation. The system is modelled, and its performance is simulated under change in grid reference active power, varying wind speed, sharing of reactive power and unbalanced nonlinear load using Simpower Systems toolbox of MATLAB.

Keywords: DFIG, reactive power sharing, flux-oriented control, regulated power flow, wind energy conversion system, battery energy storage, power quality.

I. INTRODUCTION

The rise in population and industrialization has led to an increase in energy consumption. Although coal, oil, and gas are the most common sources of conventional energy, these resources are finite in scope. In order to meet the world's growing demand for energy in the future, we must now turn to renewable resources [1]. The fact that this renewable resource is non-polluting and limitless in nature are other major advantages [2]. The cost of wind power is now equivalent to that of conventional power plants because to technological developments. As a result, of all the renewable energy options, wind power is the most popular [3]. Squirrel cage induction generators and capacitor banks were initially utilized in fixed-speed wind turbines. Because of their simplicity and low cost, the majority of wind turbines are fixed-speed

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[4]. The machine can run at a variety of speeds thanks to contemporary power electronic converters [5]. It's therefore possible to increase the amount of renewable energy generated by these variable-speed turbines DFIGs are the most popular variable-speed wind turbines because of their inexpensive cost. Additional benefits include advanced energy output, lower converter rating and improved generator usage [8]. For the weak grid, these DFIGs give excellent damping performance. Using the decoupled vector control technique described in [10, 11], it is possible to independently regulate the active and reactive power. The vector control of such a system is often implemented in a synchronously rotating reference frame oriented in either the voltage or flux axis. In this study, a voltage-oriented reference frame is used to achieve RSC control. There are grid code regulations for wind farm grid connection and operation in [12]. In [13] compares the responsiveness to grid disturbances of the DFIG-based wind energy conversion system (WECS) with that of the fixed speed WECS. While the GSC is responsible for maintaining DC link voltage, RSC typically fulfils DFIG's reactive power requirements for magnetization. The reactive power can be shared across two converters, thanks to control mechanisms proposed by some researchers. Reactive power distribution between converters in a DFIG has been the subject of several control techniques described by Kahili et al. However, there is no explanation of how to supply the DFIG itself with reactive power. Reactive power sharing is not taken into consideration by the authors, which results in additional power loss. Despite this, the writers haven't talked about the loss of power in the rotor and stator windings. In addition, no discussion of hardware implementation of control mechanisms is included. As wind speed fluctuates, so does the amount of electricity generate by DFIG.

When power is generated and sent to the grid, problems arise, especially if the grid is poor, as it is in rural areas. There are two ways to regulate power flow in the grid using the wind energy conversion system: with and without energy storage. Batteries, supercapacitors, flywheels, fuel cells, and superconducting magnetic energy storage (SMES) are all forms of energy storage. Non-energy-storage features include inertia and pitch angle control, as well as DC link voltage adjustment. There's a lot of information out there about how to regulate power flow on the grid in. Using a variable frequency transformer, Wang et al. [14] have been power oscillations in the grid have been eliminated. Furthermore, there is no evidence that it works. Using an optimized power point tracking technique, Ochoa et al. [15] the subject of power grid stability was discussed. If you've ever wondered how to get the most out of your battery, you've come to the right place. This means that the WECS does not run at maximum power point tracking (MPPT) in order to level out the grid's output. Furthermore, when the generation is larger than or equal to the grid reference power, it is desirable to modify the MPPT for power smoothing. When the maximum generation is less than the reference grid power, this method cannot be relied upon because there is no other source of power to balance it. Furthermore, there is no mention of how this technology could be implemented on hardware. Using a superconducting magnetic energy storage device, the authors in [13] show how to remove grid power fluctuations. The control circuits and the entire system grow more complicated, though, using this way. The system's theoretical analysis is not validated by the test findings, either. The smoothing of grid electricity by BES is explored in [14]. Based on wind patterns at a specific location, the scientists have created a BES that can store energy.

Disturbances can cause changes in both active and reactive power flow, however this hasn't been addressed by authors. [11] describe some of the MPPT strategies that can be used to obtain maximum power from a wind turbine. One of the two modular multilevel converters used in this work is called DFIG and is used in conjunction with the grid-interactive WECS.GS-MMC and RS-MMC. The main intention of MMC is reduce the THD in output voltage and improving the power quality. Nonlinear systems can benefit from the sliding mode control (SMC) strategy, which is a reliable and high-frequency method. SMC's advantages include its high level of robustness, rapid convergence speed, and ease of implementation. Nevertheless, SMC's principal downside is the chattering issue, which may affect its overall performance when operating some high-frequency harmonics-vulnerable systems. To address the issue, countermeasures were presented to reduce the level of chattering in robot control, an exponential reaching law (ERL) has been proposed [12]. [14] proposes Integer order calculus underpins the aforementioned SMC systems, which make use of differentiators or integrators of integer order. It has recently been hypothesized that the concept of fractional order sliding mode control (FOSMC) is based on fractional order calculus (FOC).

II. METHODOLOGY

Wind Energy Conversion System (WECS)

- ✓ WECS is a system that converts wind energy into another form of energy, such as electricity, that can be used to power homes and businesses.
- ✓ There are two main types of WECS: those that use wind turbines to generate electricity and those that use windmills to pump water.

WECS Classification

Wind energy conversion systems are classified according to the type of rotational axis about which the turbine rotor blades rotate. The four main classifications of WECS are rotational axis, turbine, power control, and rotational speed control.

Figure 1: WECS Classification

Rotational Axis

There are two types of rotational axis: horizontal and vertical.

- A horizontal axis wind turbine (HAWT) is the most commonly used type. The rotor blades are mounted on a horizontal shaft perpendicular to the ground.
- A vertical axis wind turbine (VAWT) has its rotor blades mounted on a vertical shaft parallel to the ground. VAWT is less common than HAWT because it is more expensive and complicated to build and is not as efficient in converting wind energy into electricity.

Power Control

The wind energy converted by the turbine must be managed appropriately to maintain a constant output of power. The two main ways to control power are active and reactive power control.

- Active power control is the most common type of power control, and it involves regulating the amount of wind that goes through the turbine blades. This is accomplished by using a pitch control mechanism, which regulates the angle of the blades.
- Reactive power control is less common, and it involves regulating the amount of electricity generated by the turbine. This is done using a generator, which converts mechanical energy into electrical energy.

Rotational Speed Control Criteria

The wind speed controls the speed of the turbine blades. The higher the wind speed, the faster the blades will spin. Two main ways to control the turbine's rotational speed are fixed speed and variable speed WECS.

- Fixed speed WECS are the most common type, and they use a device called a governor to control the speed of the turbine. The governor is a mechanical device that is attached to the turbine blades. It prevents the blades from spinning too fast, damaging the turbine.
- Variable speed WECS are less common, using an inverter device to control the turbine's speed. The inverter is an electronic device that converts direct current (DC) into alternating current (AC). It also regulates the speed of the turbine blades.

Doubly fed electric machine (DFIG)

Doubly-fed electric machines also slip-ring generators are electric motors or electric generators, where both the field magnet windings and armature windings are separately connected to equipment outside the machine.

By feeding adjustable frequency AC power to the field windings, the magnetic field can be made to rotate, allowing variation in motor or generator speed. This is useful, for instance, for generators used in wind turbines.[1] DFIG-based wind turbines, because of their flexibility and ability to control active and reactive power, are almost the most interesting wind turbine technology.

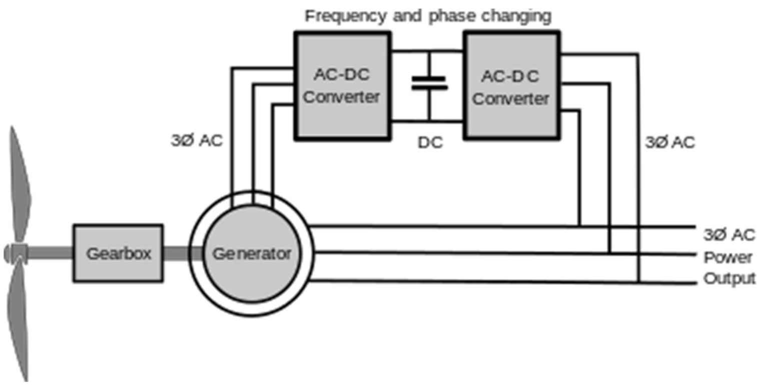


Figure 2: Doubly fed generator for wind turbine.

Doubly fed induction generator:

The principle of the DFIG is that stator windings are connected to the grid and rotor winding are connected to the converter via slip rings and back-to-back voltage source converter that controls both the rotor and the grid currents. Thus rotor frequency 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).[13] DTC has turned out to have better stability than current vector control especially when high reactive currents are required from the generator.

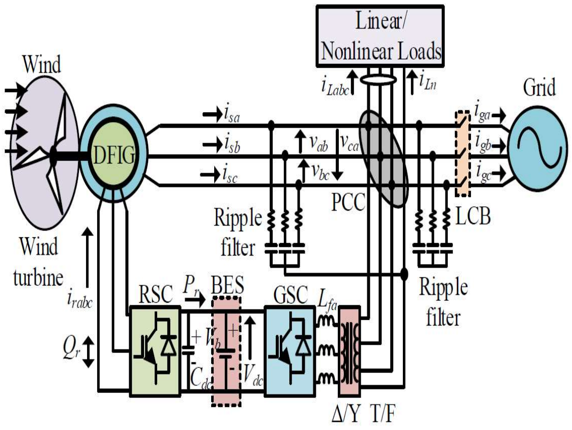


Figure 3: DFIG connected to a Wind Turbine

Sliding Mode Control (SMC)

In control systems, sliding mode control (SMC) is a nonlinear control method that alters the dynamics of a nonlinear system by applying a discontinuous control signal (or more rigorously, a set-valued control signal) that forces the system to "slide" along a cross-section of the system's normal behaviour. The state-feedback control law is not a continuous function of time. Instead, it can switch from one continuous structure to another based on the current position in the state space. Hence, sliding mode control is a variable structure control method. The multiple control structures are designed so that trajectories always move toward an adjacent region with a different control structure, and so the ultimate trajectory will not exist entirely within one control structure. Instead, it will *slide* along the boundaries of the control structures. The motion of the system as it slides along these boundaries is called a *sliding mode*[1] and the geometrical locus consisting of the boundaries is called the *sliding (hyper)surface*. In the context of modern control theory, any variable structure system, like a system under SMC, may be viewed as a special case of a hybrid dynamical system as the system both flows through a continuous state space but also moves through different discrete control modes.

III. RESULTS & DISCUSSION

This paper examines the sharing of reactive power between two converters of a DFIG-based wind energy conversion system interacting with the grid. DFIG's Rotor Side Converter (RSC) control shares reactive power at below-rated wind speeds, reducing rotor winding copper loss. The RSC control is designed to maintain unity power factor at stator terminals and extract rated power without exceeding its rating. Also, reactive power distribution reduces rotor winding copper loss. The Grid Side Converter (GSC) control feeds regulated power to the grid and reactive power to DFIG and the load at the point of common coupling. GSC controls load unbalance and harmonics. Battery energy storage connected to back-to-back converters maintains grid power flow regardless of wind speed.

Case 1: Performance of System during Increment Change in Active Power Reference

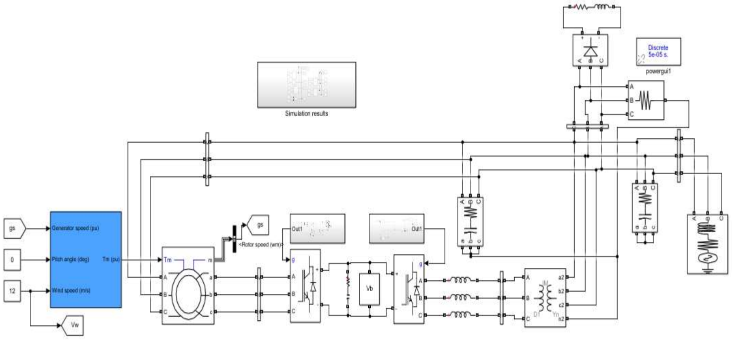


Figure 4: Proposed Simulink

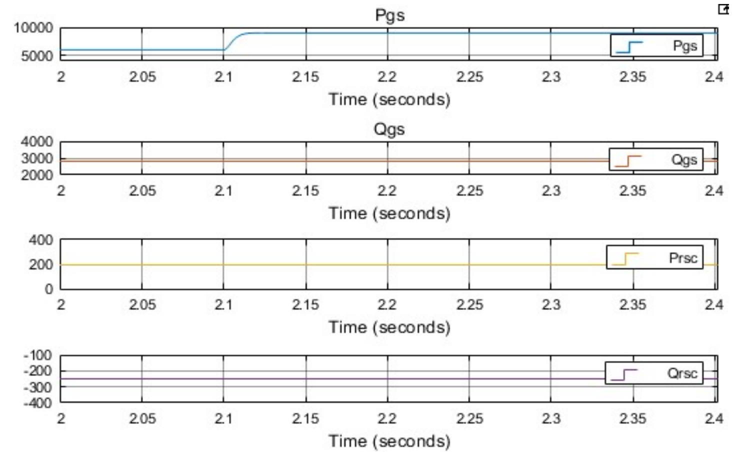


Figure 5: Performance of system during an incremental change in reference active power: grid active power (PG), grid current (iGa), battery power (Pb), stator active power (Ps)

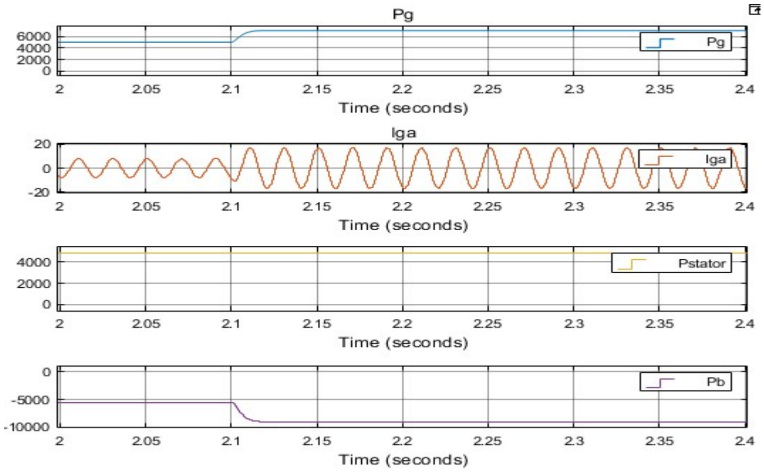


Figure 6: Performance of system during an incremental change in reference active power: GSC active power (PC), GSC reactive power (QC), RSC active power (Pr) and RSC reactive power (Qr).

Case 2: Performance of System at Variable Wind Speed

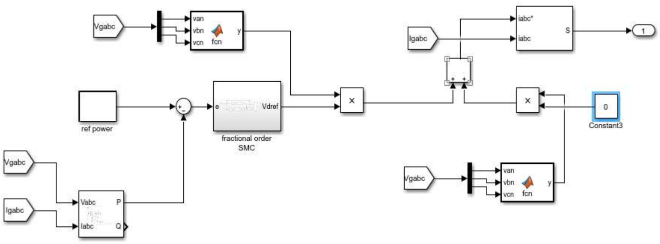


Figure 7: Grid side convertor

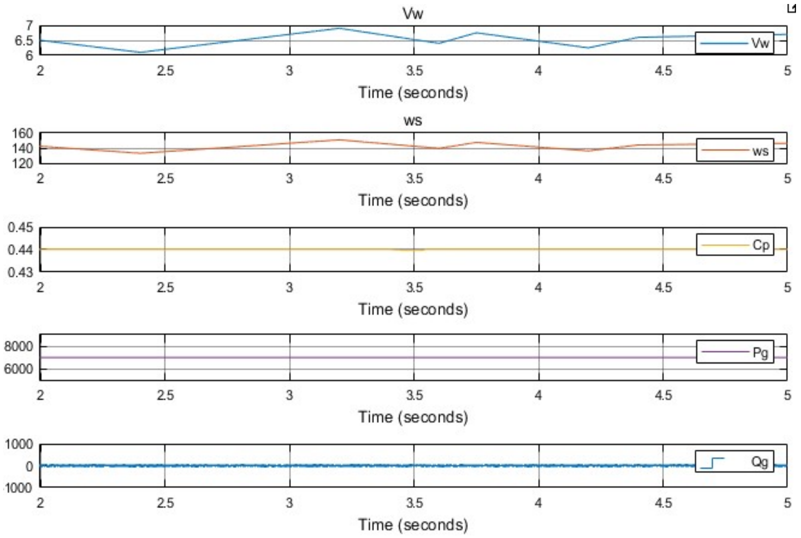


Figure 8: Performance of system at variable wind speed: wind speed (Vw), rotor speed (ωr), power coefficient of turbine (Cp)

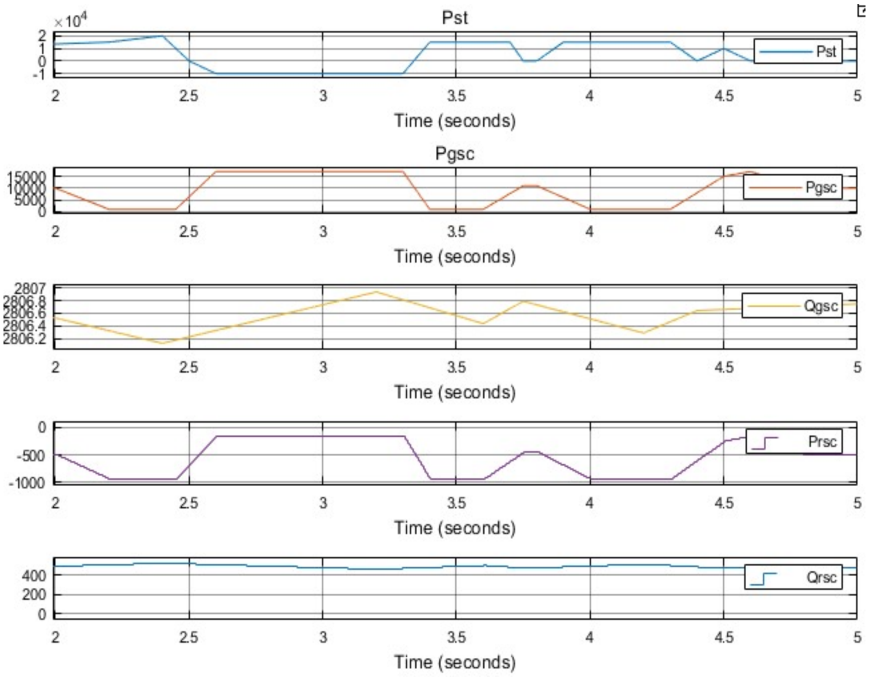


Figure 9: Performance of system at variable wind speed: grid active power (PG), grid reactive power (QG), stator active power (Ps)

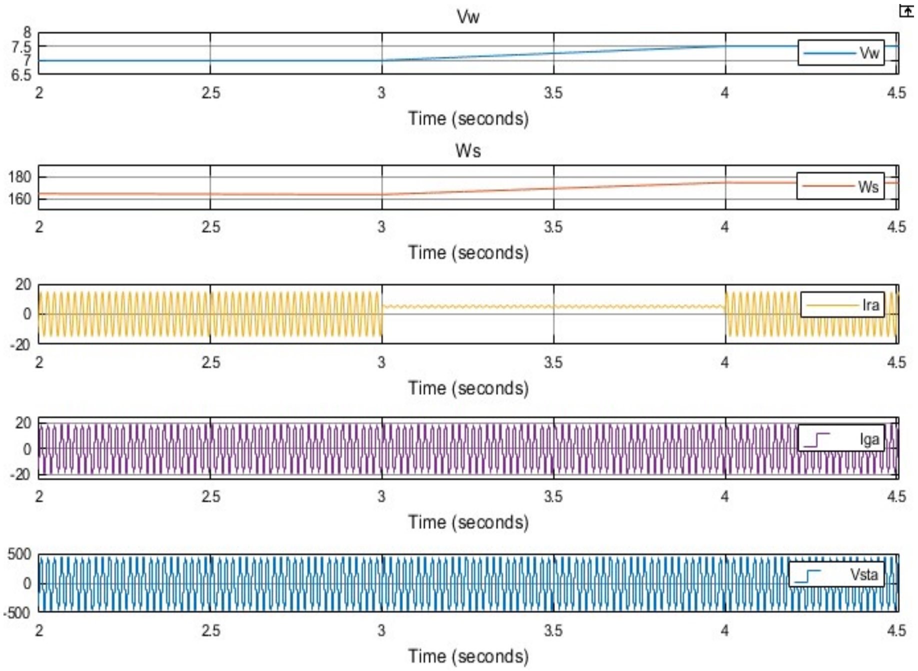


Figure 10: Performance of system at variable wind speed: GSC active power (PC), GSC reactive power (QC), RSC active power (Pr)

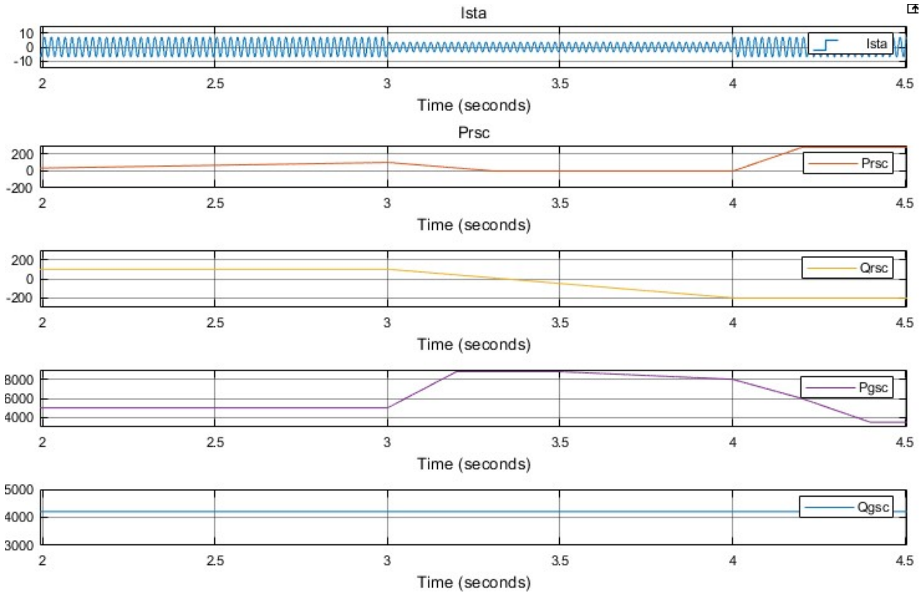


Figure 11: Performance of system at variable wind speed: stator current (isa), rotor currents (irabc), grid current (iGa), PC, QC, Pr and Qr.

Case 3: Performance of System at Unbalanced Nonlinear Loads

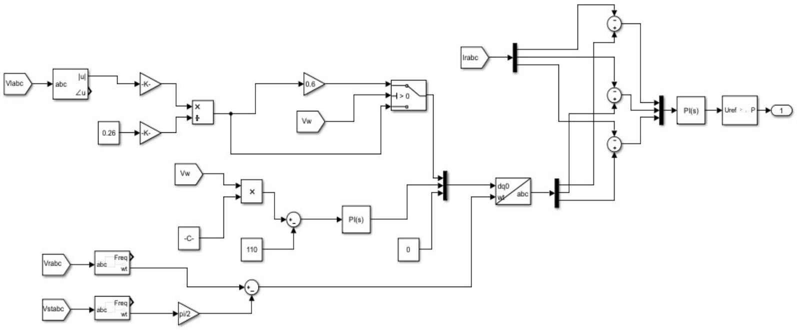


Figure 12: Rotor side convertor

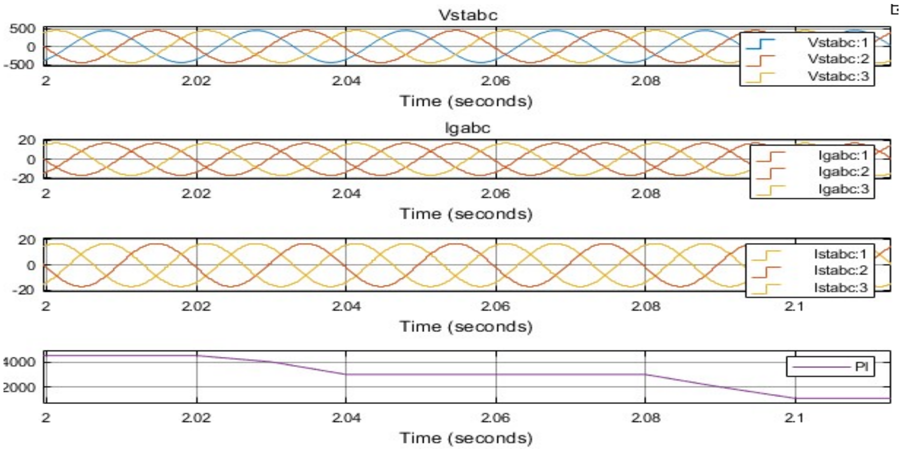


Figure 13: System performance at unbalanced nonlinear loads: stator voltages (vsabc), grid currents (iGabc), stator currents (isabc), load currents (iLa, iLb, iLc)

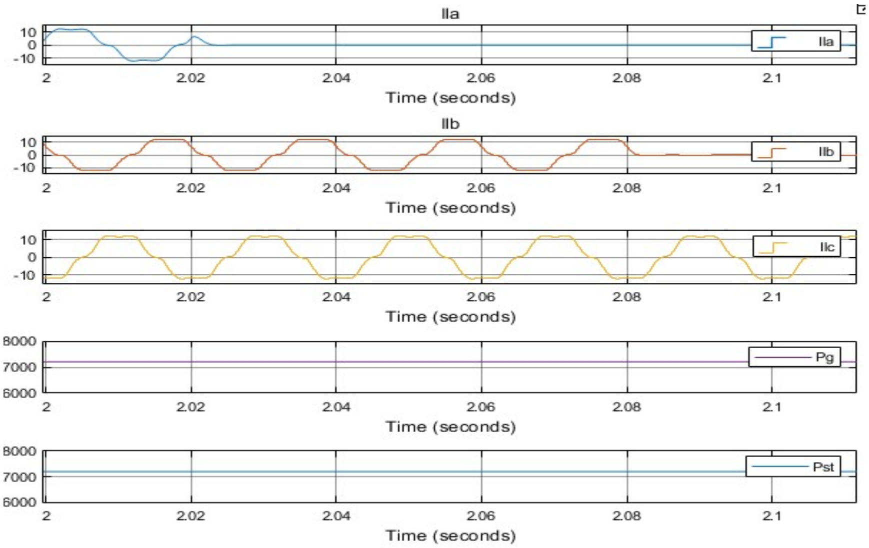


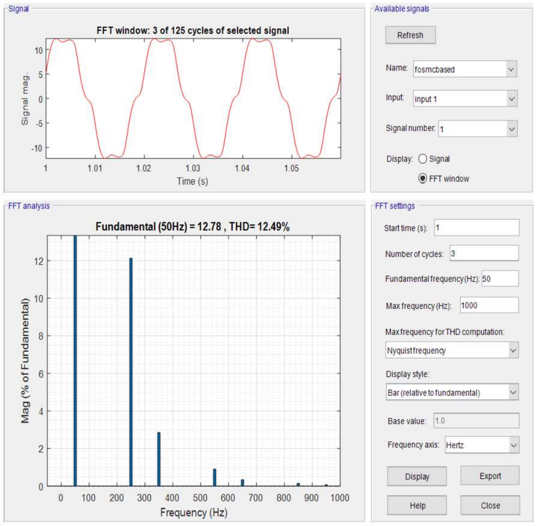
Figure 14: System performance at unbalanced nonlinear loads: grid active power (PG), stator power (Ps), and load power (PL).

Total Harmonic Distortion (THD):

The total harmonic distortion (THD) is a measurement of the harmonic distortion present in a signal and is defined as the ratio of the sum of the powers of all harmonic components to the power of the fundamental frequency. Distortion factor, a closely related term, is sometimes used as a synonym.

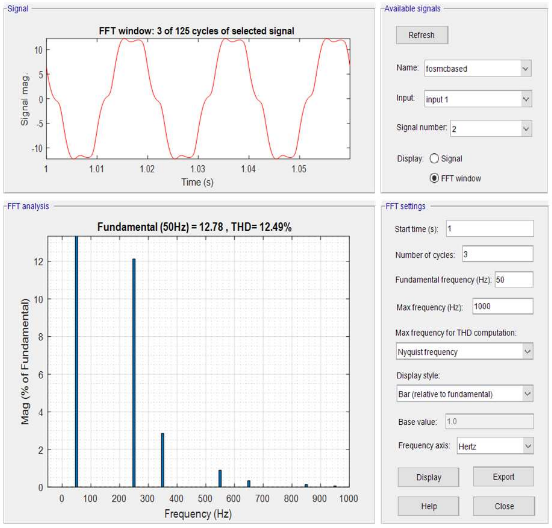
In audio systems, lower distortion means the components in a loudspeaker, amplifier or microphone or other equipment produce a more accurate reproduction of an audio recording.

In radio communications, devices with lower THD tend to produce less unintentional interference with other electronic devices. Since harmonic distortion tends to widen the frequency spectrum of the output emissions from a device by adding signals at multiples of the input frequency, devices with high THD are less suitable in applications such as spectrum sharing and spectrum sensing.



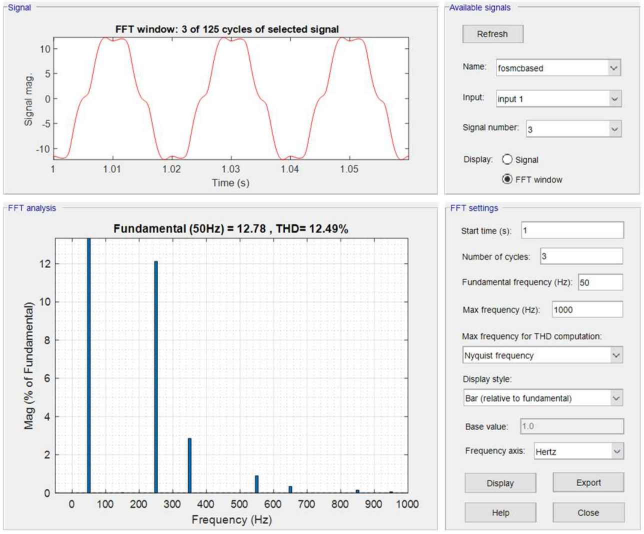
Name: fosmcbased
Input: input 1
Signal number: 1
Display: ○ Signal ● FFT window
Start time (s): 1
Number of cycles: 3
Fundamental frequency (Hz): 50
Max frequency (Hz): 1000
Max frequency for THD computation: Nyquist frequency
Display style: Bar (relative to fundamental)
Base value: 1.0
Frequency axis: Hertz

(a)



Name: fosmcbased
Input: input 1
Signal number: 2
Display: ○ Signal ● FFT window
Start time (s): 1
Number of cycles: 3
Fundamental frequency (Hz): 50
Max frequency (Hz): 1000
Max frequency for THD computation: Nyquist frequency
Display style: Bar (relative to fundamental)
Base value: 1.0
Frequency axis: Hertz

(b)



Name: fosmcbased
Input: input 1
Signal number: 3
Display: ○ Signal ● FFT window
Start time (s): 1
Number of cycles: 3
Fundamental frequency (Hz): 50
Max frequency (Hz): 1000
Max frequency for THD computation: Nyquist frequency
Display style: Bar (relative to fundamental)
Base value: 1.0
Frequency axis: Hertz

(c)

Figure 15: (a) (b) (c) Load Current THD

Table 1: System Comparison

	Existing system	Proposed system
Grid Current THD	4.39%	1.54%
PCC Voltage THD	3.89%	1.01%
Load Current THD	24.30%	12.49%

IV. CONCLUSION

The grid interactive DFIG based WECS with proposed control algorithms, has been implemented for reactive power sharing capability and regulated grid power flow. The significant reduction in rotor winding copper loss, has been found due to reactive power distribution between converters at below rated wind speeds. Moreover, there is minimal effect on decrease/increase in the converter's losses with reactive power sharing. Moreover, satisfactory performance of RSC control has been found in sharing the reactive power at below rated wind speeds, maintaining UPF at rated wind speed and extraction of maximum power from the wind turbine. In addition, the performance of GSC control has been found satisfactory in achieving regulated power flow, reactive power compensation of DFIG stator and load, compensation of load harmonics and load unbalance. Furthermore, the acceptable performance of BES has been found in maintaining the constant power flow through the grid irrespective of wind speed variation. Simulated results have shown that the system gives reasonably good performance under change in grid reference active power, varying wind speed, reactive power sharing and unbalanced nonlinear loads. Grid currents, stator currents and voltages have been found balanced and sinusoidal and their THDs are well below the permissible limits of the IEEE 519 standard. Moreover, experimental investigation has shown the satisfactory performance of the system.

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