Control of A Doubly Fed Induction Generator for Wind Energy Conversion System Using Matrix Converter with SVPWM Technique

G. Krishnan, M. Siva Ramkumar, A. Amudha, G. Emayavaramban,S. Divyapriya, D. Kavitha, M. Sivaram Krishnan

Abstract---With the aim of satisfying the power demands, and considering the economic and environmental factors, wind energy conversion is slowly becoming the field of interest in the form of a desirable source of renewable energy. In this work, a grid connected wind power generation mechanism that uses a doubly fed induction generator [3] with a direct AC-AC matrix converter is introduced. The objectives of this work are: To model and then simulate the operation of a doubly fed induction generator. The analysis uses a space vector modulated matrix converter [2] for controlling the rotor current. The matrix converter [1]-based rotor current control mechanism is focused. The system facilitates optimal speed tracking for maximum energy storage from the wind and high performance active and reactive power regulation is accomplished with the RST regulator. Finally, the simulation results obtained for various operating points are given showing thesystem's superior control performances.

Keywords---DFIG, Three Phase Phase Locked Loop, GSC, RSC, Total Harmonic Distortion, Matlab/Simulink.

I. INTRODUCTION

Electricity generated from renewable resources, and especially from the wind, is regarded in today's world to be a contending and mandatory alternate to fossil resources. Wind turbines can function with either constant speed or variable speed. Pitch-adjusting variable-speed wind turbines such as DFIG have emerged to be the dominating kind of annually installed wind turbines recently. Various reasons exists for selecting DFIG, like the minimization of both the mechanical structure stresses and the probability of controlling four quadrants' active and reactive power potential, and therefore they have been selected for variable speed operation of wind turbines.

The power electronic converters possess the capability of achieving reactive power compensation forattaining voltage control and reduction of harmonic currents.

In the recent times, RSC & GSC of DFIG that are connected between the rotor terminals of generator and the grid[4] has been designed in order to possess the capability of improving the grid power quality and accomplish the harmonic currents suppression.

The GSC is utilized in the form of a reference frame to balance the phase shift owing the inclusion of inductive load and to reduce the current harmonic and achieve unity power factor because of theinclusion of nonlinear load at PCC that is connected in shunt with inductive load along with its primary function that maintains the voltage of the DC link stable at its level and attaining unity power factor of GSC of DFIG [5].

Control systems for DFIG variable speed wind turbines [7-8] have toproceed to develop towards more and more efficient and thought-provoking solutions.

Wind energy, although available in abundance, changescontinuouslysince the wind speed experiences change all through the day.

The amount of power output received from a WECS is based on the accuracy with which the peak power points get tracked by the MPPT controller of the WECS control system with regard to the kind of generator employed.

The modeling of the wind turbine-driven DFIG was done with the back to back converter (RSC & GSC).The simulation is done depending on the turbine speed, generator output voltage, and frequency for non linear loads.

Dynamic analysis is also carried out for abrupt changes of wind speed.

The performance of the converter is regulated with the help of a PLL-Grid control loop controller.

The comparison analysis of the newly introduced input, output total harmonic distortion (THD) and compensated grid current was also evaluated.

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II. LITERATURE SURVEY

2.1. Modelling and Controlling Of DFIG Based Wind System

AdavipalliChandanaet al.,Withthe progress made in the utilization of wind turbine technologies, in comparison with other renewable sources,the cost of wind turbine tends to becontentious.

Owing to this economic challenge, other drawbacks and by taking the global warming into consideration, the usage of wind turbine has see an increase since thepast decade. For maintaining the active power at a constant level, Doubly-Fed Induction Generators with Energy Storage System such as super capacitor (or) batteries can be utilized, with a two layer control approach. This research workintroduces a new concept for regulating the doubly fed induction generator known as power transfer matrix. This power transfer matrix approach is designed on the basis of the instantaneous values of active and reactive power [6] of the system. With the aim of protecting the DFIG during faultyscenarios, a matrix converter mechanism based power/current controller is introduced.

NihelKhemiri et al, In this research work, the modeling and control designs for a variable-speed constant-frequency wind energy conversion system employing double fed induction generator (DFIG) is presented. The objective of this research work is the design and comparison of two different control mechanismsfor controlling the rotor side converter and two control approachesfor controlling the grid side converter. For the rotor side converter (RSC), a backstepping control mechanism is firstdesigned. Next, a sliding mode control mechanism is introduced. The same mechanisms are used for controlling the grid side converter (GSC). Simulation results obtained withMatlab/Simulink have demonstrated good performances of the wind energy converter system operating under common wind changes and proposed control mechanisms.

HU Jia-bing et al., For examining the improved control and functioning of wind power generation systems that depends on doubly fed induction generators (DFIGs) during the network voltage imbalance condition,a proportional-resonant (P-R) current control mechanism and coordinated control approaches for grid-and rotor-side converters (GSC and RSC) are studied. In this research work,with the objective of simultaneously controlling the positive and negative sequence rotor currents without using any sequential-decomposition process,a P-R current control mechanism that is implemented in the two-phase stator stationary αβ reference frame was presented for the DFIG's RSC when the network voltage is imbalanced. Depending on the positive-sequence d+-axis grid voltage orientation, referencecomputations of positive and negative sequence rotor currents were got simplified corresponding to different improved control targets. The respective control mechanism for a DFIG wind power generation system during network imbalance was developed and built so that the viability of the P-R current controller can be confirmed. The experimental results reveal that the newly introduced P-R current control mechanism has the capability of implementing the RSC's control targets with remarkable transient performance. Consequently, the ride-through capability of DFIG wind generation system under imbalanced network fault scenarios is improved.

Jiabing Hu et al., The electromagnetic stability problems of the grid-connected doubly fed induction generator (DFIG) system are generally neglected. This projectintroduces a reduced order small-signal model, which can be utilizedfor analyzing the stability of DFIGs dc-link voltage control system, particularly under not so good ac grid conditions. This model overlooks the DFIG flux and rapid current control dynamics. But, the impacts of operating points, grid strengths and control loops interactions on the system’s dynamic performance are taken into consideration. An eigenvalues comparison indicates that the proposed model exhibits dominant oscillation mode characterized by the comprehensive model and is desirable for the stability analysis of dc-link voltage control system of DFIG. Influence coefficients that depict the control loops interactions are also provided. Application studies of the newly introduced model confirm that it is desirable for showing the impact of grid strength on dynamic performance of the DFIGs dc-link voltage control system. At the same time, phase-locked loop (PLL) and rotor-side converter (RSC) active power control (APC)/reactive power controls (RPC) impact on system stability are also investigated.

P.GAYATHRI et al.,With the increase in the power consumption globally, the usage of fuel has also seen a surge, thus polluting the environment, and this inspires the usage of renewable energy resources. Wind energy system is most extensively used and it satisfies the power necessities. The proposed system makes use of the DFIG for Wind energy conversion system along with Harmonics reduction and frequency control. In the case of DFIG, the stator is directly connected to the grid when two back to back connected Voltage Source Converters (VSCs) are kept between the rotor and the grid. Nonlinear loads are then connected at PCC since the proposed DFIG functions as an active filter along with the active power generated in the same wayas normal DFIG. Harmonics produced by the nonlinear load connected at the PCC create a distortion in the PCC voltage. These nonlinear load harmonic currents are improved by GSC control, such that that the stator and grid currents are free of harmonic. RSC is controlled for attaining MPPT and also for achieving unity power factor at the stator side by making use of voltage oriented reference frame. Synchronous reference frame (SRF) control mechanism is utilized for the extraction of the fundamental component of load currents for the GSC control. Moreover, the frequency is monitored and regulated with PLL. This newly introduced system is assessed with the MATLAB Simulink software.

III. PROPOSED MODULE

3.1 Proposed Topology and Operational Principle

In the recent times, a new field of research on the potential of the DFIG wind turbine for compensating the grid current harmonics is gaining focus amongst the

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electrical power engineers. With the risinginvolvement of the nonlinear load that areconnected to the grid, considerable amount of harmonics has been introduced into the grid current, leading to a poor power quality. The existence of the harmonics will result in problemssuch as overheating, lower power factor, and higher power loss, interface issues in communication system and probableoutages in critical electronic equipment.

The problem then leads to the ways of compensating the harmonics employing the grid side converter (GSC), where the harmonics is identified by active filter, and then machine side current is injected to vary the reference d-q axis current of rotor side converter (RSC) for mitigating the harmonics. Harmonics regulators obtained from both RSC and GSC are used for compensating the grid current harmonics. The d-q decoupled controls are used for both RSC and GSC harmonics regulator, and the simulation results reveal the performance. Decoupled d-q control for both RSC and GSC are designed on the basis of the reference frame theory, and the transformation can be represented as

$$f_{qd0s} = K_s f_{abcs} \qquad (1)$$

$$K_s = \frac{2}{3}\begin{bmatrix} \cos(\theta) & \cos\left(\theta - \frac{2\pi}{3}\right) & \cos\left(\theta + \frac{2\pi}{3}\right) \\ \sin(\theta) & \sin\left(\theta - \frac{2\pi}{3}\right) & \sin\left(\theta + \frac{2\pi}{3}\right) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \qquad (2)$$

$$\theta = \int_0^t \omega(\varsigma)\, d\varsigma + \theta(0) \qquad (3)$$

.

wherefcan refer to voltage, current or flux linkage, ω refers to reference frame speed (rad/sec), and θ stands for the reference frame position (rad) .The quantities ω and θ are measured with a phase locked loop (PLL).

Back to Back converters are classified as below:

- Grid Side Converter (GSC)
- Rotor Side Converter (MSC)

3.1.1. Grid Side Converter Control (GSC)

The grid side converter is utilized for maintaining the constant DC link voltage. The *d* axis current is helpful in regulating the DC link voltage and the *q* axis current component is utilizedfor regulating the reactive power. The grid side vector control mechanism is introduced in Figure 3.1.

The upper part of the diagram is utilizedfor determining the *d -axis* parameters and the lower part of diagram is helpful in deciding*q-axis* parameters.

The difference between the reference DC voltage and the measured DC voltage becomes the input of the DC link PI controller. i_{dref}refers to the output of the DC link PI controller.

The error (i_{dref}-i_{dmeas}) forms the input of the current PI controller. The output obtained of this controller is the auxiliary reference voltage *V 'd* . The original reference voltage is expressed in equation (4).

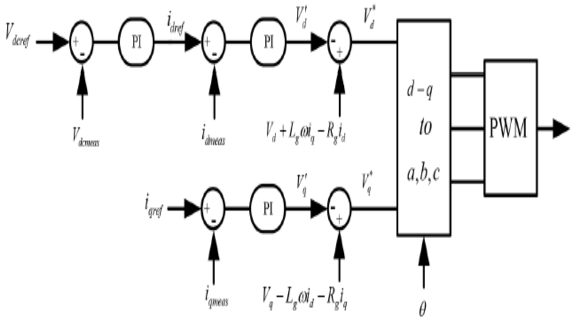


Figure 3.1: Grid Side Converter Control

The g subscript shows the grid side value. The q-axis is aligned along the stator voltage vector and thereforei$_{qref}$is fixed to be zero. In addition, it is suggested to regulate the bus voltage; at first by setting an error acquired from subtracting the measured voltage and reference voltage and control of that with a PI controller, i$_{qref}$can be computed. After this, the difference between i$_{qref}$andi$_{qmeas}$becomes the input for the current PI controller and the output of this PI controller is the auxiliary voltage V ′q .At last () can be utilizedfor determining the actual voltage given in equation (5).

$$V_d^* = V_d + L_g \omega i_q - R_g i_d - V_d' \qquad (4)$$

$$V_q^* = V_q + L_g \omega i_d - R_g i_g - V_q' \qquad (5)$$

3.1.2. Rotor Side Converter Control (RSC)

The rotor side converter is assigned to regulate the DFIG output power to the grid. It is helpfulin regulating the power factor at the DFIG terminals. The stator active and reactive powers become the inputs of rotor side converter control. The block diagram of the machine side converter control is illustrated in Figure 3.2; the upper part defines the d – axis variables and the lower part defines the q-axis variables. The below equations indicate the d - axis reference current

$$T_e = \frac{P_m - P_{loss}}{\omega_r} \qquad (6)$$

Where*Pm*, *Ploss*, and *!r* refer to mechanical power, loss power, and rotor speed, correspondingly.

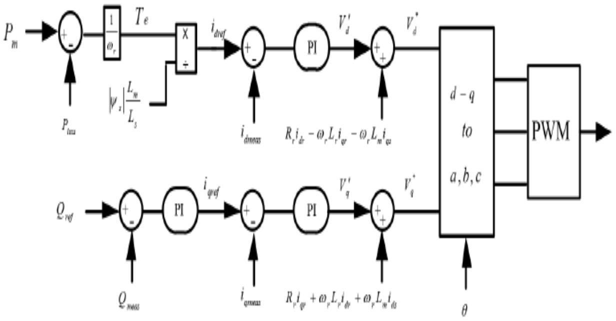


Figure 3.2: Rotor Side Converter Control

The difference between $i_{dref}$and i_{dmeas}forms the input of the current controller. The output from this controller is *V 'd* . The V_d* can be decided by the equation given as follows:

$$V_d^* = V_d' + R_r i_{dr} - \omega_r L_r i_{qr} - \omega_r L_m i_{qs} \qquad (7)$$

The *q-axis* reference current is achieved from the instantaneous reactive power. The reactive power error (Q_{ref}-Q_{meas}) becomes the input of reactive power controller and the output of this PI controller decidesi_{qref}.The difference between i_{qref}andi_{qmeas}forms the input of the current PI controller. The output from the current controller is auxiliary voltage *V 'q* .At last the *q* axis actual reference voltage is derived as below:

$$V_q^* = V_q' + R_r i_{qr} + \omega_r L_r i_{dr} + \omega_r L_m i_{ds} \qquad (8)$$

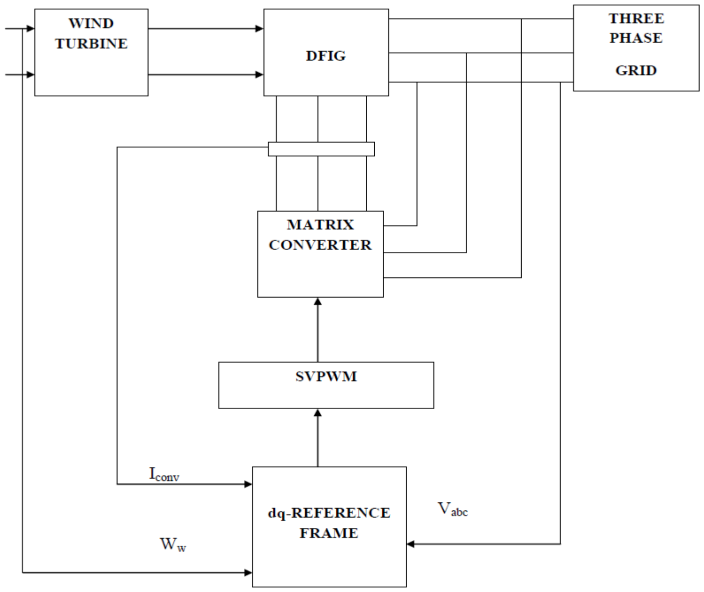


Figure 3.3: Proposed Block Diagram

3.2 Working Principle of the Proposed Converter

A control technique for a wind energy conversion system is supposed to partially function as a PLL & grid control loop (D-Q Reference frame). The control is specified in an equivalent reference frame achieved by using the Park transformation to the three-phase quantities.

The control system consists of the zero-sequence component, which facilitates the compensation of zero-sequence harmonics. It indicates that reduction in power loss and mitigation of current and voltage harmonics can be achieved in the available system.

A novel modulation approachutilized is PLL control method with grid loop controller and it will boost the output current harmonics of a wind energy conversion system, inclusive of a Doubly Fed Induction Generator (DFIG) and a matrix converter is introduced. The design and analysis of a control mechanism for a DFIG based wind energy generation under imbalanced load conditions are studied. The control goals are (i) to restrict the machine side currents, (ii) to eliminate the ripples in the torque, (iii) to eliminate the dc-link voltage fluctuation through converter controls and (iv) toboost the THD.A D-Q reference frame mechanism is presented. This technique is implemented in the machine -side and grid-side converters of the DFIG to improve the voltage ride-through capacities of DFIG-based wind turbines. During the analysis of power quality, the impacts of high penetration electric vehicles and renewable energy based generator systems, inclusive of wind turbines, grid connected photovoltaic, and fuel cell power generation units are presented. A proportional control mechanism is realized in the d-q reference frame side to reduce the machine side current harmonics and torque pulsations. The primary goal of the control mechanism is to keep the voltage and frequency constant at the output of the generator. A control mechanism is introducedwith the aim of upgrading the DFIG based proposed system to attain a low THD. The voltage harmonics mitigation is an essential task, which cannot be carried out by current source inverters (CSIs). In this research work, the novel approach is utilizedfor mitigating the harmonics current of the power system. For this, the controller in the wind turbine system is utilized in the form of a reference frame sector with control loop method. In this system, grid side converter (GSC) control is employedfor generating the currents in such a manner that they have the harmonics equal and 180 degree out of phase with harmonics of nonlinear load currents resulting in the cancellation of nonlinear load current harmonics. Moreover, a bus voltage control mechanism is utilized for this harmonic mitigation in GSC too. In this mechanism, the voltage of the DFIG installation bus, which is measured, is used to the GSC control to carry out the proposed voltage control technique. These are used simultaneously in the power system and can deal with the harmonic reduction in both normal and emergency (load change) scenarios.

3.3. Proposed System Advantages

- Low THD.
- High Power factor.
- Low Losses.
- The system provides the benefits of less reactive power flowing into the grid from the rotor side of the DFIG system.

- The important benefit of the DFIG system is that it can provide the rated power even during fluctuations in the wind velocity conditions. Improved system Performance.

IV. SIMULATION RESULTS

4.1. SIMULINK

Simulink, designed by Math Works, is a data flow graphical programming language tool used for the modeling, simulation and analysis of multi domain dynamic systems. Its primary interface is a graphical block diagramming tool and a customizable set of block libraries. It provides a strong integration with the remaining of the MATLAB environment and can either drive MATLAB or be scripted from it. Simulink is extensively utilized in control theory and digital signal processing for multi domain simulation and Model-Based Design. Simulink yields a graphical editor, customizable block libraries, and solvers for modeling and simulating dynamic systems. It is also integrated with MATLAB$^{®}$, facilitating in incorporating the MATLAB algorithms into the models and thereafter export the simulation results to MATLAB for analysing further.

4.2. Simulation Diagram of Proposed Method

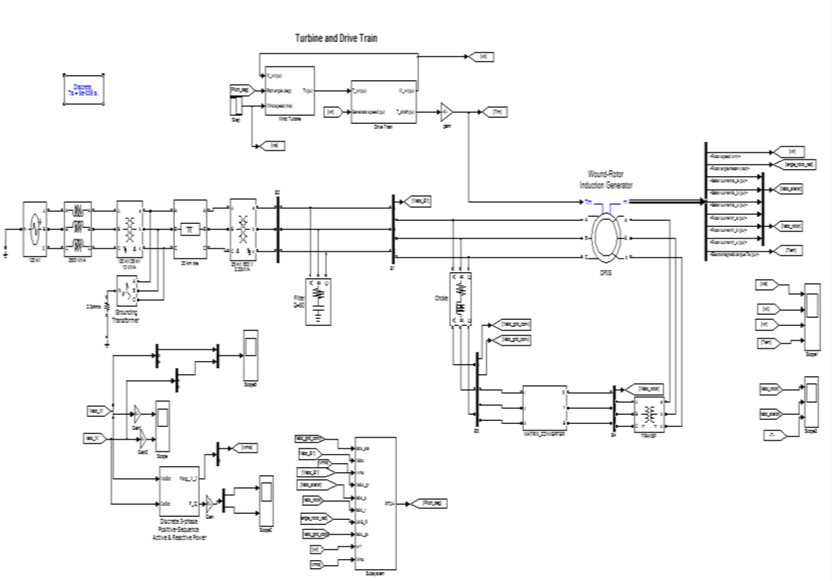


Figure 4.1: Simulation Diagram of DFIG based PLL Control Structure with MATRIX Converter & SVPWM[10]

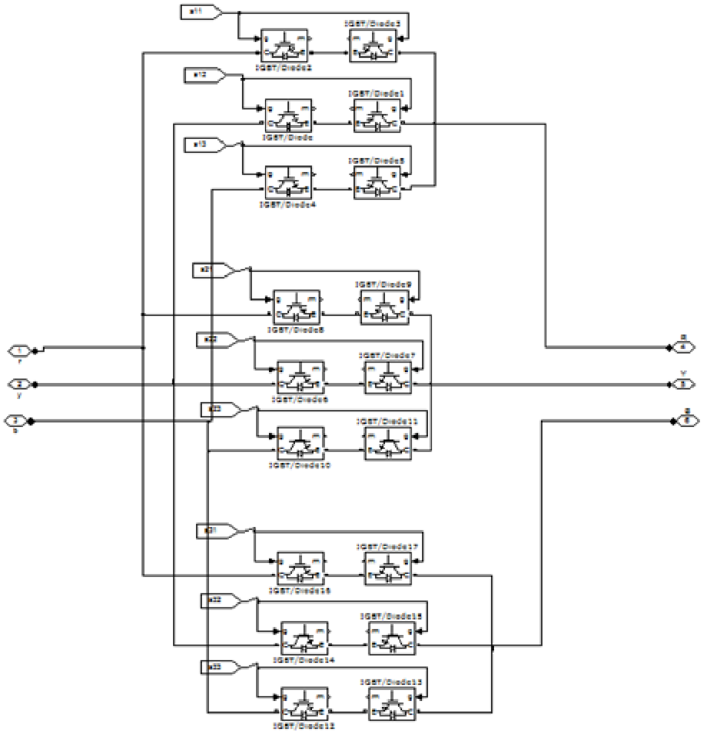


Figure 4.2: Simulation Diagram of Martix Converter

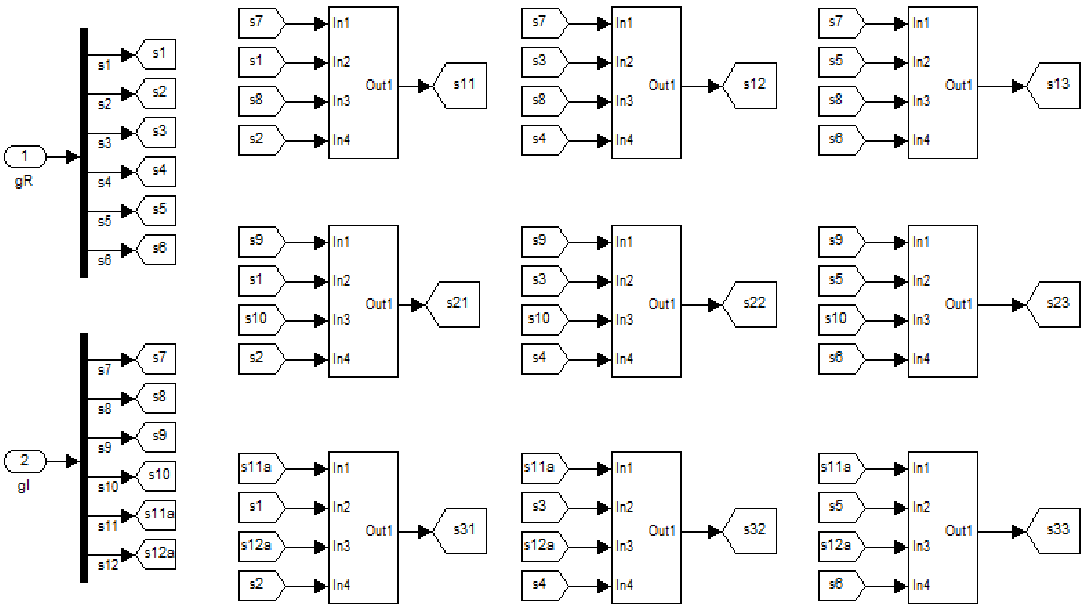


Figure 4.3: Simulation Diagram of Matrix Converter Switching Table

Figure 4.1 illustrates the DFIG-simulated model of a traditional Matrix converter (RSC & MSC) for a wind turbine driven system [9-14]. The simulation of the model was done for various wind speeds. At last, the comparison of the input and output THD was done with that of the newly introduced WECS. This model comprises of a wind turbine, a Matrix Converter, GSC, RSC with a PLL, SVPWM & grid loop controller. Figure 4.9 & 4.10 illustrates the change of the input current THD of the newly introduced system. The percentage THD of the classical system was nearly 10% higher than that of the system proposed. This results inlesser input power factor and higher switching losses. The above setbacks are balancedwith the proposed system and its results are then compared and tabulated in table 4.1.

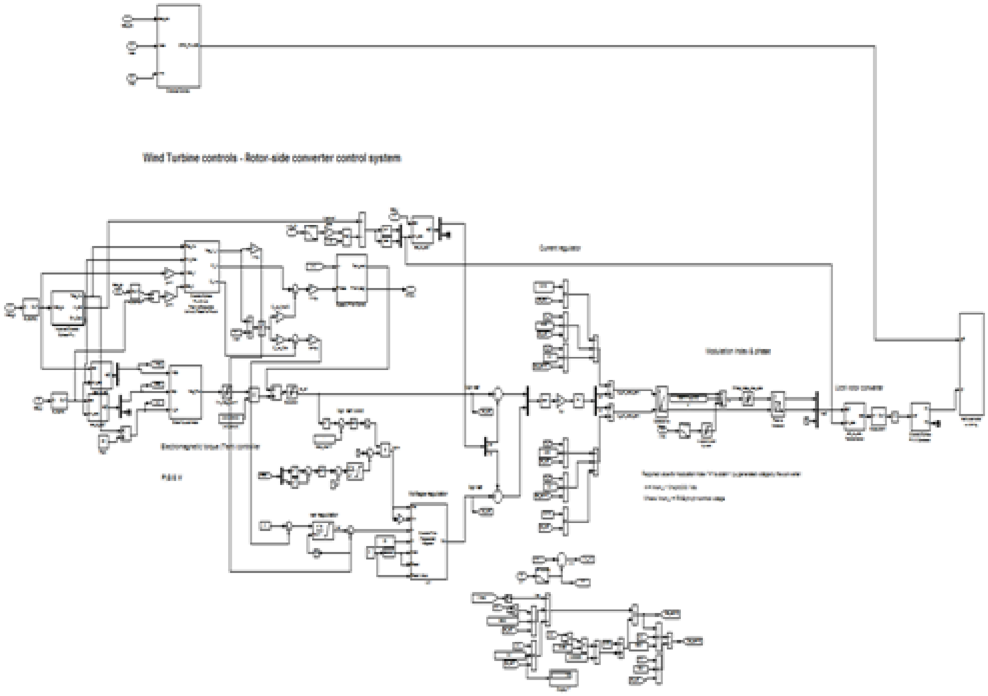


Figure 4.4: Simulation Diagram of Control Loop

Even though the terms of power quality hold true for transmission and distribution systems, their mechanism towards power quality has various aspects. An engineer working on a transmission system tackles with controlling the active and reactive power flow so as to increase both the loading capability and stability constraints of the transmission system.

A technique to get over the disadvantage of the available system - a proposed model is developed and presented in this research work. The technique is simple by structure and is dependent on the addition of one (or three in a three-phase case) integrator to the system.

This entirely eliminates the error, which results due to the dc component. Also, an estimation of the dc component is also available.

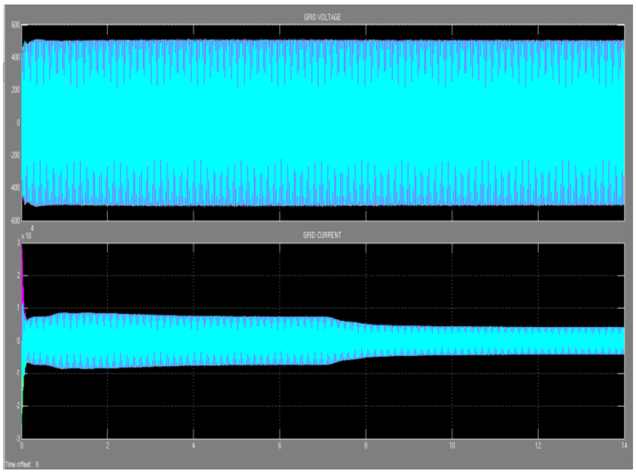


Figure 4.5: Output Waveform of Wind/Turbine/Rotor Speed/Torque

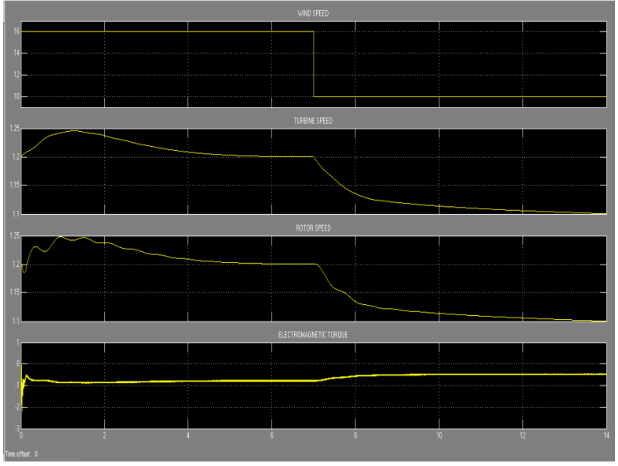


Figure 4.6 : Output Waveform of Rotor /Stator/Inverter Current

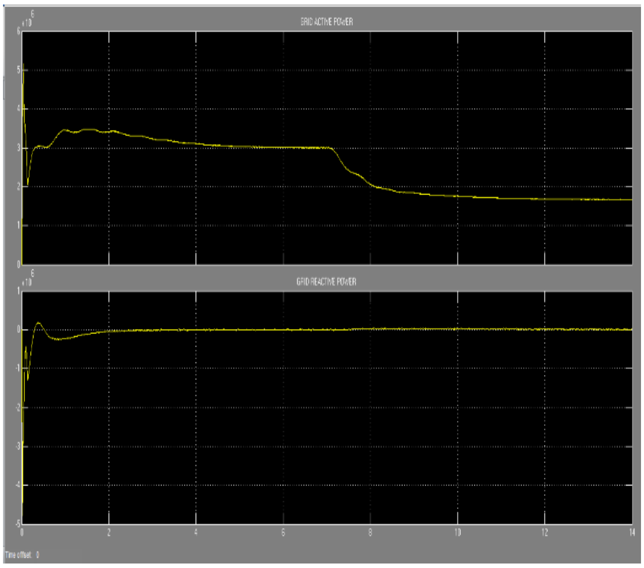


Figure 4.7: Output Waveform of Grid Current/Voltage

Fig.4.9 shows the fast Fourier transform (FFT)analyzes to the current flow in the grid, as per the Figure, THD is 1.92% at maximum load (8NM) & 3.46% at maximum load condition (12NM). The grid current waveform is illustrated in the Fig.4.10.

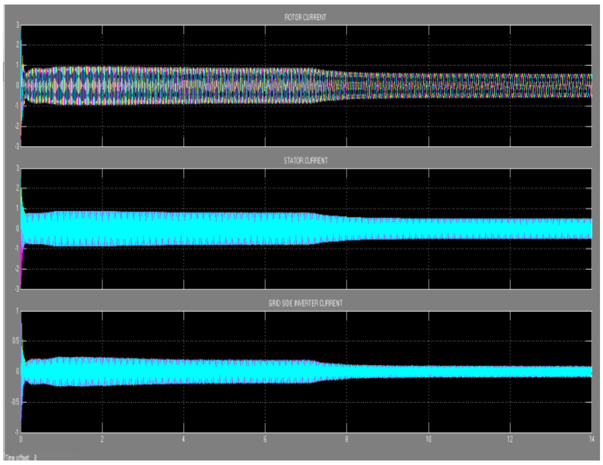
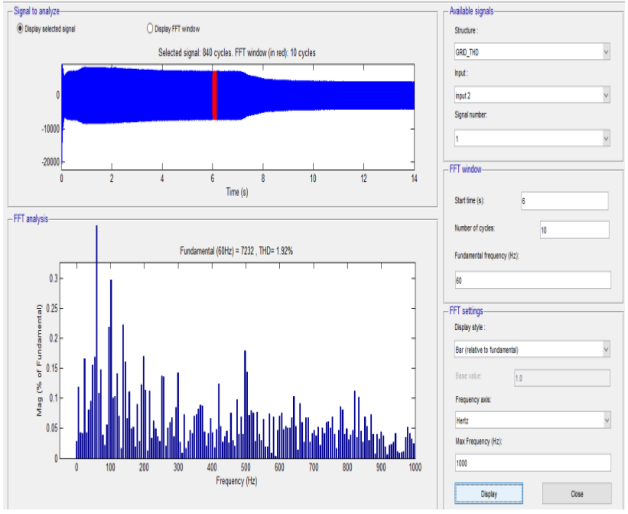
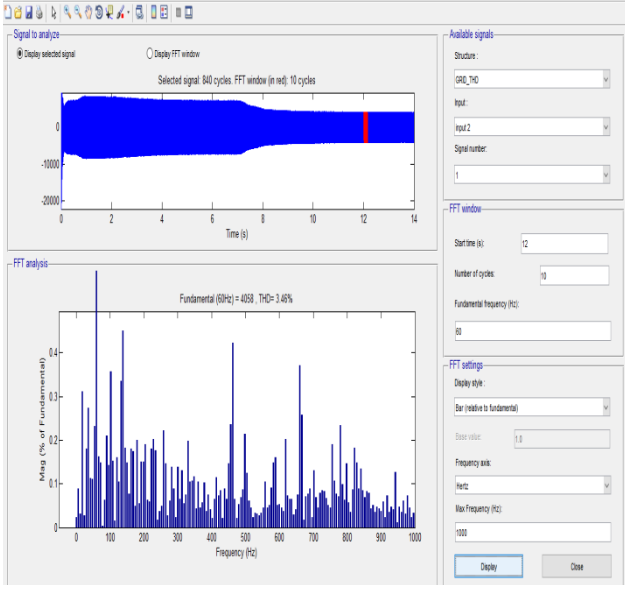


Figure 4.8: Output Waveform of Real / Reactive Power



Structure : GRID_THD
Input : input 2
Signal number: 1
Start time (s): 6
Number of cycles: 10
Fundamental frequency (Hz): 60
Display style : Bar (relative to fundamental)
Base value: 1.0
Frequency axis: Hertz
Max Frequency (Hz): 1000

Figure 4.9: Output of FFT analysis for THD at 8 NM =1.92%



Structure : GRID_THD
Input : input 2
Signal number: 1
Start time (s): 12
Number of cycles: 10
Fundamental frequency (Hz): 60
Display style : Bar (relative to fundamental)
Base value: 1.0
Frequency axis: Hertz
Max Frequency (Hz): 1000

Figure 4.10: Output of FFT analysis for THD at 12 NM =3.46%

The dc component may be inherently existing in the input signal or may be produced owing to temporary system outages or owing to the structure and constraints of the measurement/conversion processes.

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A component such as this generates low-frequency oscillations in the loop, which cannot be eliminatedwith filters as such filters will considerablydeteriorate the dynamic response of the system. The newly introducedtechnique is dependent on the addition of a new loop (D Q-Matrix converter-SVPWM) present within the PLL structure. It is simple by structure and, dissimilar to the existing techniquesexplained in this project, does not make a compromise on the high-frequency filtering level of the associated algorithm. The technique is designed for three-phase systems, its design aspects are studied, and simulations results are given above.

Table 4.1: THD Value Comparison

During presence of Wind Speed from 8 to 16 NM		
Cases of connection	8NM	16NM
THD of power grid current	1.92%	3.46%

V. CONCLUSION

The proposed concept introduces the idea of mitigating the grid current harmonics employing the Matrix converter with SVPWM approach of the DFIG wind generator. The synchronous reference frame regulators are explained for both RSC and GSC. The control of the harmonics regulator is similar to the main control of the DFIG system. The harmonics regulation techniquesstudied tackle with the dc component in various frequencies, rendering the control mechanismconvenient to be achieved and offer good dynamic stability under differential wind speed.

Making use of these two techniques (SRF & Grid control loop) together in the power system, THD percent and harmonics will be reduced. In order to validate the performance of the newly introducedtechnique, two operational scenarios for a wind speed (8 & 16 NM) conditions are taken into consideration. Hence, the evaluation of the effectiveness of the proposed technique is carried out in both the conditions. The proposed technique is used for a modified power system and the abovementioned scenarios are taken into consideration. As it can be observed, the proposed technique can deal with the harmonic reduction issue in everycondition. Hence, the results of this approach reveal the commendable performance of this scheme.Matlab/Simulink environment is used for simulating all the modes of operation.

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