A Control Strategy for A Variable Speed Wind Turbine with A Permanent Magnet Synchronous Generator Using Matrix Converter with SVPWM

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

Abstract--- ***With the aim of meeting the power demands, considering the economical and environmental factors, wind energy [11] conversion is slowly garnering interest in the form of a desirable source of renewable energy. In this work, a grid connected wind power generation approach employing a doubly fed induction generator with a direct AC-AC matrix converter[4] is introduced.***

The objectives of this research work include: To model and then simulate the operation of a doubly fed induction generator. The analysis uses a space vector modulated [1] matrix converter for controlling the rotor current. The matrix converter-based rotor current control approach [9] is focused. The system facilitates the optimal speed tracking for capture of maximum energy from the wind and high performance active and reactive power control utilizing the RST regulator. Finally, the simulation results achieved, for various operating points, are studied, showing the system's good control performances.

Keywords--- PMSG, RSC, GSC, Total Harmonic Distortion, MPPT, PLL-Grid Control Loop Controller, MATLAB/ SIMULINK.

I. INTRODUCTION

Electricity generated from renewable resources, and especially from the wind, is regarded presently to be an aggressive and required alternate to fossil resources. Wind turbines can work with either fixed speed or variable speed[3]. Pitch-adapting variable-speed wind turbines like PMSG [12] have emerged to be the pre-dominant kind of annually installed wind turbines in the last few years. There are various reasons for selecting PMSG, like the reduction of both the mechanical structure stresses and the probability to controlling the four quadrants active and reactive power capacities, have been selected for differential speed operation of wind turbines.

The differential speed wind turbine can yield decoupled control of active and reactive power of the generator and boost the power quality. Owing to multiple combination of nonlinear loads, like power electronics and large AC drives that form the polluting sources of the power grid, the recent WECS [8] is not just restricted to product active power to the clients but also to enhance the power quality under various conditions.

The power electronic converters have the potential of accomplishing reactive power compensation to achieve the voltage control and to eliminate the harmonic currents. Recently, RSC & GSC of PMSG, which is connected between the rotor terminals of generator and the grid has been developed to have the capacity of increasing the grid power quality and mitigate the harmonic currents.

The GSC is used in the form of reference frame, in order to compensate for the phase shift due to the presence of inductive load and to eliminate the current harmonic and attain unity power factor due to the presence of nonlinear load at PCC, which is shunt connected with inductive load in addition to its chief function, which maintains the voltage of the DC link constant at its level and achieving unity power factor of GSC of PMSG.

In the case of MPPT, the speed controller can constantly have the speed of the rotor adjusted in order to maintain TSR stable at the level that provides the maximum power coefficient and thereafter the efficacy of the turbine will be considerably improved, the generator is regulated by power electronic equipment that renders it feasible to have a control on the rotor speed in low wind speed [6] lesser than the rated value.

In this manner, the power fluctuations resulting due to wind changes can be more or less mitigated by varying the rotor speed and therefore the power changes that originate from the wind conversion and the drive train can be minimized.

Hence, control systems for PMSG variable speed wind turbines has to continue to develop towards more and more efficient and inventive solutions. Wind energy, although available in abundance, differs continuously since the wind speed varies throughout the entire day.

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The amount of power output from a WECS[2-3] is dependent on the accuracy with which the peak power points get tracked by the MPPT controller of the WECS control system with no regard to the kind of generator employed.

II. LITERATURE SURVEY

Walid El-Khattam et al., This project assesses the efficiency of various commercial relay functions in a local passive anti-islanding process for a permanent-magnet synchronous generator (PMSG)-based wind farm that is interfaced with a radial distribution network.

The results are achieved through an elaborate set of real-time simulation analysis, carried out on an elaborate topological model of a single-machine equivalent of the PMSG-based wind farm and the network, utilizing three diverse commercial relays.

The research work presents the study organization and techniques and, in addition, details of the mathematical and simulation models of the PMSG-based wind farm. The models and the techniques introduced in this research work can be utilized, either directly or with very small changes, for several other impact-evaluation research.

Shamik Chatterjee et al., Wind power is a green renewable source of energy, which can be an effective contender with fossil fuel in the form of a power generator in the electricity market. The important segments of a Wind Turbine System (WTS) include rotor, gearbox, generator, transformer and possible power electronic system (PES). Wind turbines need few control systems.

Horizontal-axis wind turbines need to be oriented towards the wind. In high winds, it is necessary to minimize the drive train loads and safeguard the generator and the power electronic equipment from overloading by restricting the turbine power to the rated value up to the furling speed.

At gust speeds, the machine needs to be stopped. At low and medium wind speeds, the objective has to be towards capturing the power to the maximum efficiency possible.

The high efficient power electronics in power generation, power transmission/distribution and end-user application is being utilized for control purposes.

This research work discusses on the control of the most developing renewable energy source, wind energy, with the aid of PWM converter. Because of this power electronics system, it is evolving from being a small energy source to be functioning as a significant power source in the energy system.

H. Ahuja et al., Wind energy generation systems are bombarded with rising needs for power quality and active power control. With the progress in power electronics technology, the quick evolution of variable speed WECS is now observed. But, the power quality at the point of grid connection is still a significant challenge that the researchers have to address strictly.

This research work is focused on the evolution of variable speed WECS employing i) Doubly Fed Induction Generator (DFIG) with partial scale converters and ii) Permanent Magnet Synchronous Generator (PMSG) with full scale converters and their performance comparison for comparable ratings and with identical control approaches.

The objective of the comparison is to introduce in a clear and uniform manner the aspects of power quality (PQ) at the point of grid connection, the range of wind speed, which can be handled by the generators, power derived from both WECS at different wind velocities and converter ratings. Vector control mechanism is being used for both the systems. Maximum power point tracking (MPPT) has also been realized in order to derive the maximum available power for a certain wind velocity in both the systems.

Md. Enamul Haque et al, This research work introduces a new control mechanism for the functioning of a direct-drive permanent-magnet synchronous-generator-based independent variable-speed wind turbine. The control approach for the generator-side converter with maximum power extraction is introduced.

The stand-alone control is characterized with output voltage and frequency controller, which has the capability of managing differential load.

The considerable excess power gets dissipated in the dump-load resistor with the chopper control, and the dc-link voltage is maintained.

Dynamic characterizations of dc bus and small-signal analysis are introduced. Simulation results indicate that the controllers can harness maximum power and control the voltage and frequency under different wind and load conditions. The controller exhibits superior dynamic and steady-state performance.

K. Inomata et al, The matrix converter offers several benefits in wind power system applications. Matrix converter is portable and highly effective since it directly transforms the power from AC generator to the grid without needing an intermediate DC bus when traditional back-to-back converter system needs several electrolytic capacitors in DC link bus that are heavy and are short-lived.

Matrix converter exhibits both motoring and regenerative power flow that maintains low harmonics current to the grid.

It is necessary for wind power converter to yield reactive power to the grid that is one among the most significant features for wind farms for the stabilization of the power system during and after grid outages.

In this research work, an improved fault ride through the capability of high power matrix converter [2] for wind power system is introduced. The newly introduced ride through technique during grid voltage drop is described, and it is validated through simulation and experimental results.

III. PROPOSED MODULE

3.1 Proposed Topology & Its Principle

- The output harmonics of the novel converter system is more in comparison with the newly introduced system. THD ratio is high.
- Design of the available system is too complex owing to heavy capacitors.
- In comparison with the newly introduced topology utilized in PMSG based variable speed system, the

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- available systems are in-economic, noisy and undependable structure.
- Low power quality compared to the proposed system.

3.1.1. Existing System Drawbacks

The important drawback of the conventional AC–DC–AC converter is the bulk DC capacitor utilized for energy storage.

- Low Power factor.
- Significant Losses.
- Less Efficiency.
- Decrease in system Performance.

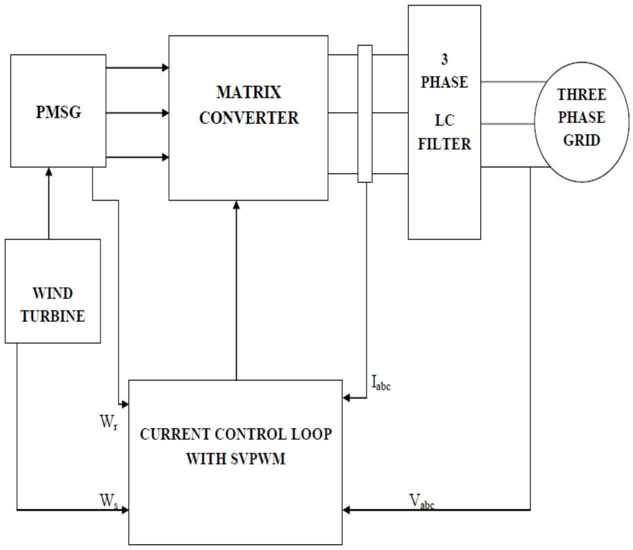

Figure 3.1: Block diagram of Proposed System

3.2 Proposed System Block Diagram Description

This research work provides an elaborate study for the dynamic performance of the gearless WECS that is based on PMSG employing a matrix converter that is connected to the grid through LC filter with the aim of injecting a pure sin wave shape voltage and current.

The important parts of the proposed WECS include the wind-turbine, the permanent magnet synchronous generator, the matrix converter, the newly introduced control system based on Current Control with SVPWM approach[7].

A novel modulation methodology utilized is PLL control approach with grid loop controller and it helps in improving the output current harmonics of a wind energy conversion system, inclusive of a PMSG and a matrix converter is introduced.

The design and analysis of a control approach for a PMSG based wind energy generation under unbalanced load conditions are studied. The control goals include (i) to inject the inverter currents, (ii) to eliminate ripples in the torque [5], (iii) to eliminate the dc-link voltage variations through converter controls and (iv) to boost the THD.

A current control approach is proposed. This technique is implemented in the machine -side and grid-side converters of the PMSG to improve the voltage ride-through capabilities of PMSG-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 implemented in the synchronous reference frame end to reduce the machine side current harmonics and torque pulsations. The foremost goal of the control approach is the maintenance of stable voltage and frequency at the generator output.

A control approach is introduced for upgrading the PMSG based proposed system to attain low THD. Mitigating the voltage harmonics is an essential task, which cannot be carried out by inverters. In this research work, the novel mechanism is utilized for mitigating the harmonics current of the power system.

The newly introduced control makes use of the active and reactive parts of the PMSG current to maximize the control ability of the active and reactive power generation at both the PMSG and the grid side during differential speed operation.

Moreover, a dynamic limiter is utilized for controlling the reactive power that is injected to the grid without going beyond the rated current of the matrix converter. The controller is utilized to avoid the rated power of the generator exceeding at high wind speed by restricting the speed of the PMSG.

3.2.1 Proposed System Advantages

- Superior Efficiency & enhanced THD.
- High Power Density & High Power Factor.
- Low Noise and Easy to Control.
- Current Control (CC) exhibits the benefit of its quick response and simplicity.
- The matrix converter controller has to tackle the grid-side quantities like grid-side reactive power to enhance the system stability and power quality.
- Minimize the current ripples of the injected power to the grid.

IV. SIMULATION RESULTS

4.1 About MATLAB

The simulation of this project is done in MATLAB R2011a tool, a user friendly software. MATLAB is a high-level language and interactive environment for numerical computation, visualization, and programming.

With the help of MATLAB, data can be analyzed, algorithms can be developed, and models and applications can be created.

The language, tools, and built-in math functions facilitate in exploring numerous techniques and attain a solution quicker compared with spreadsheets or conventional programming languages, like C/C++ or Java™. MATLAB can be used for multiple applications, inclusive of signal processing and communications, image and video processing, control systems, test and measurement, computational finance, and computational biology. Several million engineers and scientists in industry and academia make use of MATLAB, which is the language of technical

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computing, Simulink is a data flow graphical programming language tool used for modeling, simulation and analysis of multi domain dynamic systems. Its primary interface is basically a graphical block diagramming tool and a customizable group of block libraries.

It provides a good integration with the remaining of the MATLAB environment and can either used to drive MATLAB or can be scripted from it. Simulink is extensively employed in control theory and digital signal processing for multi domain simulation and Model-Based Design.

4.1.1 Simulink

Simulink, the brain child of Math Works, is a data flow graphical programming language tool used for 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 great integration with the remaining portion of the MATLAB environment and can be used for either driving MATLAB or can be scripted from it. Simulink is extensively employed 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 the modeling and simulation of dynamic systems.

It is merged with MATLAB®, facilitating to include MATLAB algorithms into models and export the simulation results to MATLAB for further evaluation. Figure 4.1 Simulation Diagram of PMSG based Current Control Structure with MATRIX Converter & SVPWM.

4.2. Simulation Diagram of Proposed Method

Figure 4.1 illustrates the PMSG-simulated model of a traditional Matrix converter with SVPWM and current control loop for a wind turbine driven system. The model was simulated for various values of wind speeds.

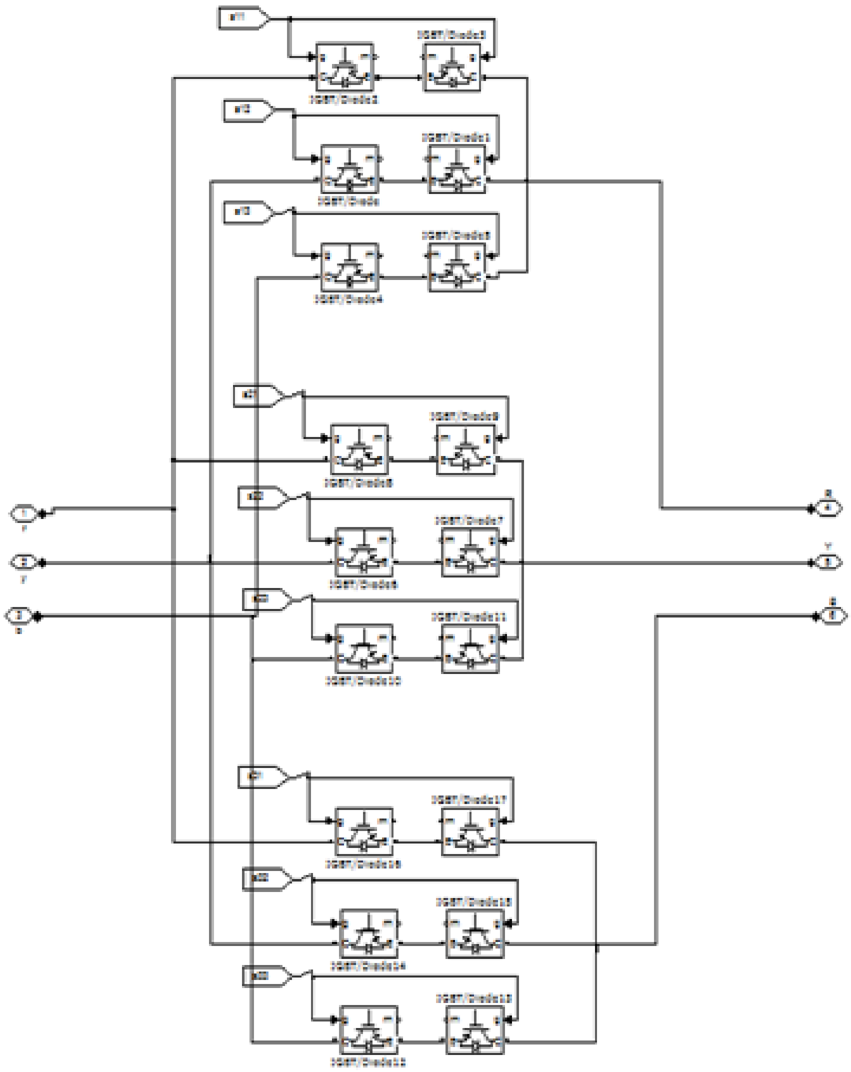

Figure 4.1: Simulation Diagram of PMSG based Current Control Structure with MATRIX Converter & SVPWM

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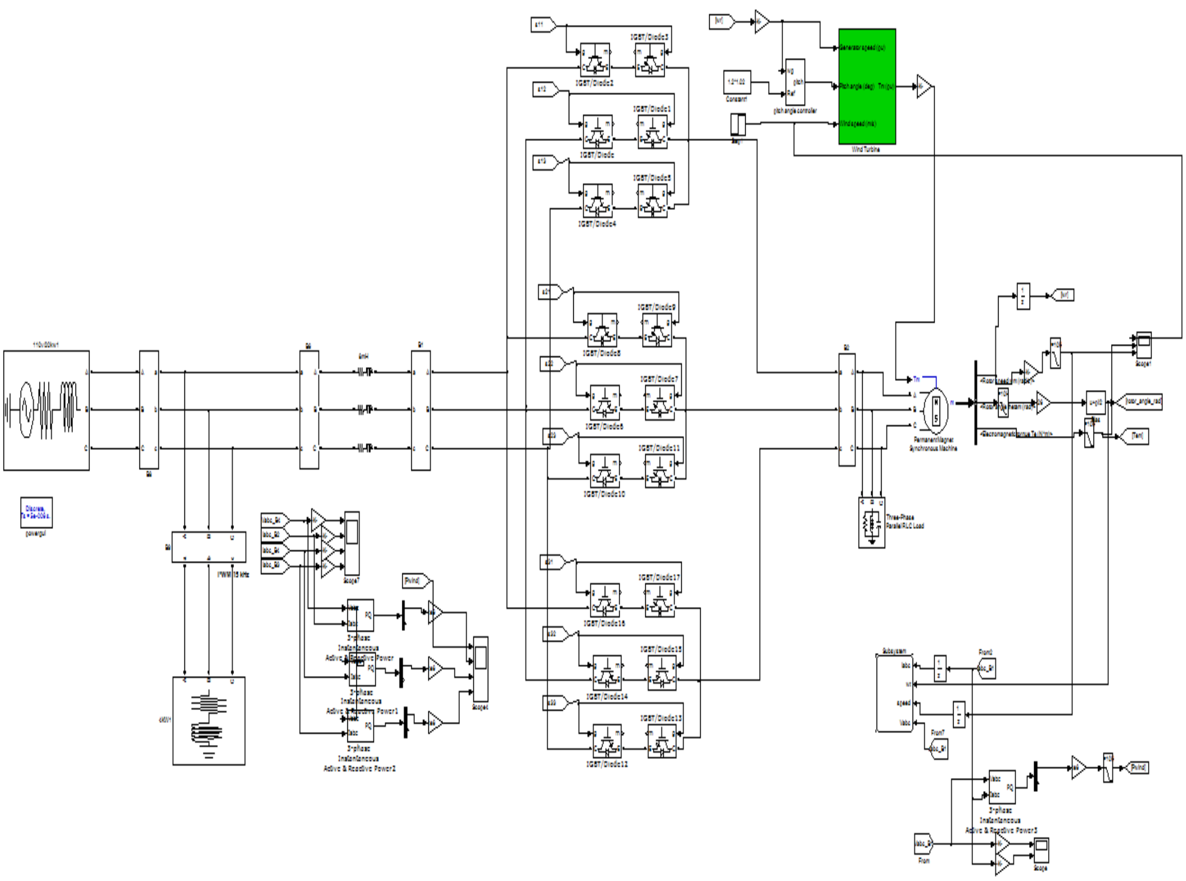

Figure 4.2: Simulation Diagram of Matrix Converter

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, Current Control Loop DC link and with a PLL, SVPWM [10] controller. Figure 4.7 illustrates the change of the input current THD of the newly introduced system. The percentage THD of the traditional system was nearly 15% greater than that of the newly introduced system. This results in lesser input power factor and higher switching losses. The above disadvantages are compensated with the help of the proposed system.

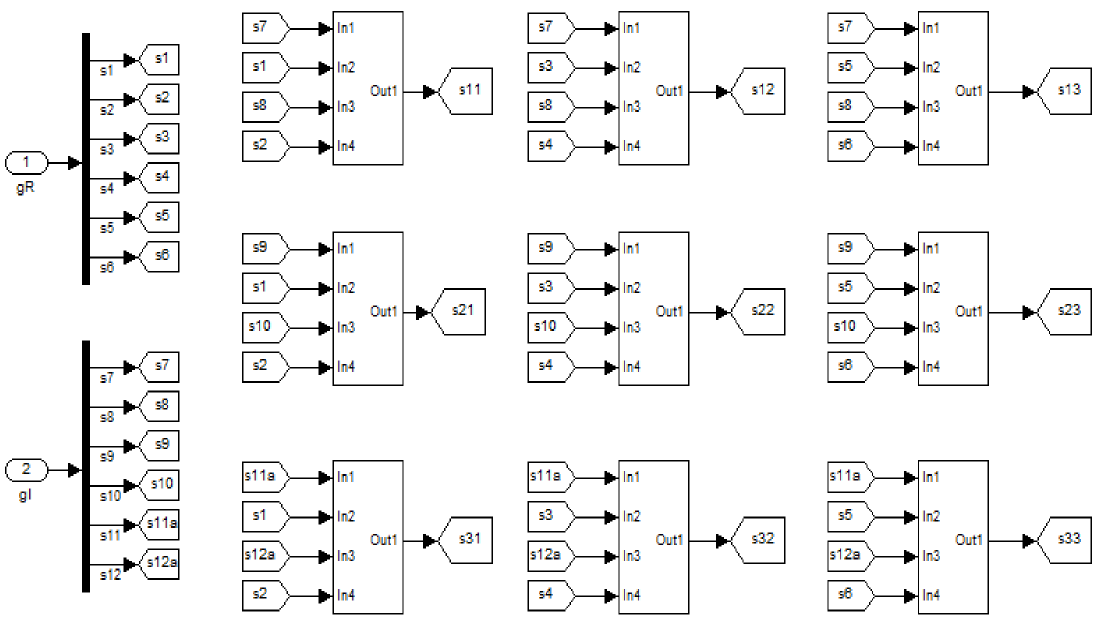

Figure 4.3 Simulation Diagram of Matrix Converter Switching Table

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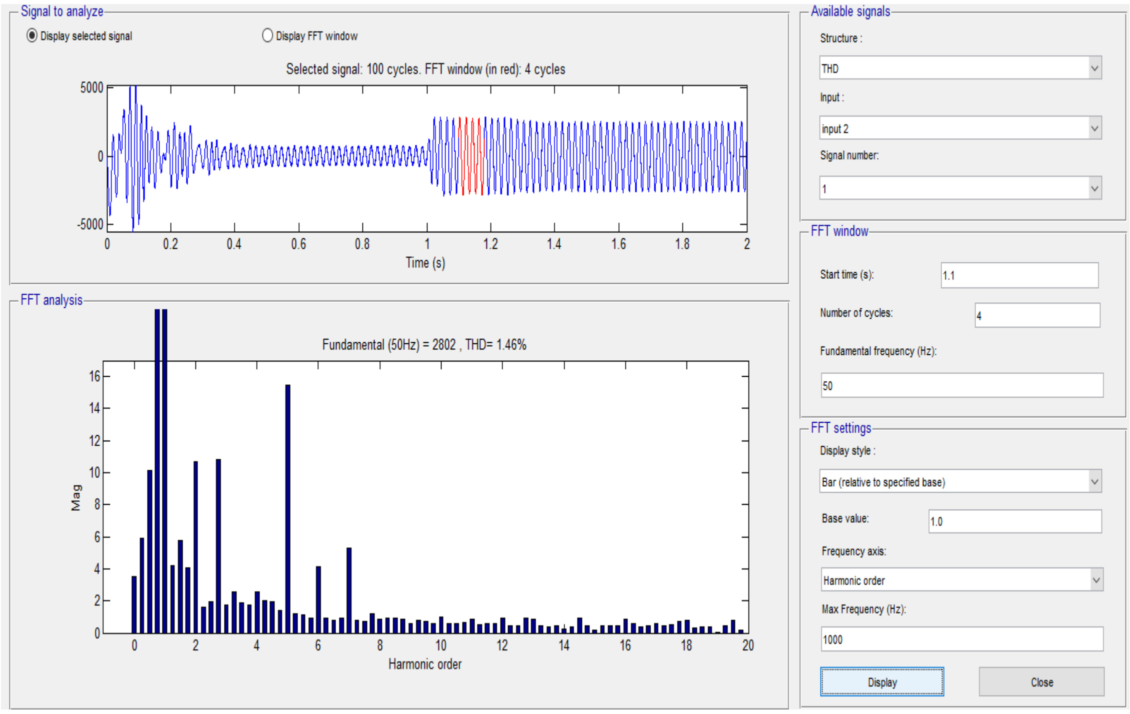

Figure 4.4: Simulation Diagram of Control Loop

Even though the terms of power quality hold true for transmission and distribution systems, their technique to power quality has various aspects. An engineer of transmission system tackles with controlling the active and reactive power flow with the aim of maximizing both the loading capacity and stability limitations of the transmission system.

A technique to get over the disadvantage of existing - a new model is developed and analyzed in this research work. The technique is structurally easy and is dependent on adding one (or three in a three-phase case) integrator to the system. This entirely discards the error, which results from the dc component. In addition, the dc component is estimated.

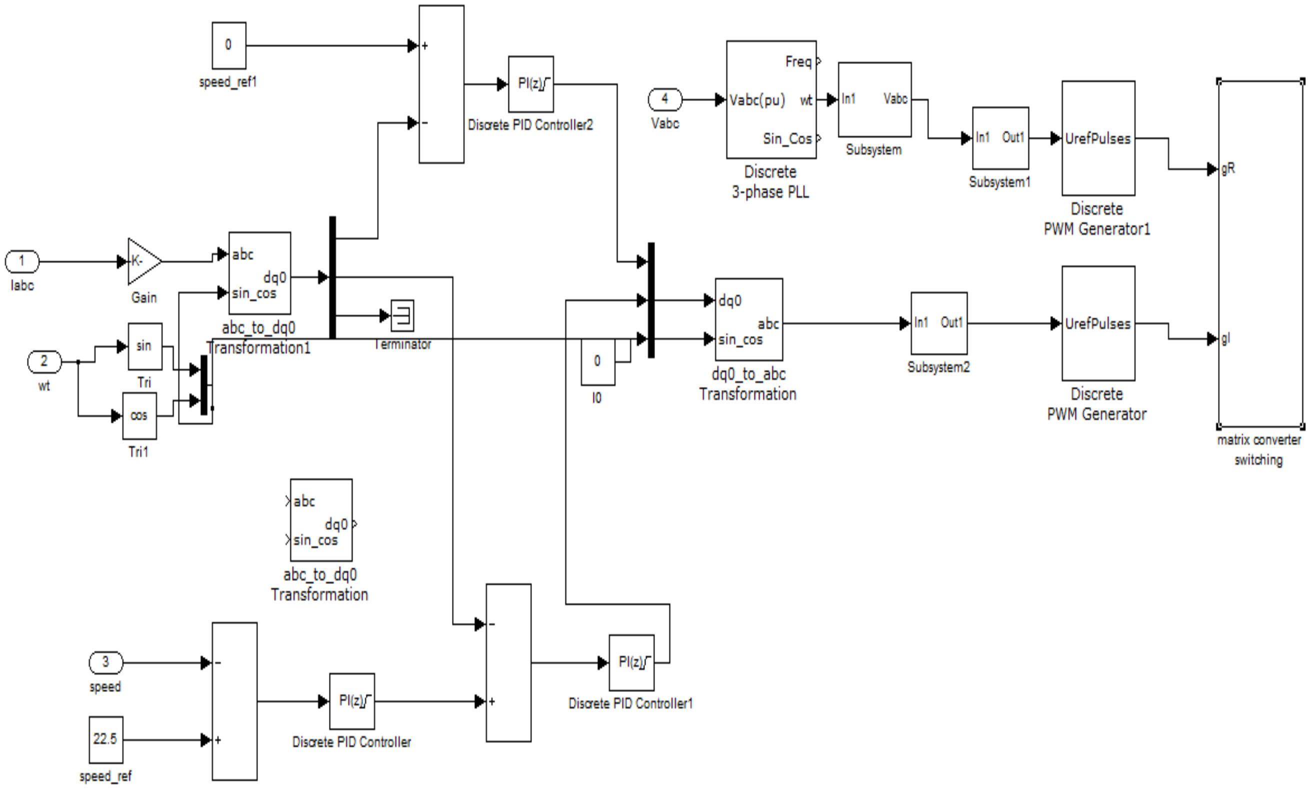

Figure 4.5: Output Waveform of Grid Voltage/Inverter Current/Grid Current/Load Current

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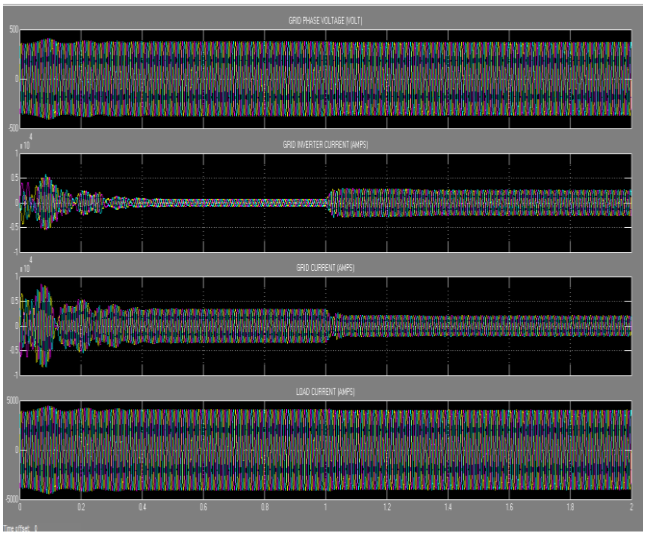

Figure 4.6 : Output FFT analysis for THD =1.46%

Fig.4.6 graphically provides the fast Fourier transform (FFT) analyzes to the current that flows in the gird, and in that Figure THD is 1.46%

The dc component may be inherently existing in the input signal or may be produced owing to temporary system failures or owing to the structure and drawbacks of the measurement/conversion processes. A component such as this generates low-frequency oscillations in the loop, which cannot be eliminated employing filters as such filters will considerably deteriorate the dynamic response of the system. The newly introduced technique is dependent on the addition of a new loop (Current control Loop--Matrix converter-SVPWM) within the PLL structure. It has a simple structure and, dissimilar to the available techniques explained in this project, it does not balance the high-frequency filtering level of the related algorithm. The technique is implemented for three-phase systems, and its design aspects are explained, and simulations results are introduced above.

V. CONCLUSION

The proposed concept introduces the concept of balancing the grid current harmonics employing the Matrix converter with SVPWM approach and current control loop of the PMSG wind generator. This research work introduced a high performance current control approach for matrix converter based wind energy conversion system installed with PMSG. A MPPT controller is developed in order to decide the optimum speed, which leads to the extraction of the maximum power from wind at various wind velocities.

It has been demonstrated that the newly introduced approach offers a good dynamic response by regulating the generator speed with under wind velocities lesser compared to rated value. At higher wind velocities, where the generator speed is greater than its rated value, a pitch angel controller is used for regulating the speed and restricting the power extracted from the turbine. In addition, the newly introduced control of the matrix converter meets the grid-codes demands of injecting a controllable reactive power that is in proportion to the decrease in the grid voltage. The supplied reactive power of the turbine is based on the *d*-component of the PMSG current and the extracted active power is proportional to the generator speed. The simulation results of the newly introduced interface system show its efficiency and rapid transient response under various wind speeds. The dynamic interactions between variable-speed WECS and the grids are examined. The newly introduced technique is used to a changed power system and the suggested scenarios are taken into consideration. As it can be observed, the newly introduced technique can deal with the harmonic reduction challenge in every scenario. Hence, the results of this approach depict the remarkable performance of this mechanism. All of the modes of operation are simulated with the help of Matlab/Simulink environment.

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