Load Analysis of Statcom with Voltage Regulation Controller Based Standalone Wind Energy System

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Abstract- **The actual values of the output voltages of the wind turbine have been observed, where the wind speed varies between 0 and 25 m / s. It is designed to handle heavy loads and the voltage drop is controlled and compared to the system using the STATCOM voltage regulator with AC DC. The load has been permanently modified to determine the optimal load value for which both systems are compatible. The waveform of the open circuit voltage output varies from 800 to 1000 volts. This voltage must be maintained when a load must be transported without loss of value. It has been observed that the voltage drop in the system without STATCOM is above 1000 KW and a load of 500 KW. However, the optimal value of the system until the load can work is 18 kW and STATCOM has a controller for CC regulation. The value has been improved to 50 kW.**

Keyword – **controller, grid system, DFIG controller, solar system.**

1. INTRODUCTION

Renewable energy sources like solar, wind, and tidal are sustainable, inexhaustible, environmentally friendly and clean energy sources. Due to all these factors, wind power generation has attracted great interest in recent years. Undoubtedly, wind power is today's most rapidly growing renewable energy source. Even though the wind industry is young from a power systems point of view, significant strides have been made in the past 20 years. Increasing reliability has contributed to the cost decline with availability of modern machines reaching 97-99%. Wind plants have benefited from steady advances in technology made over past 15 years. Much of the advancement has been made in the components dealing with grid integration, electrical machine, power converters and control capability, and now able to control the real and reactive power of the induction machine, limit power output, control voltage and speed. There is lot of research going on around the world in this area and technology is being developed that offers great deal of capability. It requires an understanding of power systems, machines and applications of power electronic converters and control schemes put together on a common platform.

1.1 Converter Protection Systems

The prevalent DFIG converter protection scheme is crowbar protection. A crowbar is a set of resistors that are connected in parallel with the rotor winding on occurrence of an interruption. The crowbar circuit bypasses the rotor side converter. The active crowbar control scheme connects the crowbar resistance when necessary and disables it to resume DFIG control and the DFIG with protection scheme.

For active crowbar control schemes, the control signals are activated by the rotor side converter devices. These have voltage and current limits that must not be exceeded. Therefore the rotor side converter voltages and currents are the critical regulation reference. The DC link bus voltage can increase rapidly under these conditions, so it is also used as a monitored variable for crowbar
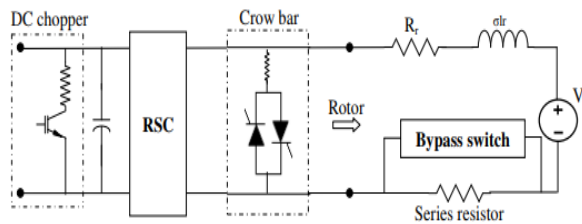
triggering.

Figure 1 DFIG with protection scheme

A braking resistor (DC chopper) can be connected in parallel with the DC link capacitor to limit the overcharge during low grid voltage. This protects the IGBTs from overvoltage and can dissipate energy, but this has no effect on the rotor current. It is also used as protection for the DC link capacitor in full rated converter topologies, for example, PMSGs. In a similar way to the series dynamic braking resistor, which has been used in the stator side of generators, a dynamic resistor is proposed to be put in series with the rotor (series dynamic resistor) and this limits the rotor over current. Being controlled by a power electronic switch, in normal operation, the switch is on and the resistor is bypassed; during fault conditions, the switch is off and the resistor is connected in series to the rotor winding.

2. LITERATURE REVIEW

Marouane El Azzaoui et al.[1] This paper presented with the modeling and control of a wind turbine driven doubly fed induction generator (DFIG) that feeds AC power to the utility grid. Initially, a model of the wind turbine and maximum power point tracking (MPPT) control strategy of the doubly-fed induction generator is presented. Thereafter, control vector-oriented stator flux is performed. Finally, the simulation results of the wind system using a doubly-fed of 3MW are presented in a Matlab/Simulink environment. Wind energy has become one of the most important and promising sources of renewable energy.

Andrés Peña Asensio et al. [2]This paper addresses the design and analysis of a voltage and frequency control (VFC) strategy for full converter (FC)-based wind energy conversion systems (WECSs) and its applicability for the supply of an isolated load. When supplying an isolated load, the role of the back-to-back converters in the FC must change with respect to a grid-connected application. Voltage and frequency are established by the FC line side converter (LSC), while the generator side converter (GSC) is responsible for maintaining constant voltage in the DC link. Thus, the roles of the converters in the WECS are inverted.

Peiyuan Li et al. [3] this paper proposed the dc bus current optimization control strategy in DFIG wind power systems with current source converter (CSC). In CSC-based systems, the converter losses are dependent on the dc bus current so that it is important to reduce it to minimum. The dc current is chosen as the larger value of rotor side converter (RSC) current and grid side converter (GSC) current. The RSC current is usually larger than GSC current because RSC will provide the generator's exciting current additionally.

Hong-Hee Lee et al. [4] this paper presented investigated the control of a standalone DFIG based wind power conversion system with unbalanced and nonlinear loads. Under these load conditions, the quality of stator voltage and current waveforms of the DFIG is strongly affected due to the negative and distorted components, reducing the performance of other normal loads connected to the DFIG.

3. OBJECTIVE

The work on the dual voltage source inverter deals with the following main objectives:

- To create a MATLAB SIMULINK model of dual doubly fed induction generator based wind energy system.
- Study the system capacity of driving loads by performing load analysis by variation of load from minimum to maximum.
- Compare the system outputs by using a STATCOM and design a voltage regulator based control for it such that it shows lesser voltage dips for heavy loads when compared to the system without any STACOM
- Finally Integrate the system with wind energy system and then to the grid so as to make it more reliable and efficient.

4. METHODOLOGY

4.1 Methodology

The model has been developed in MALAB/SIMULINK environment. This is a high-level matrix/array language with control flow statements, functions, data structures, input/output, and object-oriented programming features. It has following key features:

- High-level language for scientific and engineering computing
- Desktop environment tuned for iterative exploration, design, and problem-solving
- Graphics for visualizing data and tools for creating custom plots

- Apps for curve fitting, data classification, signal analysis, control system tuning, and many other tasks
- Add-on toolboxes for a wide range of engineering and scientific applications
- Tools for building applications with custom user interfaces
- Royalty-free deployment options for sharing MATLAB programs with end users

The modeling of Dual Voltage Source Inverter system is done which is capable of feeding the load with either solar or wind resources depending on the availability thus making the system more reliable

4.2 wind energy system modelling:

Model of wind turbine with PMSG Wind turbines cannot fully capture wind energy. Output aerodynamic power of the wind-turbine is expressed as:

$$P_{Turbine} = \frac{1}{2}\rho A C_p(\lambda, \beta)v^3$$

Where, ρ is the air density (typically 1.225 kg/m3), A is the area swept by the rotor blades (in m2),CP is the coefficient of power conversion and v is the wind speed (in m/s).
The tip-speed ratio is defined as:

$$\lambda = \frac{\omega_m R}{v}$$

Where ω_m and R are the rotor angular velocity (in rad/sec) and rotor radium (in m), respectively.
The wind turbine mechanical torque output m T given as:

$$T_m = \frac{1}{2}\rho A C_p(\lambda, \beta)v^3 \frac{1}{\omega_m}$$

The power coefficient is a nonlinear function of the tipspeed ratio λ and the blade pitch angle β (in degrees). Then Power output is given by

$$P_{Turbine} = \frac{1}{2}\rho A C_{p_{max}}v^3$$

A generic equation is used to model the power coefficient C_P based on the modeling turbine characteristics described in [2], [7-9] and [11] as:

$$C_p = \frac{1}{2}\left(\frac{116}{\lambda_i} - 0.4\beta - 5\right)e^{-\left(\frac{21}{\lambda_i}\right)}$$

For each wind speed, there exists a specific point in the wind generator power characteristic, MPPT, where the output power is maximized. Thus, the control of the WECS load results in a variable-speed operation of the turbine rotor, so the maximum power is extracted continuously from the wind.

 This mechanism uses the variable torque output w_m and tries to optimize the output current and voltage waveform to its maximum value.
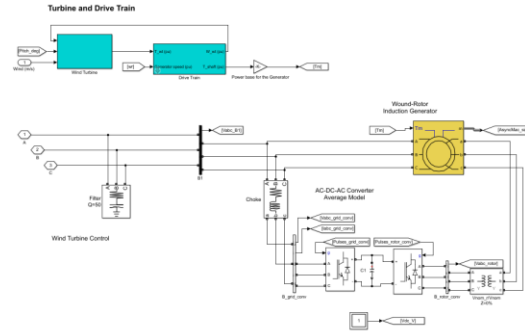

Figure 2: MATLAB/SIMULINK model of DFIG wind energy system

The generator side converter is controlling the speed of the generator for maximum power extraction. The grid side converter controls the voltage on the DC-link and also the reactive power flow between the WT and grid. Another control for the WT is the pitch control. It is applied to the rotor blades and modifies the angle of attack of the blades so that the output power can be controlled during high wind speeds. The turbine rotor converts the fluctuating wind energy into mechanical energy, which is converted into electrical power through the generator, and then transferred into the grid through a transformer and transmission lines. Wind turbines capture the power from the wind by means of aerodynamically designed blades and convert it to rotating mechanical power.
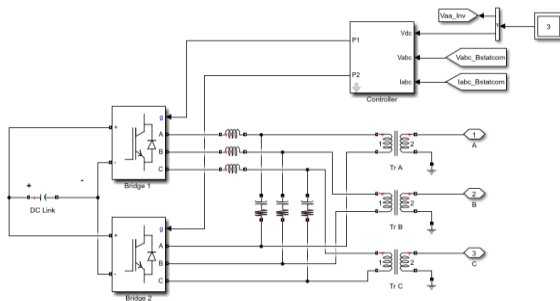
The generator converts the mechanical power into electrical energy, which is fed into a grid through possibly a power electronic converter, and a transformer with circuit breakers and electricity meters.

4.3 Modelling of STATCOM

In this paper, a STATCOM is added to the power network to provide dynamic voltage control for the wind farm. FACTS is one aspect of the power electronics revolution that happened in all areas of electric energy. These controllers provide a better adaptation to varying operational conditions and improve the usage of existing installations. FACTS controller is defined as a power electronic-based system that provide control of one or more AC transmission system parameters (series impedance, shunt impedance, current, voltage, phase angle).

STATCOM is a new breed of reactive power compensators based on VSC. It has a characteristic similar to a synchronous condenser, but because it is an electrical device it has no inertia and it is superior to the synchronous condenser in several ways. STATCOM consists of one VSC with a capacitor on a DC side of the converter and one shunt connected transformer. Voltage Source Converter is usually built with Thyristors with turn-off capability like Gate Turn-Off (GTO) or today Integrated Gate Commutated Thyristors (IGCT) or with Insulated Gate Bipolar Transistors (IGBT) based converter. Configuration of the STATCOM circuit is
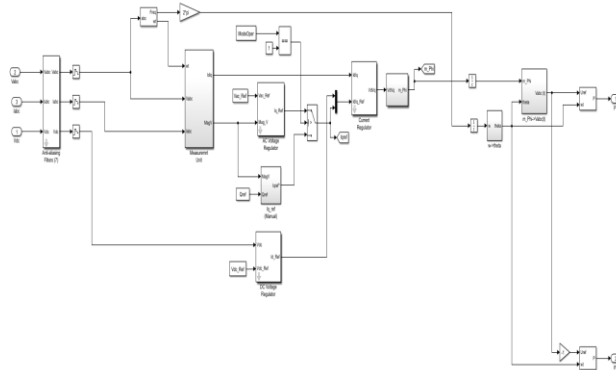
presented.

Figure 3 MATLAB/SIMULINK model of the STATCOM used

As it was mentioned before STATCOM can be treated as a synchronous voltage source, because its output voltage can be controlled as desired. The STATCOM is operated in bus voltage regulation mode. In this model, The D-STATCOM either by absorbing or generating the reactive power regulates the voltage of bus B3. And the power transfer takes place through the coupling transformer leakage reactance by generating a secondary voltage in phase with the primary voltage.

As it was mentioned before STATCOM can be treated as a synchronous voltage source, because its output voltage can be controlled as desired

4.4 AC DC voltage regulation controller

Figure 4 MATLAB/SIMULINK model AC DC voltage regulation controller for STATCOM

The voltage regulation of the controller operates by taking the output voltage of the transformer as a AC reference signal. The signal is first passed through second order filter to eliminate the harmonics and then dq form is obtained from abc form. The control will begin if, Vm(t) ≠ Vss. The measured bus voltage Vm(t) is compared with Vref (t).

Then, gain adjustments on Kp_V and Ki_V are done in the outer loop i.e., voltage regulator block and thereby an updated Iqref is obtained through the current limiter as

shown in Fig. 4. Then, this Iqref and measured q-current Iq are compared. The control gains Ki_I(t) and Kp_I(t) can be adjusted. At last the phase angle α is determined and given through a limiter for output. Kit is then fed as pulses to the universal bridges for regulation.

Table 1: Control System Parameters

AC voltage set point (V_{ref})(pu)	1
V_{ac} regulator gains K_P,	0.55
V_{ac} regulator gains K_i	2500
V_{dc} regulator gains K_P,	0.001,
V_{dc} regulator gains ,K_i	0.15
Current regulator gain K_P,	0.8
Current regulator gain K_i,	200

5. RESULTS AND DISCUSSION

5.1 Simulation Environment

MATLAB stands for Matrix Laboratory, which is a programming package exclusively designed for speedy and effortless logical calculations and Input/output. It has factually hundreds of inbuilt functions for a large form of computations and plenty of toolboxes designed for specific analysis disciplines, as well as statistics, optimization, solution of partial differential equations, information analysis.
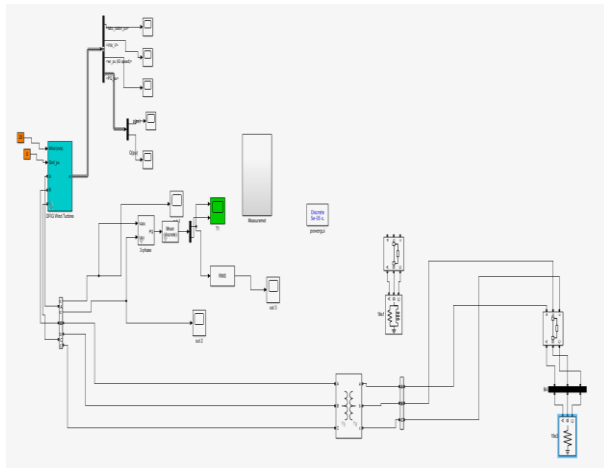
In this research work MATLAB platform is used to show the implementation or simulation of implemented algorithm performance. Measurement toolboxes are used and some inbuilt functions for generating graphs are used. Simulation results and comparison of the performance of implemented model with some existing ones are calculated by MATLAB functions.

5.2 Model Description

The first model was created by modeling of wind energy system integrated with the grid and feeding a balanced load and is compared by varying its condition. In the first model the system is made to drive the load without using AC DC voltage regulator controller based STATCOM via transformer. Further in this work the voltage profile of the wind energy system has been improved using a STATCOM based on AC DC voltage regulator controller. The voltage profile of the output from the system was again analyzed to observe the difference in the two models. Load analysis of the two system has been done by checking the amount of load it can handle independently and how AC DC voltage regulator controller proves to be beneficial in handling high loads. Also further the wind energy system model has been integrated with the grid in order to enhance the efficiency and reliability of the system.
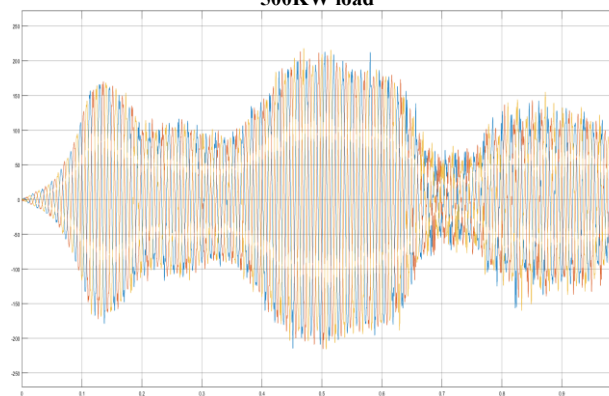
5.3 Case1: System driving 500KW loads
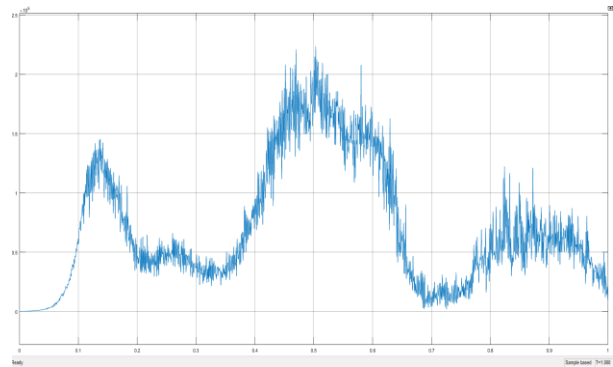**a) Only Wind Energy System Driving the Load**

Figure 5 Only Wind Energy System Driving the Load

Figure 6 Voltage output from wind energy system only with 500KW load
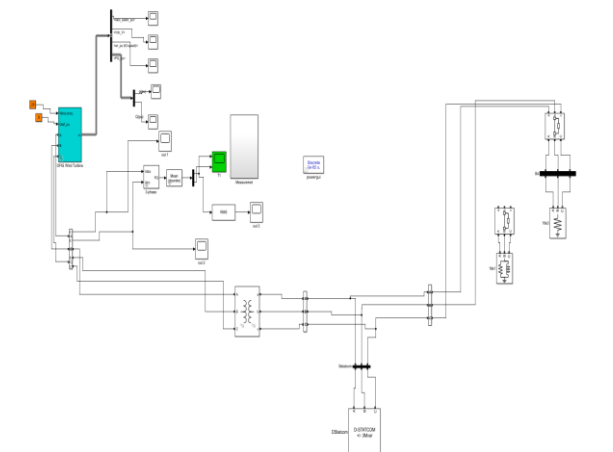

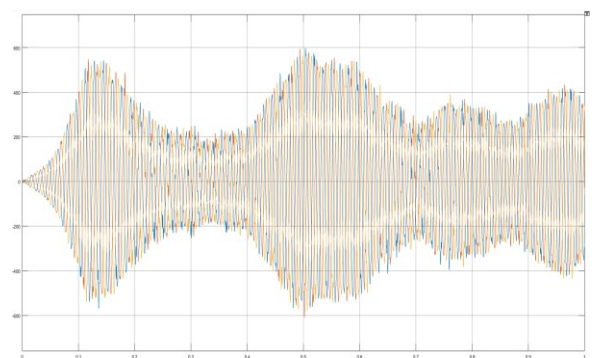**Figure 7 Current Output from wind energy system only with 500KW load**

Figure 8 Active Power Output from wind energy system only with 500KW load
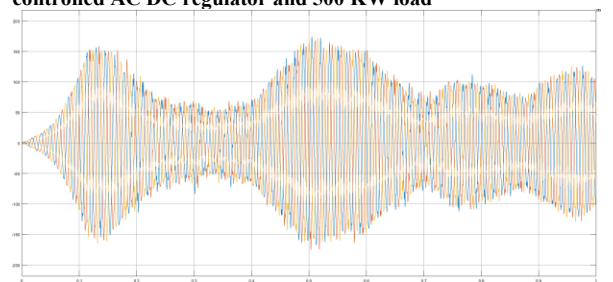
5.4 Wind Energy System Driving the Load with voltage controlled AC DC regulator .

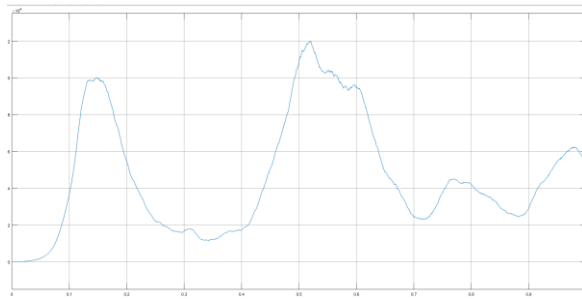**Figure 9 Wind Energy System with voltage controlled AC DC regulator driving the Load**

Figure 10 Voltage Output from Wind Energy System with voltage controlled AC DC regulator and 500 KW load
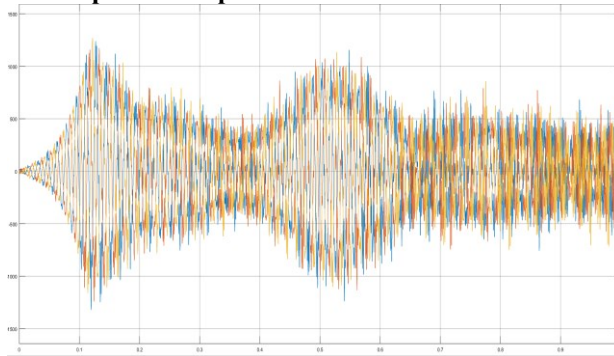
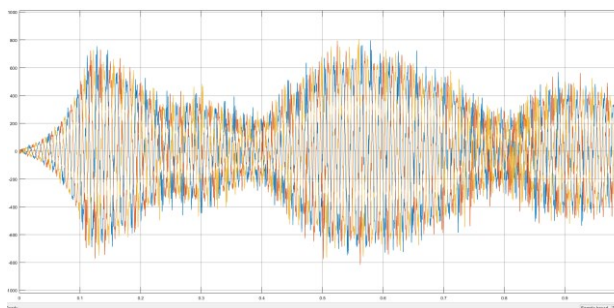**Figure 11 Current Output from Wind Energy System with voltage controlled AC DC regulator and 500 KW load**

Figure 12 Active Power Output from Wind Energy System with voltage controlled AC DC regulator and 500 KW load

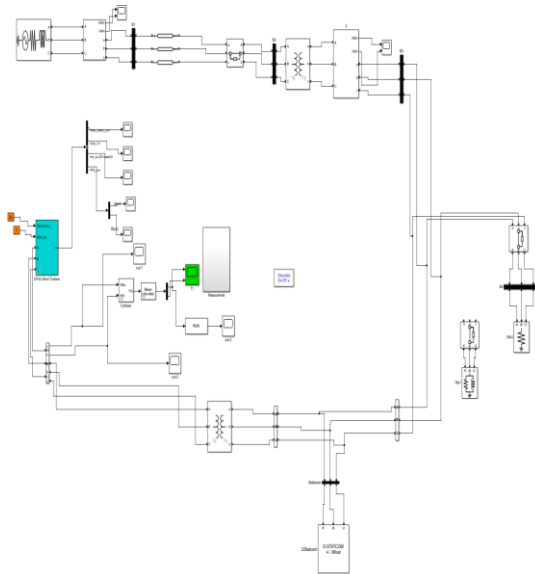## 5.5 Outputs with optimum load

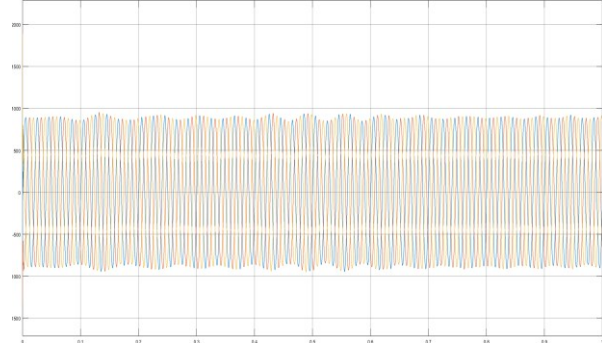**Figure 13 Voltage with 18 KW in system having no STATCOM**

Figure 14 Voltage with 50 KW in system having STATCOM

Form the above two waveforms of the two systems it is clearly observed that the voltage output of the system at the load terminal is maintained with their respective loads without experiencing any dip from the open circuit voltage waveform. The system with STATCOM having AC DC voltage regulation controller can drive the load of up to 50 KW as compared to the system without the device which can drive a load of up to 18 KW.
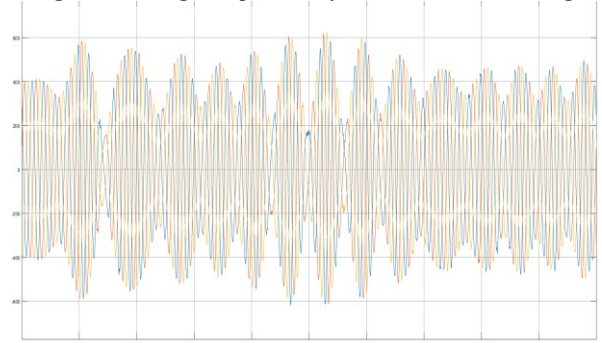
5.6 Final integration of the systems with grid

Figure 15 System integrated with grid

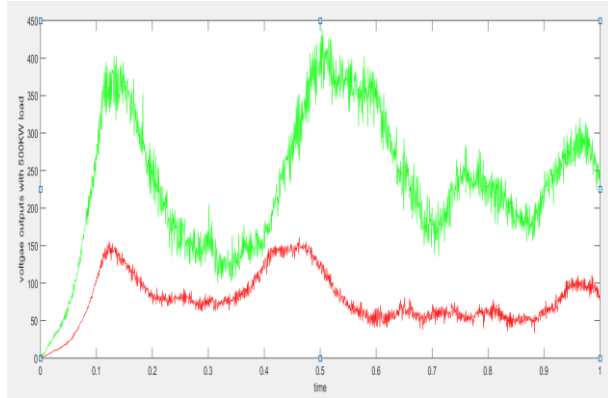**Figure 16 Voltage Output with system connected with the grid**

Figure 17 Current Output with system connected with the grid

The output from the grid system has maintained the grid voltage of about 1100 volts. This voltage is the final grid voltage which is constant. When we change the load connected to it the power demand changes and hence the output current can vary according to changes in the load.

6. VALIDATION

In this work while validating the outputs following waveforms were observed. The RMS values of the voltage outputs from the wind energy system where the speed of wind varies between 0 to 25 m/s has been observed. It is made to drive the heavy loads and the drop

in the voltage outputs is being observed and compared with the system having the STATCOM with AC DC voltage regulation controller. The load has been varied continuously to observe the optimum value of load up to which both the systems are compatible.

Figure 19 Comparative values of voltage waveform from the system driving 500KW load

While driving heavy loads with 500KW power requirement, it again was observed that the voltage dip in system without STATCOM is more where the voltage has been dropped in between 80 volts to 150 volts. The system with STATCOM with AC DC voltage regulation has variation between 150 volts to 400 volts and hence is maintaining the voltage level to certain extent according to the wing speed variation.

7. CONCLUSION

The main component of a wind turbine connected to the network, which includes wind turbines, reducers, generators, electronic power supply interfaces and transformers for connection to the grid.
The wind speed varies between 0 and 25 m / s and with this variation the output voltages of the wind turbine have been observed. It is designed to handle heavy loads and the voltage drop is monitored and compared with the system using the STATCOM AC DC voltage regulator. The following conclusions were drawn:

Table 2 Comparative table for voltage outputs with different loads				
Variation in load	Voltage level		Drop from open circuit voltage (800 to 1000 volts)	
	Without STATCOM	With STATCOM	Without STATCOM	With STATCOM
500KW	80 to 150 volts	150 to 400 volts	Approx. 650 volts	Approx. 400 volts

Hence it can be concluded that the voltage profile is improved with the STATCOM with AC DC voltage regulation. Later this system is integrated with the grid.

- The system with STATCOM having AC DC voltage regulation controller can drive the load of up to 50 KW as compared to the system without the device which can drive a load of up to 18 KW.
- It was found clearly that the voltage output of the system at the load terminal is maintained with their respective loads without experiencing any dip from the open circuit voltage waveform.
- System efficiency is enhanced after its integration with the grid. The voltage level is constant and current shows variation according to load demand

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