VISVESVARAYA TECHNOLOGICAL UNIVERSITY

BELGAUM-590 018, KARNATAKA, INDIA

A Project Report

On

"STABILITY ANALYSIS OF GRID INTERACTIVE WIND ENERGY SYSTEM-A CASE STUDY"

Submitted in the partial fulfillment of the requirements for the award of degree of

BACHELOR OF ENGINEERING

IN

ELECTRICAL AND ELECTRONICS ENGINEERING

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2019-2020

CERTIFICATE

This is to certify that the Project work entitled, **"STABILITY ANALYSIS OF GRID INTERACTIVE WIND ENERGY SYSTEM - A CASE STUDY"** carried out by **MALATESH KUMAR K P, MANOHAR M C, SHASHIDHARA K M, MOHAMAD ZABIULLA K,** are the bona fide student of JIT, Davanagere in the partial fulfilment for the award of Bachelor of Engineering in Electrical & Electronics Engineering of the **Visvesvaraya Technological University, Belgaum** during the year **2019-2020**. It is certified that all correctness/suggestions indicated have been incorporated in the report. The Project report has been approved as it satisfies the academic requirements in respect of work prescribed for the Bachelor of Engineering Degree.

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CANDIDATES DECLARATION

We hereby certify that the work which is being presented in the report entitled "**STABILITY ANALYSIS OF GRID INTERACTIVE WIND ENERGY SYSTEM-A CASE STUDY"** in partial fulfilment of the requirements for the award of degree of bachelor of engineering in electrical and electronics engineering of Visvesvaraya Technological University, Belgaum, carried out during period of 2019-2020, we hereby declare that the project work has independently carried out by us, under the guidance of ***Mrs.Shailaja B M*** Assistant Professor, Department of Electrical and Electronics Engineering , JIT, Davanagere.

We hereby declare that this submission is our own work and to the best of our knowledge and belief. The matter embodied in this thesis has not been submitted by us for award of any other Degree/Diploma of this or any other University/Institute.

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ABSTRACT

This report is the outcome of Flexible AC Transmission System (FACTS) operation in doubly fed induction generator-based wind energy system to analyze the different stability related issues. Flexible AC Transmission System (FACTS) uses thyristor-controlled devices which optimally utilizes the existing power systems. The principal operating modes and applications of FACTS equipment in transmission system such as Static synchronous compensator (STATCOM) are discussed here.

STATCOM have the important role in controlling the active and reactive power flow to the power network voltage regulation and transient stability. Simulation STATCOM using SIMULINK is carried out in this study. Finally, the best suited FACTS device is suggested for the application in the grid interactive wind energy system.

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Although a single sentence hardly suffices, we would like to thank almighty God for blessing me with his grace and taking my endeavor to a successful culmination.

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ABBRIVATIONS

DFIG	Doubly Fed Induction Generator
AC	Alternating Current
DC	Direct Current
WT	Wind Turbine
FACTS	Flexible AC Transmission System
SVC	Static Var Compensator
STATCOM	Static Synchronous Compensator
TCSC	Thyristor Controlled Series Capacitor
SSSC	Static Synchronous Series Compensator
UPFC	Unified Power Flow Controller
IEEE	Institute of Electrical and Electronics Engineers
TCR	Thyristor Controlled Reactor
TSC	Thyristor Switched Capacitor
GTO	Gate Turn off Thyristor
WPP	Wind Power Plant
PCC	Point of Common Coupling
VSC	Voltage Source Converter
PLL	Phase Locked Loop

CHAPTER 1

INTRODUCTION

1.1 Overview

The Grid-connected wind energy systems are gaining momentum and the growth rate is approximately twenty to thirty percentage. There is considerable increase in the capacity of wind turbines and the penetration of wind energy in a power system may cause problems due to nature of the wind and the characteristics of the wind thereby affecting the grid performance. The dip in the voltage is one of the main disturbances related to quality of power in distribution networks. The power associated with wind is given by the expression,

$$\mathbf{P=0.5\ \rho A V^3}$$

Where

P is the power in watts

P is the air density, Standard air density is1.2kg/m³

A is the the swept area of the turbine blades in m²

V is the wind speed in meters per second

In earlier days, different types of wind generators were used for extracting electrical power. Some of such generators are permanent magnet type, brushed DC type, etc. The noticeable advancement in the field of converters and power electronic systems has led to many inventions in the field of converters. Nowadays the most common technology used for extracting electrical power from wind energy is doubly fed type induction generators.

1.2 Doubly Fed Induction Generator DFIG:

The DFIG system can operate in both sub synchronous and super synchronous modes with a speed of rotor range around the synchronous speed. The rotor winding is connected via slip-rings to a three-phase converter while the stator circuit is directly connected to the grid. The DFIG will meet small speed range requirement and exhibit acceptable performance [19]. An AC-DC-AC converter is incorporated in the induction generator rotor circuit. This reduces converter losses compared to a system where the power electronics converter is to handle the entire power.

The Doubly fed induction generator power flow system is shown in Fig 1.1

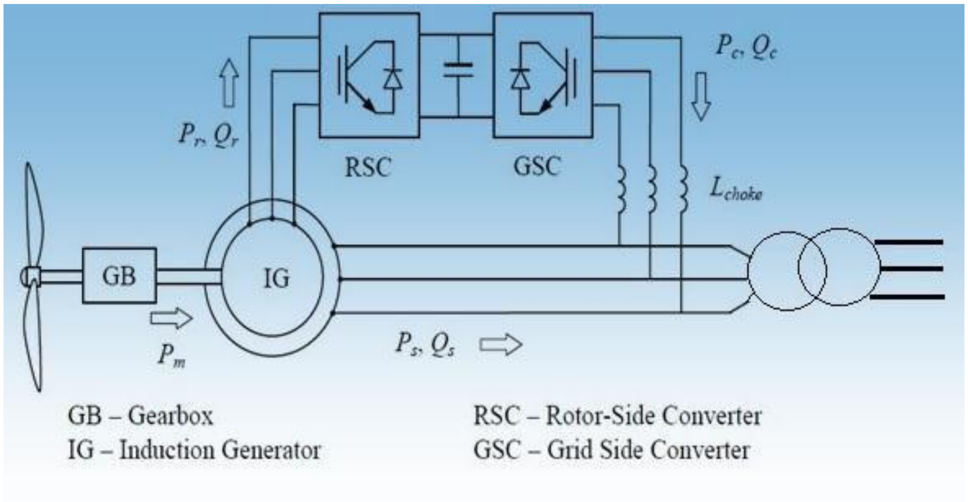


Fig 1.1: System of power flow in Doubly Fed Induction Generator

Stability is a challenging issue in grid connected wind interactive systems due to unpredictable changes in wind patterns and other technical issues. Some of the most common challenges with respect to stability issues in wind energy systems are:

1.3 Stability issues in wind energy system

Power outages: Power outages are total interruptions and failure in wind energy system and are mainly due to ice storms, lightning, erratic wind speed, and equipment failure etc. This will affect the operation completely.

Voltage fluctuations: Voltage variations are the changes in the steady-state voltage above or below the indicated input range for a piece of equipment. The voltage variations include both sags and swells. The reasons for voltage variation are large equipment's or appliances start up or shut down, sudden change in load etc. The adverse effects of voltage variations include errors in data, loss of memory, equipment shutting down, flickering, motors stopping etc.

Transients: Transients are disturbances of very short duration in the power system. Transients are generated due to lighting, start up and shutdown of equipment, welding equipment etc. The transients will affect processing, burning of circuit boards, degradation of electrical insulation, equipment damage etc.

Harmonics: Harmonics are periodic steady state distortions of the sine wave due to equipment's generating frequency other than the fundamental component. The harmonics are generated due to electronic loads or ballasts, non-linear loads, variable frequency drives etc. If the harmonics are not suppressed then it will result in to overheating of electrical equipment, random tripping of breakers etc.

CHAPTER 2

LITERATURE SURVEY

Literature survey is carried out to identify the present technological developments and implementations in this domain of engineering. This helps in formulating the problem. A survey of the topics related to the stability issues in grid interactive wind energy systems are reviewed and existing methods and approaches are studied.

2.1 Literature Review

An extensive literature survey reveals that the concerted efforts are in progress by researchers in the field of renewable energy and allied areas. Quite a good number of papers have been discussed about the different facets like concept, layout, application and analysis of grid interactive wind energy system. The study of few papers helped in locating the state of the art technology and to carry out the further work.

The STATCOM control scheme for the grid connected wind energy generation system for power quality improvement is simulated using MATLAB/SIMULINK in power system block set and indicating relief the main supply source from the reactive power demand of the load and the induction generator [3]. The static compensator (STATCOM) in order to deal with harmonic current injection, compensation of reactive power and voltage variation is dealt is already in use [4]. The usage of wind energy conversion and storage system is also presented. A brief explanation of future wind power and possible integration with Hybrid Electrical Vehicles is also provided. Static synchronous compensator and battery energy storage system implementation in order to address the issue of voltage stability in wind farms connected to the distribution network is discussed is available [5]. It is made clear that the STATCOM-battery combination can be very effective in compensating generator rotor angle oscillations and thus well suited for improving transient stability and the dynamic behavior of the power system. STATCOM provides a real power flow path for battery, but the battery operation is independent of the STATCOM controller. A technical review of Power Quality problems associated with the Renewable based wind energy system and the investigation of causes of poor power quality issues related with grid connected wind farm is studied [6]. Distributed Generation i.e. renewable Energy Sources (RES) integrated at distribution level and wind energy system integration issues and associated PQ problems are highlighted.

A paper on the static synchronous compensator implementation in order to address the issue of voltage stability in wind farms connected to the distribution network is referred [7]. This opens up the use of STATCOM as a dynamic reactive power compensator to stabilize the voltage at the point of common coupling by protecting DFIG-based wind farm interconnected to the distribution system. A reactive power control scheme for a doubly fed induction generator drive that minimizes the system power losses [8]. This topology enables besides the control of active power, an independent control of reactive power with both inverters. The steady-state power losses are modeled and the optimal reactive power is discussed. The control structure design is presented, discussed as well as implemented.

A voltage stability issue caused by the high penetration of wind energy in a transmission network is dealt in this paper [9]. Voltage stability during normal operation, voltage sag and low voltage ride through capability, harmonics and flickers produced by fixed-speed wind turbine and doubly-fed induction generator wind farms with series and shunt compensation are analyzed. The static synchronous compensator (STATCOM), the converter side of a DFIG and a load are considered as harmonics generating sources and are modeled according to IEC standard 61000. FACTS devices such as STATCOM and wind turbine can also provide a certain amount of reactive power compensation, depends upon the wind speed and the active power control strategy [10]. A paper analyses the reactive power capability of Doubly Fed Induction Generator based wind turbine, considering the stator current limit, the rotor current limit, the rotor voltage limit, and the reactive power capabilities of the grid side convertor (GSC). The boundaries of reactive power capability of DFIG based wind turbine are derived. The performance of shunt flexible alternating current transmission system devices connected to wind farm based Doubly-Fed induction generator under short circuit fault has been analyzed [11]. To provide voltage support to the grid, mandatory reactive current supply is necessary. The protection schemes for wind turbines and the necessary measures are in practice [12]. In this paper the behavior of DFIG based wind turbines during grid faults is discussed. It is shown that with properly designed crowbar and DC-link chopper even zero voltage ride-through is possible.

In all the literature survey reveals the scope of the work to be done in respect the power system stability and wind energy system by using the different FACTS controllers and the use of FACTS controllers to enhance the steady state stability and transient stability. Hence, there is an avenue to work on the enhancement of stability related issues such as voltage stability, reactive power issues, etc. This requires the design of suitable controllers' effective operation of the wind energy system.

CHAPTER 3

DESCRIPTION OF PROJECT

3.1 Problem Formulation

To ensure the stability of the system, with reference to power quality and voltage level, all the grid system demand that the Wind Power Plant (WPP) must be able to produce reactive power at the Point of Common Coupling (PCC). When dealing with WPP, addition of reactive power capability to each individual wind turbine may not be sufficient to comply with the grid system norms. This is due to the losses in connection cables and line losses between WPP and PCC. The solution is to use external reactive power compensation, for example use of FACTS device at the PCC.

Thus, the FACTS Controllers are the feasible planning alternative to the power system stability and wind energy system besides power flow control. The work undertaken here is to mainly concentrate on the enhancement of steady state stability and wind energy stability using FACTS controllers with the following objectives.

Objectives:

1. To study the existing scenario of the Stability issues in wind energy system and visit to Harapanahalli plant to collect all the relevant data
2. To study the opportunities to improvise the stability of Wind energy systems connected to grid.
3. To Study the feasibility of FACTS controllers and their modeling in wind systems.
5. To Enhance the Stability of the Wind Energy system using FACTS controllers.

3.2 Methodology:

The aim of this project is to analyze the stability of the wind energy system taking into account the design of STATCOM controller for stability enhancement of the wind energy system, by considering the interactions among the different control levels. The work flow goes in a sequence of gathering of real time data, analyzing the existing methods for Grid Connected wind energy system for power quality improvement. Grid interactive Wind Energy System stability assessment of the system for different conditions of the power system is carried out by using MATLAB/Simulink software. The model is developed using the SIMULINK model and the steady state analysis for the voltage variation, reactive power compensation for both the system is carried out. The voltage variation, reactive power compensation for the system with and without STATCOM controllers are analyzed.

CHAPTER 4

Case Study on - Harapanahalli Wind Farm

4.1 SITE STUDY REPORT

A case study is carried out at Harapanahalli wind farm, owned by green infra wind Power Corporation, Harapanahalli, Karnataka, India. Green infra wind power corporation is one of the leading power company that generates power and feeds to Karnataka Power Transmission corporation Limited. Green infra wind Power Corporation, Bellary has 40 wind turbines, which is divided as 2 sections. one is consists of 18 wind turbines at Harapanahalli taluk (Capacity-36 MW) and second one consists of 22 turbines at Ananthanahalli village (Capacity- 48 MW) and the both the section is commissioned at 2017. And analysis of the plant and simulation of the same is carried out in this work.

Each unit is connected with 2.1 MVA 690V/33kV step-up transformer; units are grouped in three rows and fed by separate inter-farm lines up to pooling station. From pooling station generation will be evacuated via 33/110kV 30MVA Power Transformer and an 110kV line for a distance of about 6 kms up to KPTCL's Substation.

4.2 WTG DETAILS

WTG: - A WTG stands for WIND TURBINE GENERATOR, A wind turbine generator contain a following components.

4.2.1 FMP: Foundation mounting part (2.1 MW)

A FMP is installed after raft concrete of civil work to install turbine in to the foundation, before erecting FMP 3 base plate are used to align the FMP center of foundation.
It's having 3- anchoring point to lift the FMP to erect.

FMP TECHNICAL SPECIFICATION of 2.1 MW 80 m hub height: -

Height	-	1670mm
Top dia	-	4300mm
Bottom dia	-	4596mm
Weight	-	8500kgs**.**

4.2.2 Tower's /turbine's/shell's: -

A tower is like vertical column, in YWF site 2.1 WTG's having 3 Section of 77.30m Length**.**

1) Bottom Tower: -

A bottom tower contains a DTA (DOWN TOWER ASSEMBLY), it means we have a power control cabinet.

i) Greed feeder panel
ii) Convertor cabinet
iii) Bottom plc cabinet (i.e. system cabinet / communication cabinet)
iv) LVDP cabinet
v) IGBT coolant circulation with radiator.
vi) 246 sq. mm Cu Power cables

Technical specification of Bottom Tower: -

Bottom flange dia (D1)	-	4556mm
Bottom flange dia (D2)	-	4300mm
Length	-	22300mm
Weight	-	50821.6 MT.

2) Tower middle: -

A middle tower looks like slight conical shape & having power cables to connect to top tower to nacelle generator side.

Technical specification: -

Mid bottom dia (D1)	-	4300 mm
Mid top dia (D2)	-	3400 mm
Length	-	25000 mm
Weight	-	34317 MT

3) Tower Top: -

A tower top is final shell of 2.1 WTG Its look like a conical shape, it holds the nacelle / machine head.

Technical specification of Top tower:

Top bottom dia (D1)	-	3400mm
Top top dia (D2)	-	2564mm
Length	-	30000mm
Weight	-	26075MT.

4.2.3 NACELLE /MACHINE HEAD :

A Nacelle or machine head having a gear box, generator, PLC panel, yaw bearing, yaw motor. Coolant motor, hydraulic braking system etc.

Nacelle body	: - carbon fiber glass
Type of generator	: - DFIG (double feed induction generator), a generator rest on bed sheet which mount to nacelle cabinet anchoring point.
Gear ratio	: - 1:100, it’s having high end shaft lower end shaft together in pillow block having ball bearing coupled in a coupling to rotate generator higher rpm then rotor rpm.
Type of yaw bearing	: - kyden type roller, ball bearing
Yaw drive motor	: - 4.5HP 4 NOS

Rotor lock to lock the rotor etc. a nacelle hold hub with rotor assembly.

Technical specification: -

Weight	- 51000kgs
Length	- 8838mm
Width	- 3550mm
Height	- 3466mm.

4.2.4 HUB :

A Hub is assembly of 3 blade’ s in hub holes, its contain a pitch control cabinet with led acid battery to pitch the blade ,to require angle to increase the efficiency of m/c, production & safe to blade to operate as per wind condition.

Technical specification of Hub: -

Height	- 3650mm
Width	- 3430mm
Diameter	- 3200mm
Weight	- 14500kgs

4.2.5 BLADE: -

A blade is the major part of wind turbine generator, it converts mechanical energy to electrical energy the mechanical energy in the of Kinetic energy.

A blade efficiency depends of its blade profile length, airfoils, a blade having trailing edge, leading edge, root, tip air flow at tip side.

Blade made of	- carbon fiber glass it having earth strip. to protect from lighting.
Rotor diameter	- 75m

Blade having vortex generator to lift the air without spreading wind, and it also have ppt to following wind on blade without any obstacles.

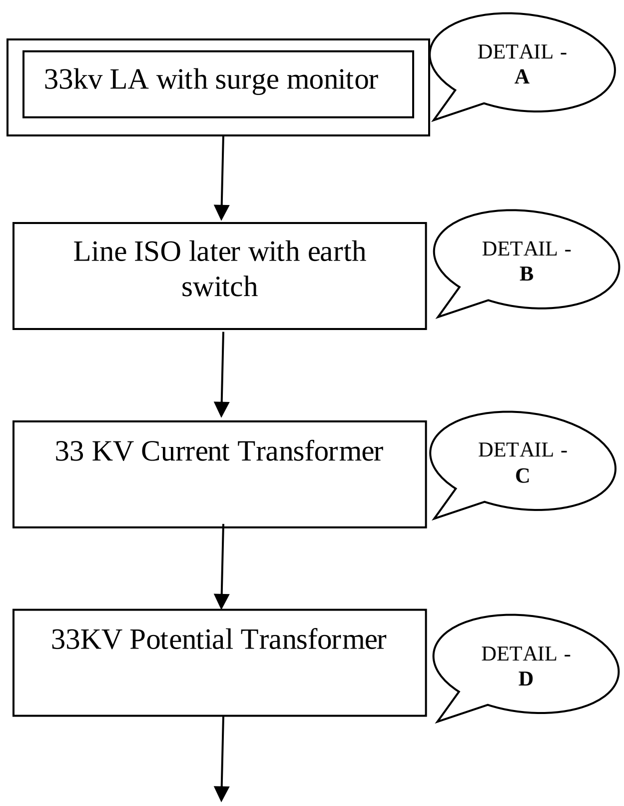
Technical specification: -

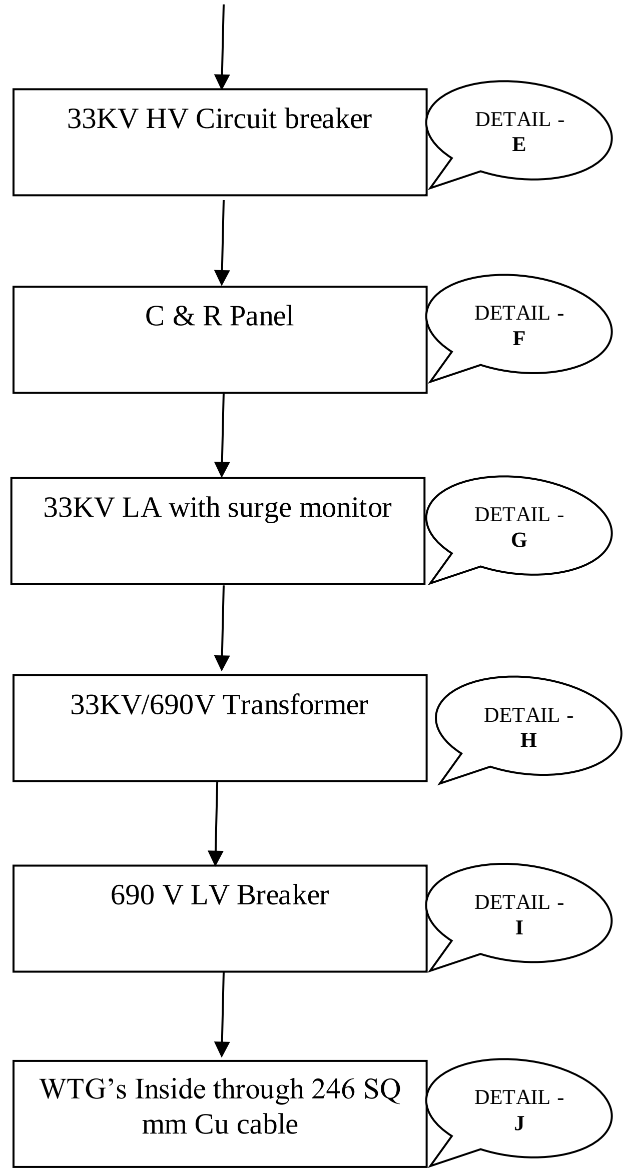
Length - 37250mm
Width - 1892mm
Height - 3092mm
Weight - 5968kgs.

4.3 33KV/690V S/S DETAILS:

A HARAPANAHALLI PLANT HAVE 18 WTGS, Each WTG's having individual 33kv/690 substations. We classified wind site by 3-feeders /rows i.e. row -1, row-2, row-3 each row having 33kv line.

A 33kv line enter from 33kv line gantry pole in to the switch yard as shown below Line flow diagram from grid to wtg's & same as vice versa pumping to grid.





DETAIL "A" (Surge monitor): -

<u>Technical specification</u>:-

Surges monitor
Make –Crampon greaves (C.G).AC mA,

DETAIL "B" (Line isolator with earth switch): -

Technical specification: -

Type	: VB
RATING	: 110KV (Un)
In	: 1250A
Impulse	: 550kv
operation mechanism	: manual

DETAIL "C" (Current transformer): -

Technical specification: -

Type	: VB
RATING	: 110KV (Un)
In	: 1250A
Impulse	: 550kv
operation mechanism	: manual

DETAIL "D" (Potential transformer): -

Technical specification: -

Make-Vidyut Control System
Type – 33pt/D
Nsv-33kv
Hsv-36kv

DETAIL "E" (H. V breaker): -

Technical specification

Make	: Cromopngreavees(C.G)
Voltage	: 36000v
Current	: 800A
Fq	: 50Hz
No of poles	: 3
Stunt Trip	: 110VDC
Breaker capacity	: 25kva
Making capacity	: 62.5kA
Short Current	: 25kA

DETAIL "F" (control and relay panel): -

In Each Wtg's We Have A Separate C&R Panel To Control /Protect Our Switch Yard Operation Equipment.

A C&R Panel Contain A 3 Relay S i.e. Is Over Current, Under Current and Dc Fail Indication Relay, And Meters Like, Ammeter, Voltmeter, Mw Meter Etc.

DETAIL "H" (33KV/690V transformer) :-

<u>Technical specification :-</u>

Make : Volt amp Transformer.
Capacity : 1.6Mva.

DETAIL "I" (690VOLT LV BREAKER): -

Make : koodays pvt. limited
It's have a ammeter, Voltmeter Battery backup charger unit, unit contain DC volt meter, AC voltmeter, Ammeter.

Breaker Make
It's having 246 sq. mm Cu cable from transformer to LV panel, and from LV panel WTG inside Grid feeder panel. and MCB s for auxiliary supply 110kv transformer and it contain 2 batteries of 26Ah, 12V.

4.4 Technical Specifications

4.4.1 Rotor

Parameters	Values
Rotor blades	3
Nominal Speed	20 rpm
Speed(Blade pitched Control & Operation)	10-20 rpm
Inclination of Rotor Axis	4 degrees
Rotation	Clockwise
Rotor arrangement v/s Tower	Upwind rotor

4.4.2 Wind Turbine (WT) Details

Rated power	2.1 MW
Nominal apparent power	1.666 MVA
Rated voltage(V)	690
Rated current(A)	1340
Power factor	0.9-1-0.9
Type of generator	DFIG
Number of poles	4
Nominal speed(rpm)	1800
Power(kW)	1500
Direction of rotation	Right
Useful life hour	>100000

4.4.3 Gear box

Parameters	values
Type	Planetary spur gear box
Rated mechanical power	1660 kw

4.4.4 Operating Data

Parameters	Values
Cut in wind speed	4 meter/sec
Rated wind speed	12 meter/sec
Cut out wind speed	25 meter/sec

CHAPTER 4

Double Fed Induction Generator

4.1 Types of Wind Turbines

Generally, the wind turbine generators work in a range of wind speed between the cut in speed (minimum wind speed required for the generator to connect to the power grid) and cut off speed (maximum wind speed required for the generator to disconnect from the power grid)

4 Types of Wind Turbine Generators:

- Type 1: It consists of a squirrel cage induction generator connected directly to the power grid. It is used for a small range of wind speed.
- Type 2: It consists of an AC-DC-AC converter in addition to the induction generator before being connected to the power grid.
- Type 3: It consists of a wound rotor induction generator connected directly to the grid, where the rotors speed is adjusted using a rheostat.
- Type 4: It consists of a Double Fed Induction Generator connected directly to the grid, where the rotor speed is adjusted using back to back converters.

4.2 About Double Fed Induction Generator

The DFIG consists of a 3-phase wound rotor and a 3-phase wound stator. The rotor is fed with a 3 phase AC signal which induces an ac current in the rotor windings. As the wind turbines rotate, they exert mechanical force on the rotor, causing it to rotate. As the rotor rotates the magnetic field produced due to the ac current also rotates at a speed proportional to the frequency of the ac signal applied to the rotor windings. As a result, a constantly rotating magnetic flux passes through the stator windings which cause induction of ac current in the stator winding. Thus, the speed of rotation of the stator magnetic field depends on the rotor speed as well as the frequency of the ac current fed to the rotor windings.

The basic requirement for the electricity generation using wind energy is to produce AC signal of constant frequency irrespective of the wind speed. In other words, the frequency of the ac signal generated across the stator should be constant irrespective of the rotor speed variations. To achieve this, the frequency of ac signal applied to the rotor windings need to be adjusted.

4.3 Why Wind Power Generation using Doubly Fed Induction Machine is Preferred

Because of these 5 reasons –

1. Constant frequency output signal to the grid irrespective of the variable rotor speed.
2. Low power rating required for the power electronic devices and hence low cost of control system.
3. Power factor is controlled, i.e. maintained at unity.
4. Electric power generation at low wind speed.
5. Power electronic converter has to handle the fraction of the total load i.e.,20-30% and also cost of this converter is low than in case of the other types of generators.

4.4 Simulation Model

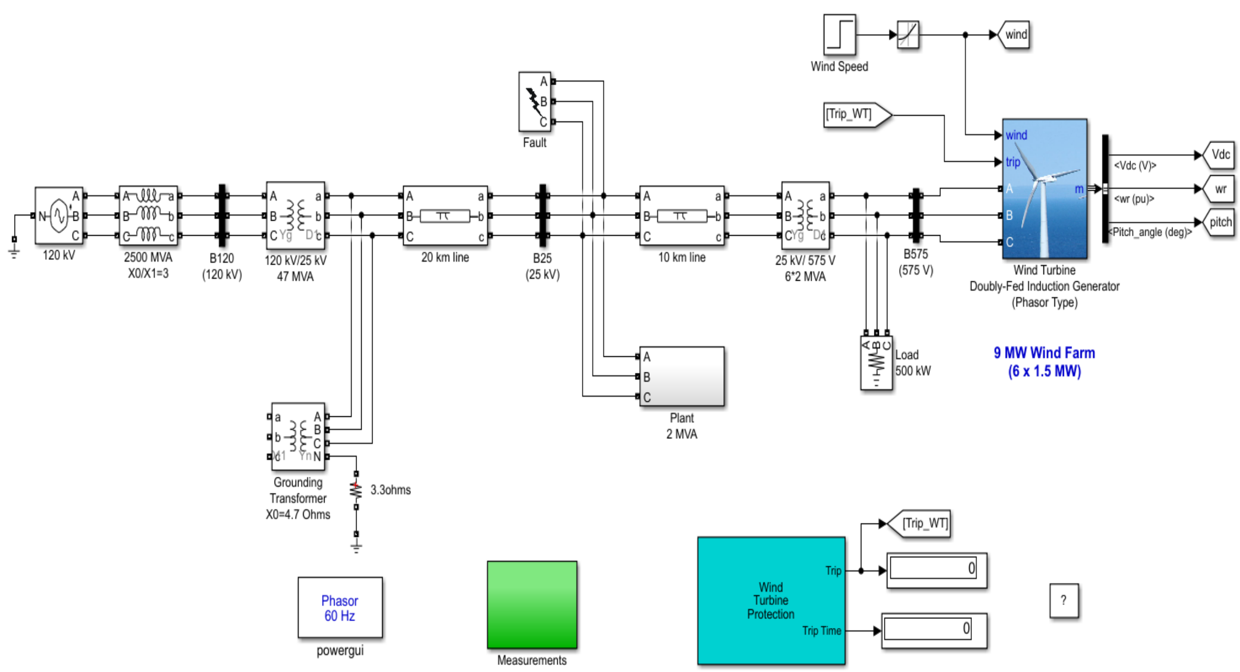


Fig 4.1: Simulink Module of Double Fed Induction Generator

4.5 Block diagram of DFIG wind turbine

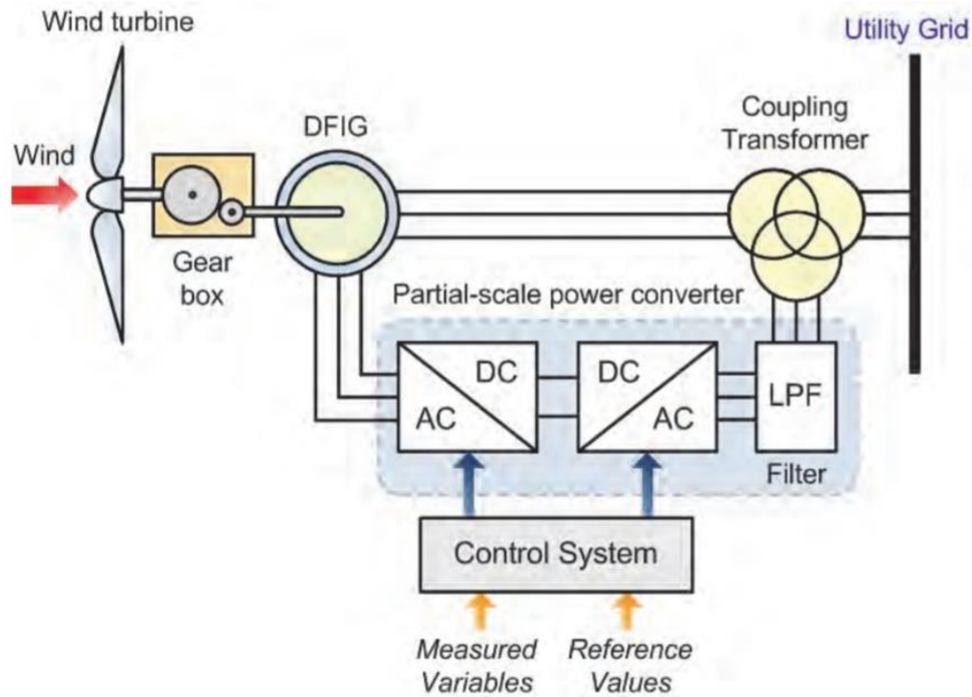


Fig 4.2 Block diagram of DFIG wind turbine

GEAR BOX

A gear box is typically used in a wind turbine to increase rotational speed from a low-speed rotor to a high-speed electrical generator. A common ratio is about 90:1 with a rate 16.7 rpm input from the rotor to 1500 rpm output for the generator. some multi megawatt wind turbines have dispensed with a gearbox. In these so-called direct drive machines, the generator rotor turns at the same speed as the turbine rotor. This requires a large and expensive generator. Other wind turbines on the market sit in between the reliability of slower.

DFIG

Doubly-fed electric machines are basically electric machines that are fed ac currents into both the stator and the rotor windings. Most doubly-fed electric machines in industry today are three-phase wound-rotor induction machines. Although their principles of operation have been known for decades, doubly-fed electric machines have only recently entered into common use. This is due almost exclusively to the advent of wind power technologies for electricity generation. Doubly-fed induction generators (DFIGs) are by far the most widely used type of doubly-fed electric machine, doubly-fed induction generators can be directly connected to the ac power network and remain synchronized at all times with the ac power network. Other advantages include the ability to control the power factor (e.g., to maintain the power factor at unity), while keeping the power electronics devices in the wind turbine at a moderate size. This manual covers the operation of doubly-fed induction generators, as well as their use in wind turbines. It also covers the operation of three-phase wound-rotor induction machines used as three-phase synchronous machines and doubly-fed induction motors. Although it is possible to use these machines by themselves, they are primarily studied as a stepping stone to doubly-fed induction generators

ROTOR

The rotor is the heart of a wind turbine and consists of multiple rotor blades attached to a hub. It is the turbine component responsible for collecting the energy present in the wind and transforming this energy into mechanical motion. As the overall diameter of the rotor design increases, the amount of energy that the rotor can extract from the wind increases as well. Therefore, turbines are often designed around a certain diameter rotor and the predicted energy that can be drawn from the wind.

Drag design rotors operate on the idea of the wind “pushing” the blades out of the way, thereby setting the rotor into motion. Drag design rotors have slower rotational speeds but high-torque capabilities, making them ideal for pumping applications. wind moves past the blades. The airfoil operates on the basis of Bernoulli’s Principle where the shape of the blade causes a pressure differential between its upper and lower surfaces. This disparity in pressure causes an upward force that lifts the airfoil. In this case, this lift causes the rotor to rotate, once again transforming the energy in the wind into mechanical motion.

POWER ELECTRONIC CONVERTER

Power electronic systems are used by many wind turbines as interfaces. Wind turbines function at variable rotational speed; thus the generator electric frequency varies and needs to be decoupled from the grid frequency through a power electronic converter system. The power electronic converter enables wind turbines to operate at variable (or adjustable) speed, and thus permits to provide more effective power capture than the fixed-speed counterparts. In variable speed operation, a control system designed to extract maximum power from the wind turbine and to provide constant grid voltage and frequency is required according to the type of wind turbine used. With the advance of power electronics technology, this objective is easy to be accomplished, as will be noted from description of the subsequent section. The power converter is an interface found between the load/generator and the grid. Depending on the topology and the applications present in the system, power can flow into the direction of both the generator and the grid. In using converters, three important things must be considered: reliability, efficiency, and cost.

Converters are made by power electronic devices, and circuits for driving, protection and control. Two different types of converter systems are currently in use grid commutated and self-commutated converters. Grid commutated converters are thyristor converters containing 6 or 12 pulse, or even more, that can produce integer harmonics. This kind of converter does not control the reactive power and consume inductive reactive power. The other type of converter, self-commutated converter systems, are pulse width modulated (PWM) converters that mainly use Insulated Gate Bipolar Transistor (IGBTs). In contrast to grid-commutated, self-commutated converters control both active and reactive powers. PWM-converters, therefore, have the capacity to provide for the demand on reactive power and a high frequency switching that make them produce high harmonics.

ROTOR-SIDE CONVERTER (RSC)

The rotor-side converter (RSC) applies the voltage to the rotor windings of the doubly-fed induction generator. The purpose of the rotor-side converter is to control the rotor currents such that the rotor flux position is optimally oriented with respect to the stator flux in order that the desired torque is developed at the shaft of the machine. The rotor-side converter uses a torque controller to regulate the wind turbine output power and the voltage (or reactive power) measured at the machine stator terminals. The power is controlled in order to follow a pre-defined turbine power-speed characteristic to track the maximum power point. The actual electrical output power from the generator terminals, added to the total power losses (mechanical and electrical) is compared with the reference power obtained from the wind turbine characteristic. Usually, a Proportional-Integral (PI) regulator is used at the outer control loop to reduce the power error (or rotor speed error) to zero. The output of this regulator is the reference rotor current *irqref* that must be injected in the rotor winding by rotor-side converter. This *q*-axis component controls the electromagnetic torque *Te*. The actual *irq* component of rotor current is compared with *irqref* and the error is reduced to zero by a current PI regulator at the inner control loop. The output of this current controller is the voltage *vrq* generated by the rotor-side converter. With another similarly regulated *ird* and *vrd* component the required 3-phase voltages applied to the rotor winding are obtained. The generic power control loop is illustrated in the next section.

GRID-SIDE CONVERTER (GSC)

The grid-side converter aims to regulate the voltage of the dc bus capacitor. Moreover, it is allowed to generate or absorb reactive power for voltage support requirements. The function is realized with two control loops as well: an outer regulation loop consisting of a dc voltage regulator. The output of the dc voltage regulator is the reference current *icdref* for the current regulator. The inner current regulation loop consists of a current regulator controlling the magnitude and phase of the voltage generated by converter.

TRANSFORMER

The wind turbine transformer act as a link between wind turbine and distribution grid. It steps up the low output voltage from generator to higher distribution voltage level. however, wind turbine transformer are considered to be one of the sensitive and weak component in a wind farm. The role of wind turbine transformer are usually done by conventional off shell transformer, but the intermitting of wind power improves some demanding specifications. The variable speed of wind is identified as one of the wide spread failure of transformers wind turbine is faced with various electrical. mechanical and corrosion related problems. This highlights the fact that conventional distribution transformers cannot act as wind turbine transformers always its design has to be modified according to the generated output and other external factors.

CHAPTER 6

STATIC SYNCHRONOUS COMPENSATOR (STATCOM)

The Static Synchronous Compensator (STATCOM) is a shunt device that uses power electronics to control power flow and improve transient stability on power system grids. The STATCOM regulates voltage at its terminal similar to SVC. The variation of reactive power is obtained by means of a Voltage-Sourced Converter (VSC) connected on the secondary side of a coupling transformer. The VSC uses forced-commutation method (GTOs, IGBTs or IGCTs) to synthesize a voltage V_2 from a DC voltage source.

6.1 The Principle of a STATCOM

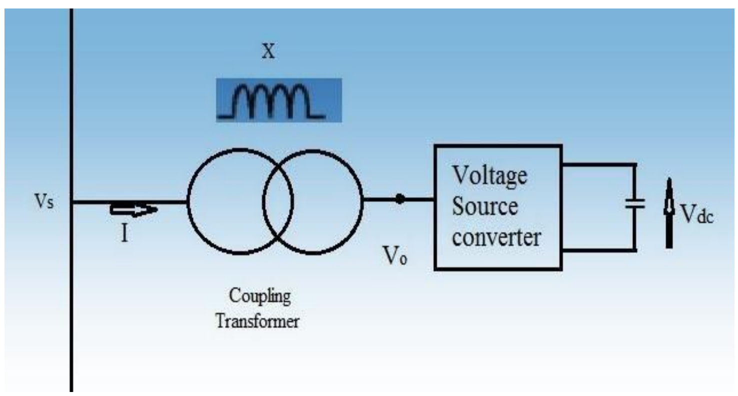


Fig 6.1 Schematic representation of STATCOM

STATCOM is a new breed of reactive power compensators based on Voltage Source Converter. The major advantages of this technology are cost of investment, cost of operation and low maintenance. STATCOM consists of one VSC with a capacitor on a DC side of the converter and one shunt connected transformer.

STATCOM can be treated as a synchronous voltage source, because its desired output voltage can be controlled. Assuming that no active power is exchanged between STATCOM and the grid (lossless operation) the voltage of the controller is in phase with the grid voltage. If the voltage of compensator magnitude is smaller than the voltage at the connection node current will flow from the grid to STATCOM. So as to reactive power will be consumed. The reactive power will be delivered to the grid for opposite situation. Schematic representation of this principle is presented on Fig. 5.1

6.2 STATCOM Control Strategy:

The components along with their functions of the control strategy are as under:

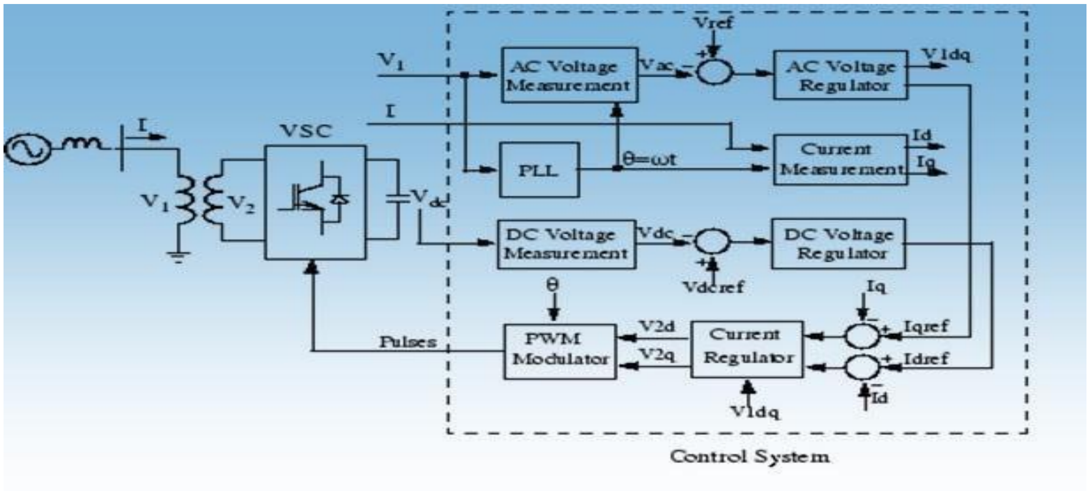


Fig 6.2 Block diagram of STATCOM Control Strategy

- A phase-locked loop synchronizes on the positive-sequence component of the three-phase primary voltage V1. The output of the PLL is used to compute the direct-axis and quadrature-axis components of the AC three-phase voltage and currents.
- Measurement system is measuring the d and q components of AC positive-sequence voltage and currents to be controlled as well as the DC voltage Vdc.
- An outer regulation loop consisting of an AC voltage regulator and a DC voltage regulator. The AC voltage regulator output is reference current Iqref for the current regulator. The DC voltage regulator output is reference current Idref for the current regulator.
- Current regulator will control the magnitude and phase of the voltage generated by the PWM converter (V2d V2q) from the Idref and Iqref reference currents produced respectively by the DC voltage regulator and the AC voltage regulator.
- Current regulator is a feed forward type regulator which predicts the V2 voltage output (V2d V2q) from the V1 measurement (V1d V1q) and the transformer leakage reactance.

6.2.1 Simulink Model of STATCOM

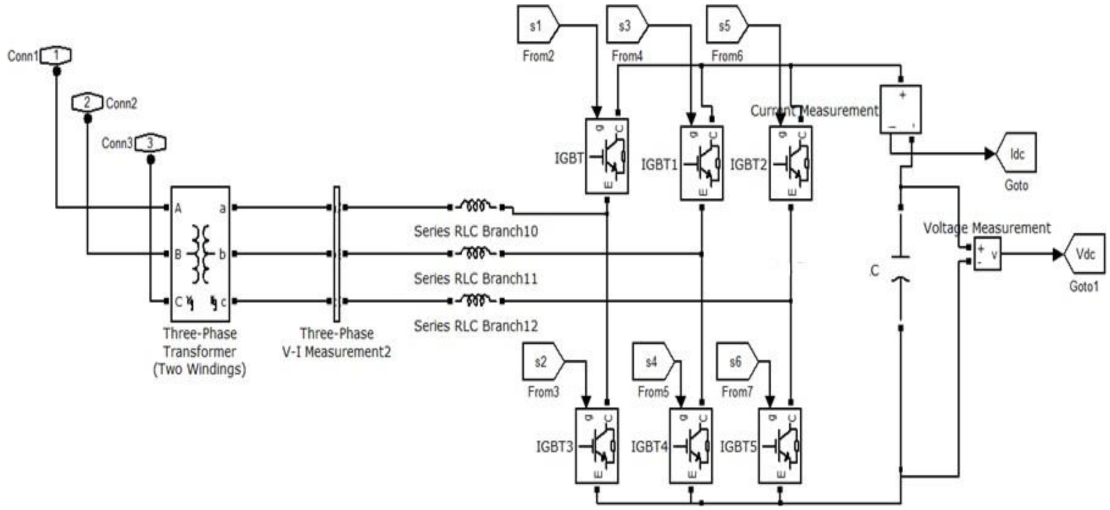


Fig 6.3 Simulink model of STATCOM

6.3 Simulation Model and Results

MATLAB/Simulink model of DFIG Wind energy system with STATCOM for different conditions.

CASE 1: Full Load Condition with STATCOM (9 MW)

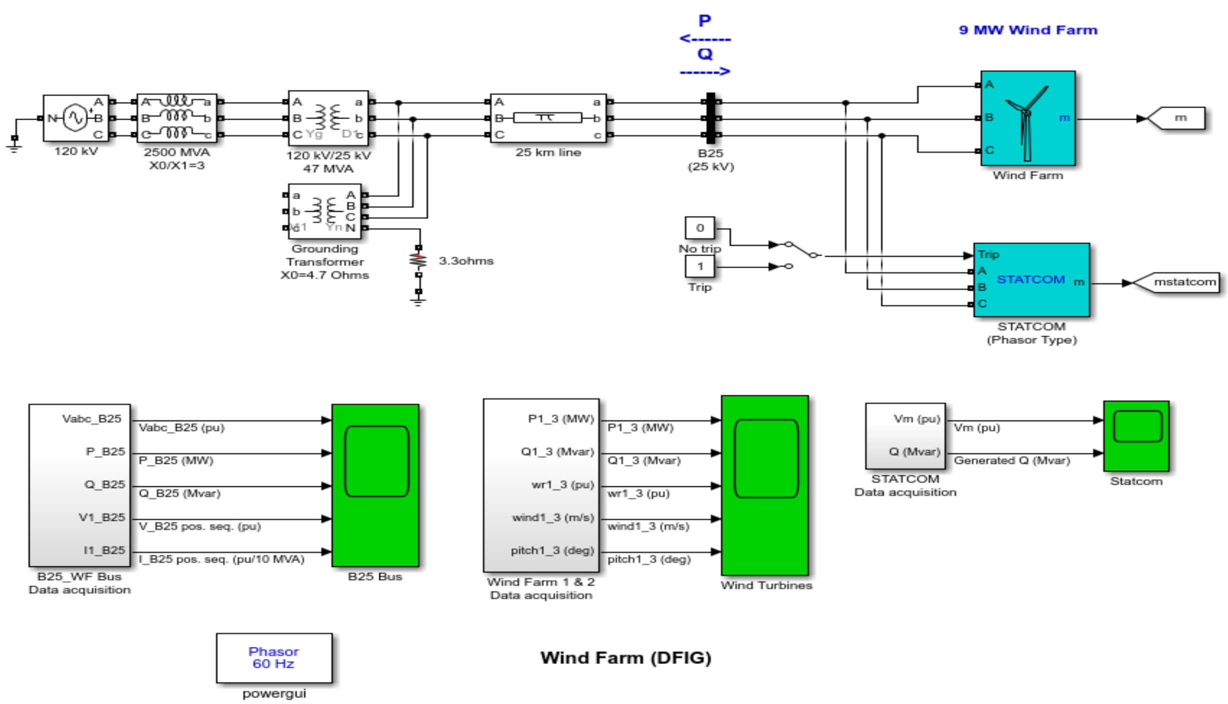


Fig 6.4 Simulink model of DFIG wind energy system with STATCOM at Full Load

BUS VALUES			
TIME (SEC)	P (MW)	Q (MVAR)	V_PLANT POS. SEQ (P.U)
2	5.55	1.13	0.99
4	7.00	1.59	0.99
6	8.31	1.98	0.98
8	9.40	2.22	0.97
10	9.26	2.16	0.98
14	8.96	2.05	0.98
16	8.55	2.04	0.87
18	8.95	2.04	0.98
20	8.95	2.04	0.98

Table 6.1 Bus values of DFIG wind energy system with STATCOM at Full load

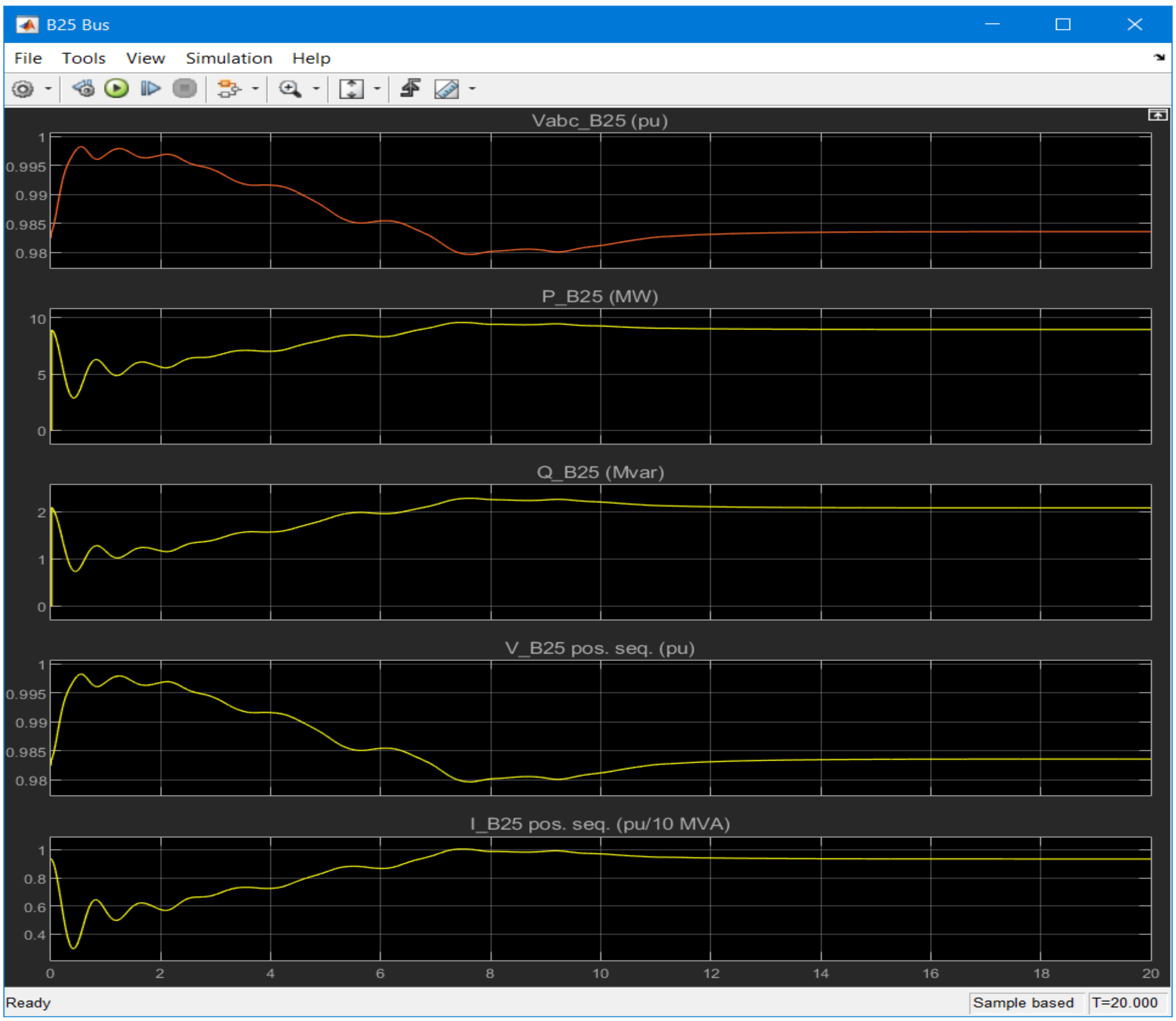


Fig 6.5 Bus wave form of DFIG wind energy system with STATCOM at Full Load

WIND TURBINE VALUES			
TIME (SEC)	P (MW)	Q (MVAR)	WIND SPEED (M/S)
2	1.88	0.84	8
4	3.18	1.59	9
6	3.24	1.69	11
8	3.04	1.51	11
10	3.01	1.48	11
14	3.00	1.47	11
16	3.00	1.47	11
18	3.00	1.47	11
20	3.00	1.47	11

Table 6.2 Wind Turbine values of DFIG wind energy system with STATCOM at Full load

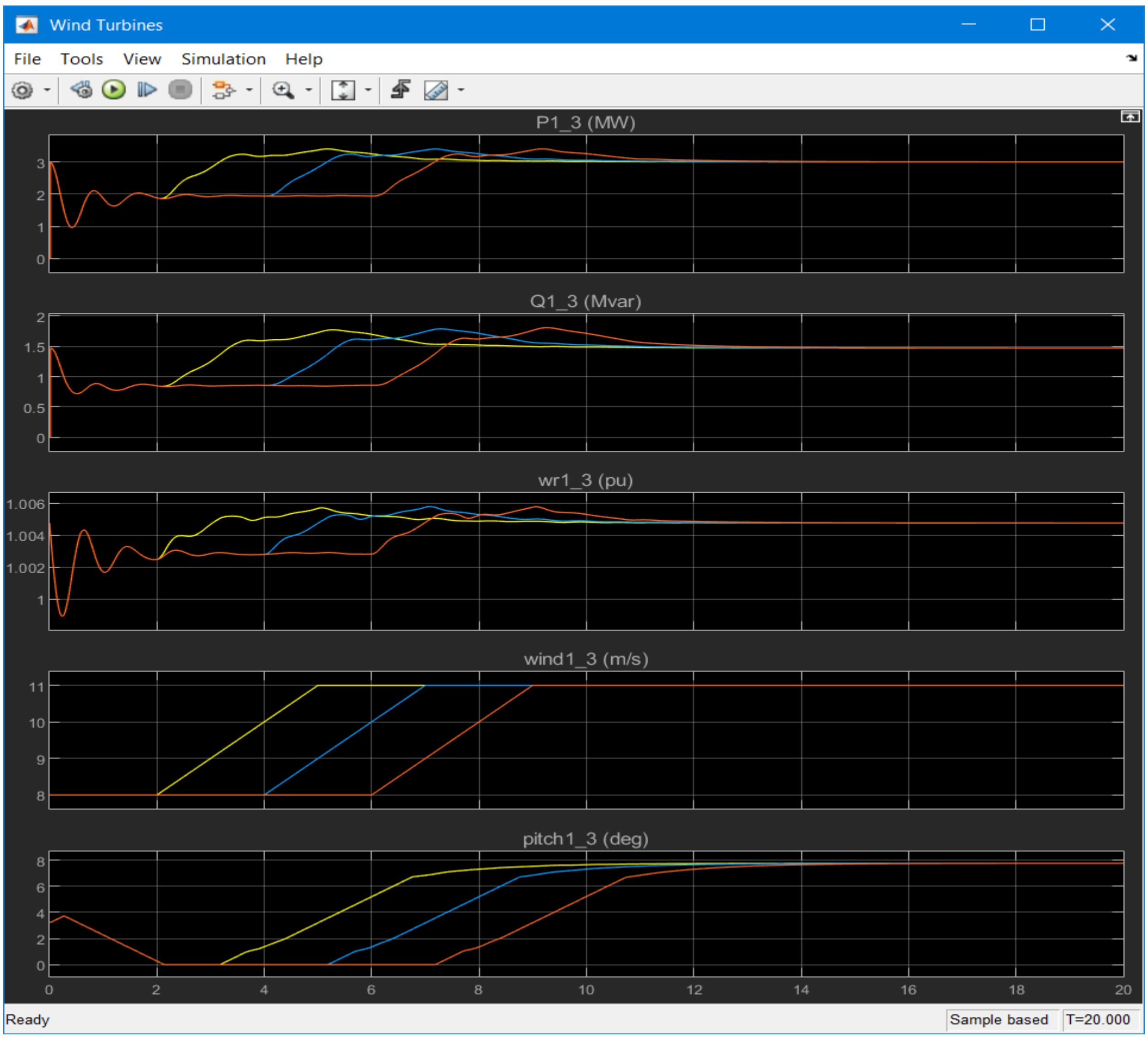


Fig 6.6 Wind Turbine Wave form of DFIG wind energy system with STATCOM at Full load

TIME (SEC)	VM (PU)	GENERATED Q (MVAR)
2	0.996	0.373
4	0.991	0.872
6	0.984	1.48
8	0.979	1.99
10	0.980	1.89
14	0.963	1.67
16	0.963	1.66
18	0.963	1.65
20	0.963	1.65

Table 6.3 Voltage and Reactive power generation in DFIG wind energy system with STATCOM at Full load condition

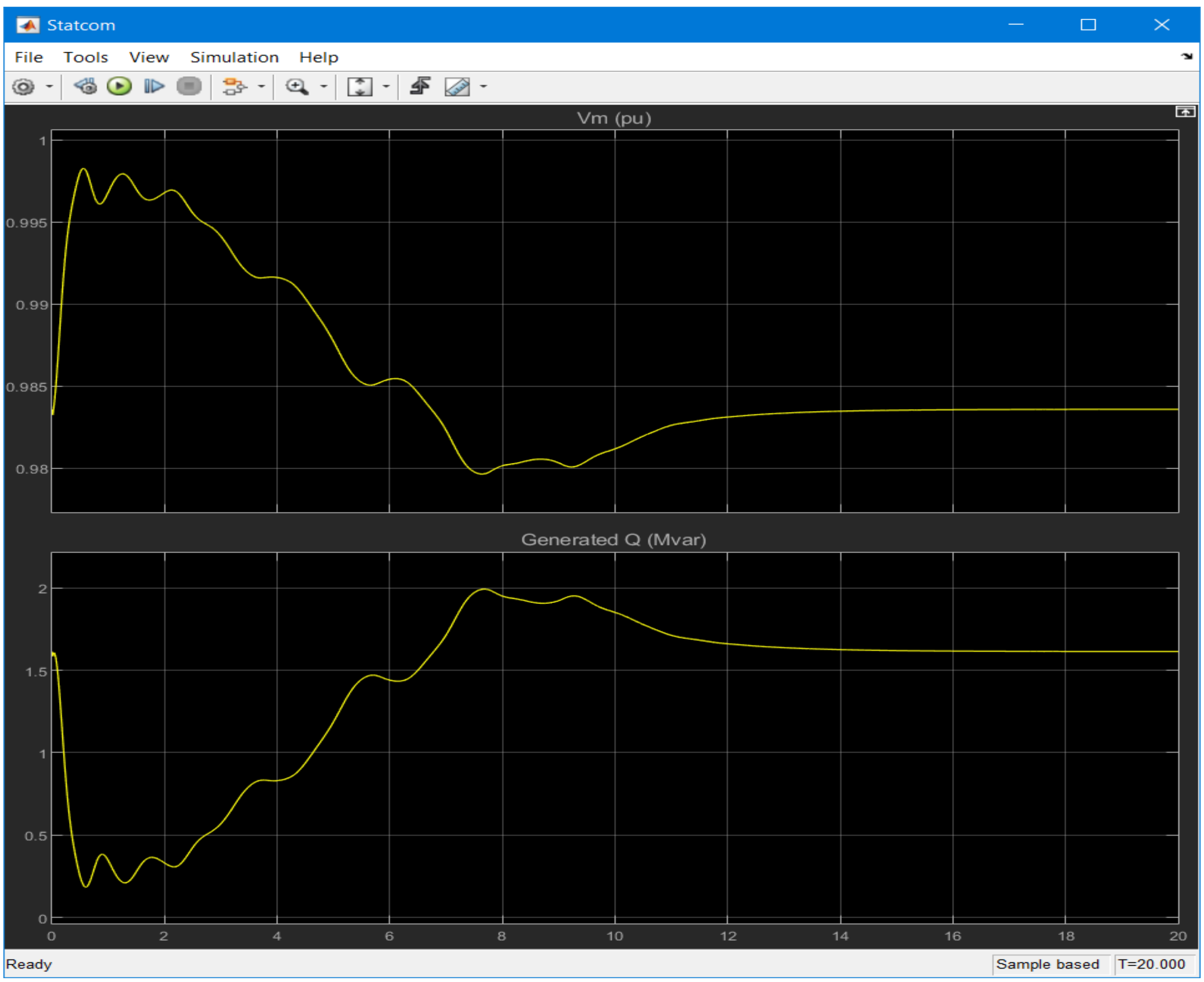


Fig 6.7 waveform of Voltage and Reactive power generation in DFIG wind energy system with STATCOM at Full load condition

CASE 2: Full Load Condition without STATCOM

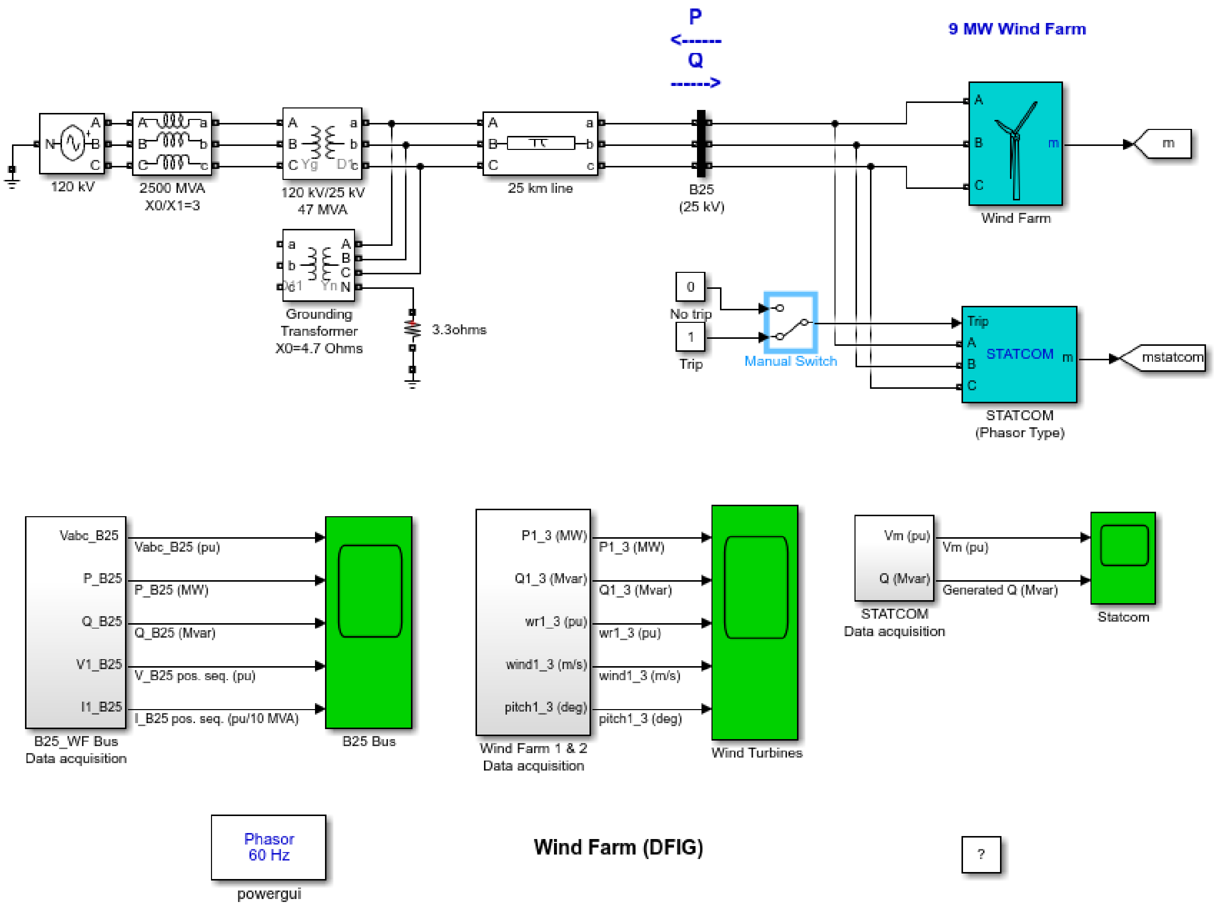


Fig 6.8 Simulink model of DFIG wind energy system without STATCOM at Full Load

BUS VALUES			
TIME (SEC)	P(MW)	Q (MVAR)	V (P.U)
2	5.63	1.52	0.989
4	7.00	2.47	0.972
6	8.31	3.71	0.946
8	9.41	4.96	0.915
10	9.27	4.98	0.916
14	6.01	2.29	0.930
16	5.96	2.11	0.974
18	5.96	2.11	0.977
20	5.96	2.11	0.977

Table 6.4 Bus values of DFIG wind energy system without STATCOM at Full load

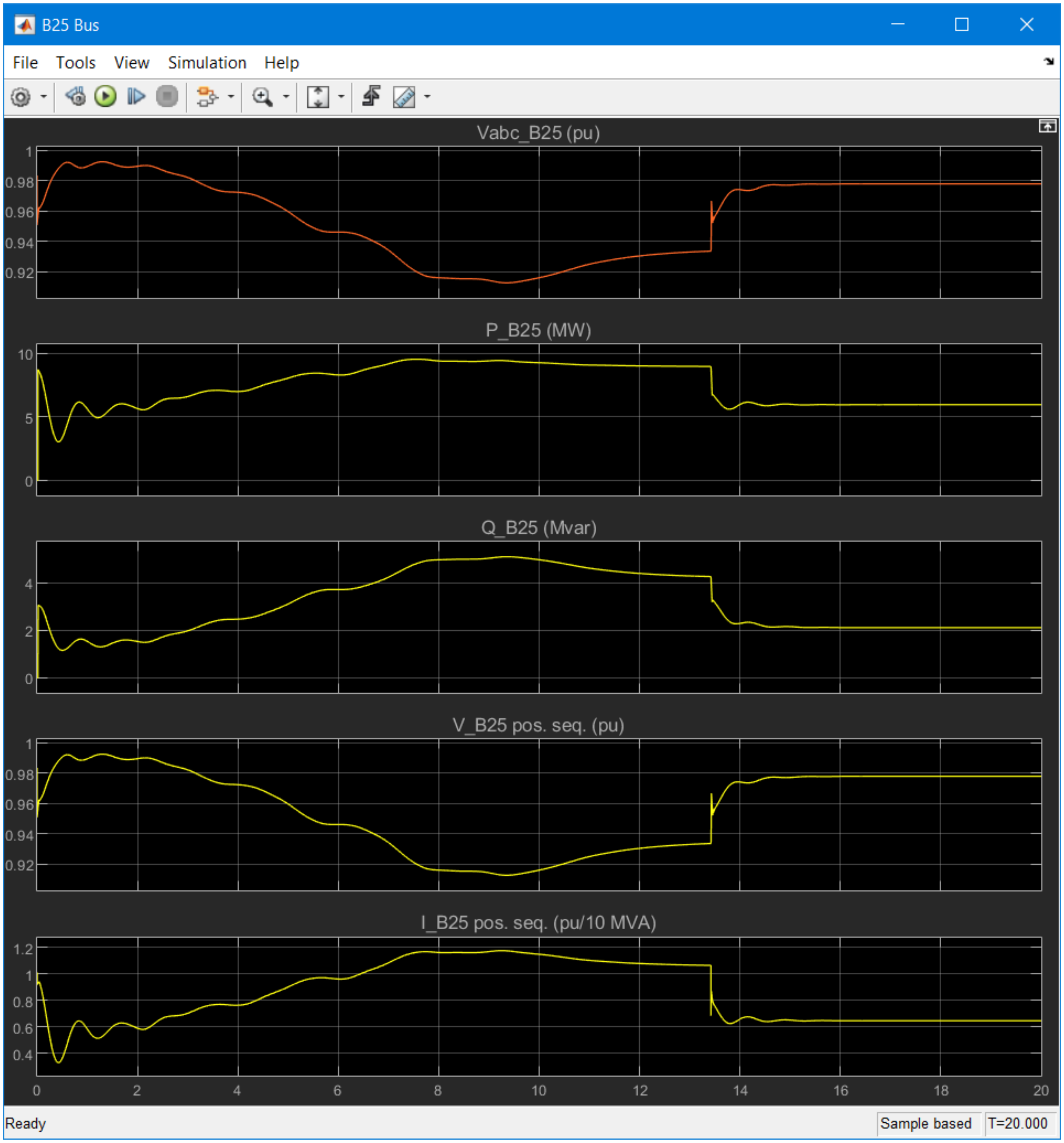


Fig 6.9 Bus wave form of DFIG wind energy system without STATCOM at Full Load

WIND TURBINE VALUES			
TIME(SEC)	GENARATED P(MW)	GENERATED Q(MVAR)	WIND SPEED (M/S)
2	1.89	0.847	8
4	3.17	1.62	10
6	3.24	1.79	11
8	3.05	1.65	11
10	3.01	1.67	11
14	-3.00	-1.34	11
16	-3.00	-1.34	11
18	-3.00	-1.34	11
20	-3.00	-1.34	11

Table 6.5 Wind Turbine values of DFIG wind energy system without STATCOM at Full load

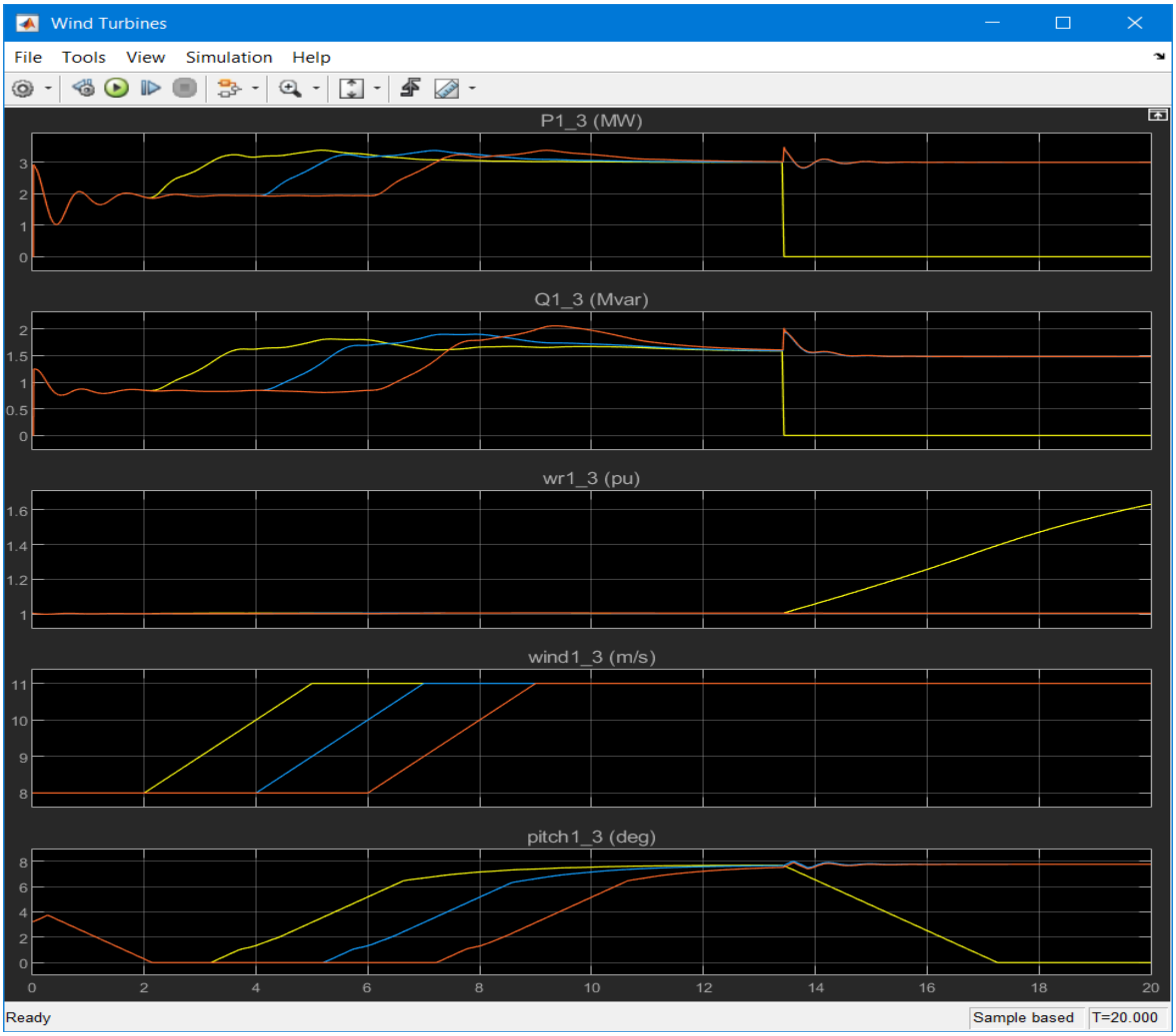


Fig 6.10 Wind Turbine wave form of DFIG wind energy system without STATCOM at Full Load

CASE 3: Phase to Phase Fault Condition at Turbine 2, with STATCOM

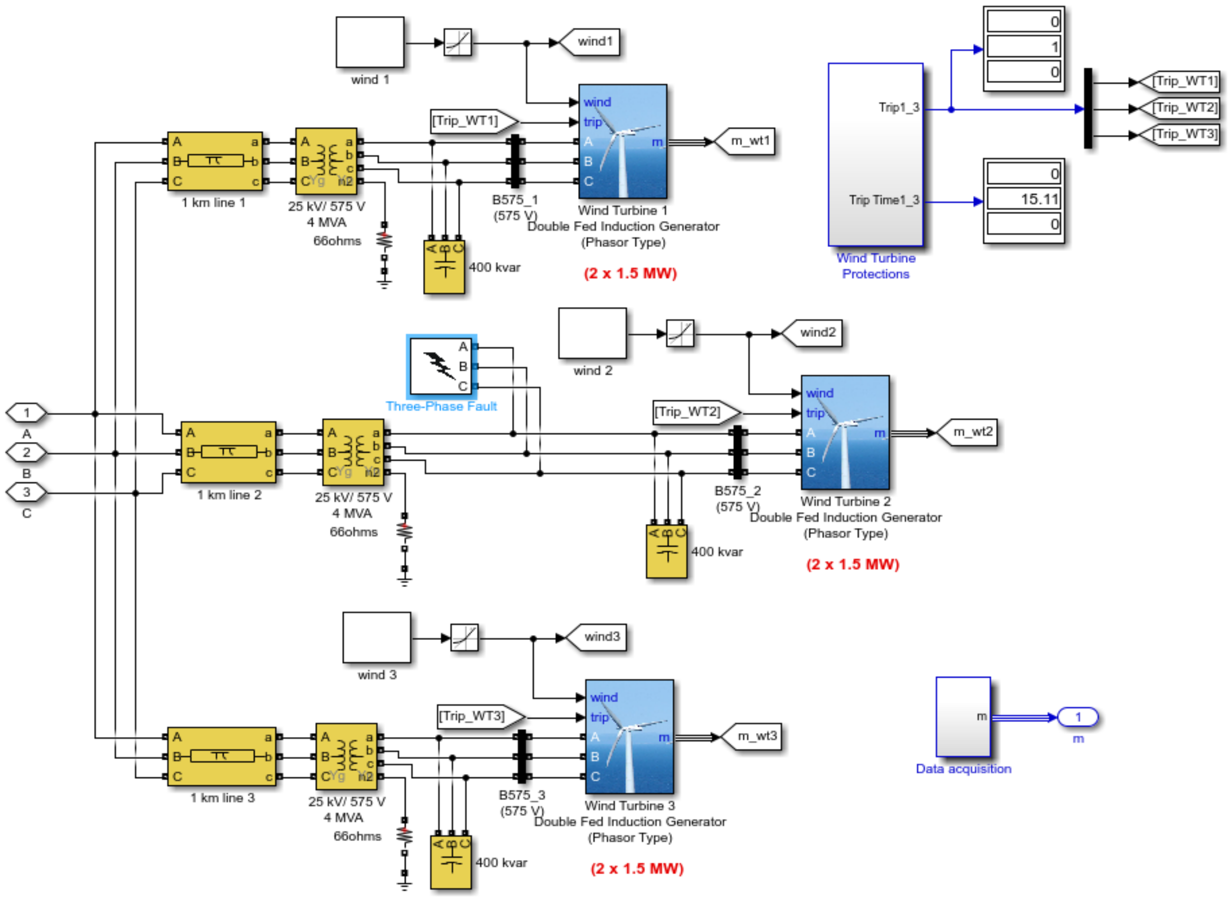


Fig 6.11 Simulink model of DFIG wind energy system with STATCOM at Fault condition

BUS VALUES			
TIME (SEC)	P(MW)	Q (MVAR)	V_PLANT POS.SEQ (P.U)
2	5.62	1.33	.996
4	7.00	1.53	0.991
6	8.31	1.92	0.984
8	8.40	2.21	0.979
10	9.26	2.16	0.960
14	8.26	2.05	0.983
16	6.05	1.37	0.992
18	5.96	1.33	0.993
20	5.96	1.33	0.993

Table 6.6 Bus values of DFIG wind Power system, P-P fault condition with STATCOM

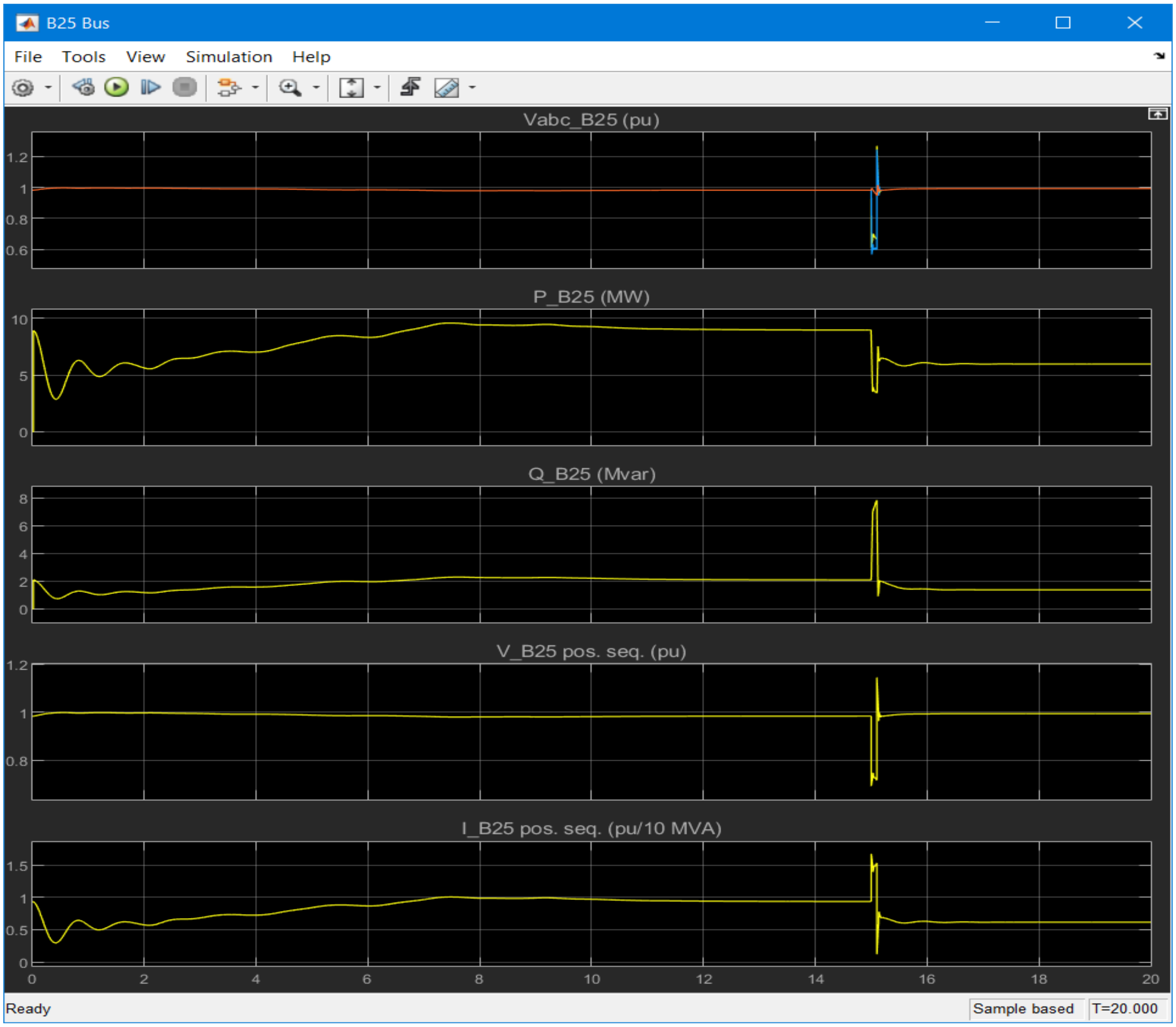


Fig 6.12 Bus Wave form of DFIG wind Power system, P-P fault condition with STATCOM

WIND TURBINE VALUES			
TIME(SEC)	**GENARATED P(MW)**	**GENERATED Q(MVAR)**	**WIND SPEED (M/S)**
2	1.88	0.847	8
4	3.18	1.59	10
6	3.24	1.69	11
8	3.00	1.51	11
10	3.01	1.48	11
14	3.00	1.47	11
16	3.05	1.52	11
18	3.00	1.45	11
20	3.00	1.45	11

Table 6.7 Wind turbine values of DFIG wind Power system, P-P fault condition with STATCOM

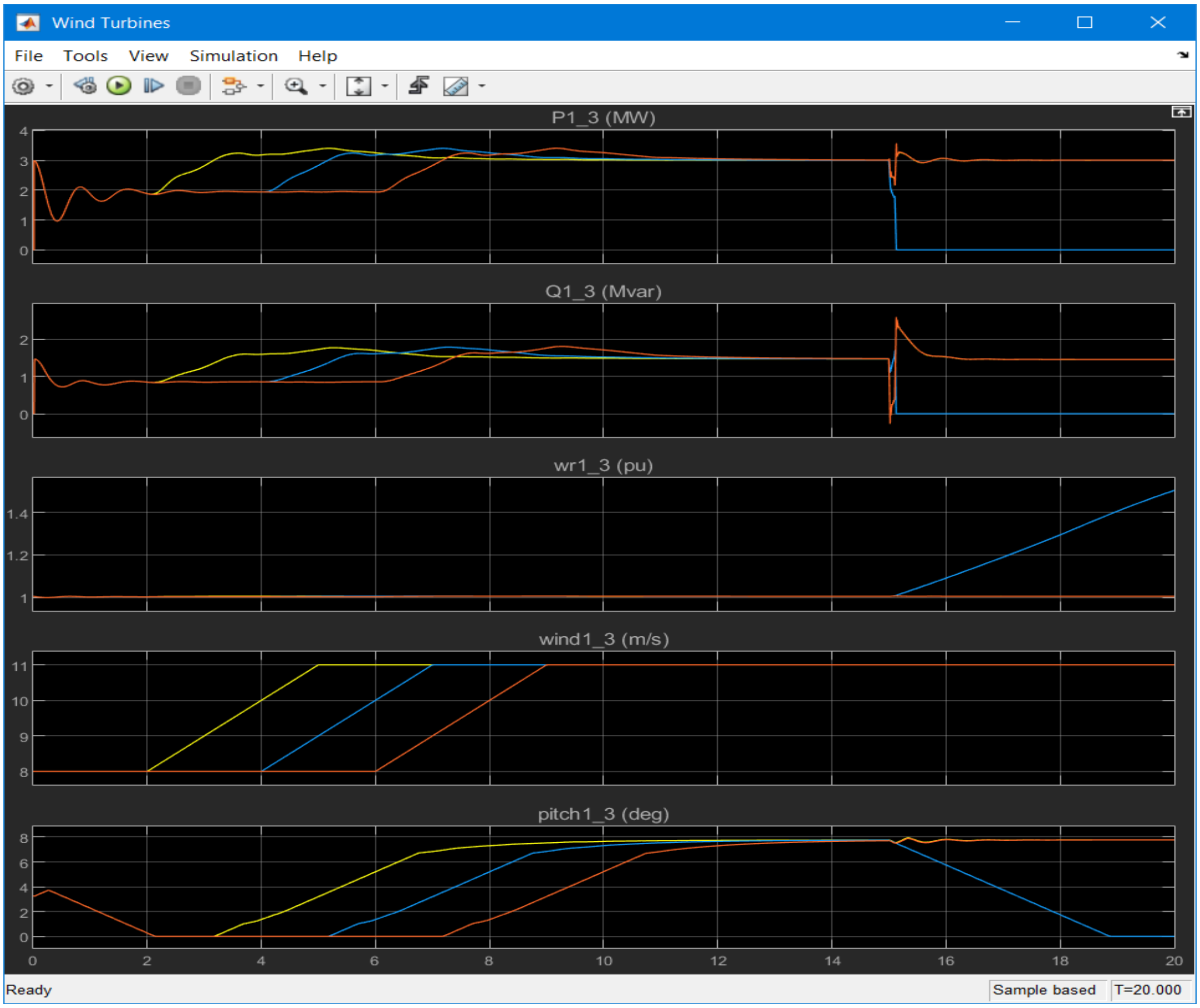


Fig 6.13 Wind Turbine Wave form of DFIG wind Power system, P-P fault condition with STATCOM

TIME (SEC)	VM (PU)	GENERATED Q(MVAR)
2	0.996	0.371
4	0.991	0.872
6	0.984	1.48
8	0.979	1.99
10	0.980	1.89
14	0.983	1.67
16	0.992	0.787
18	0.993	0.683
20	0.993	0.683

Table 6.8 Voltage and Reactive power generation values in DFIG wind energy system with STATCOM, under P-P Fault condition

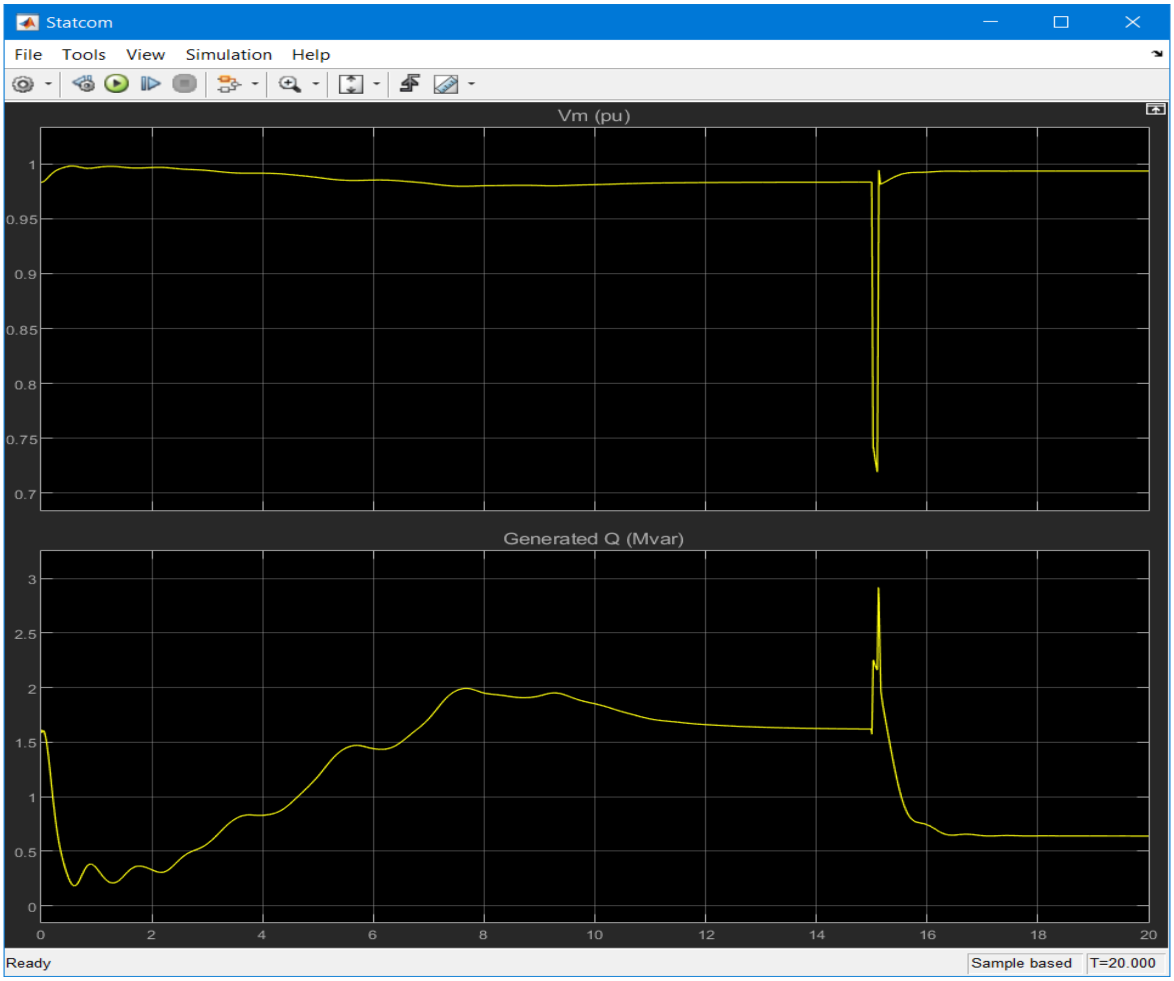


Fig 6.14 Voltage and Reactive power generation in DFIG wind energy system with STATCOM, P-P Fault condition

CASE 4: Phase to Phase Fault Condition at Turbine 2, without STATCOM

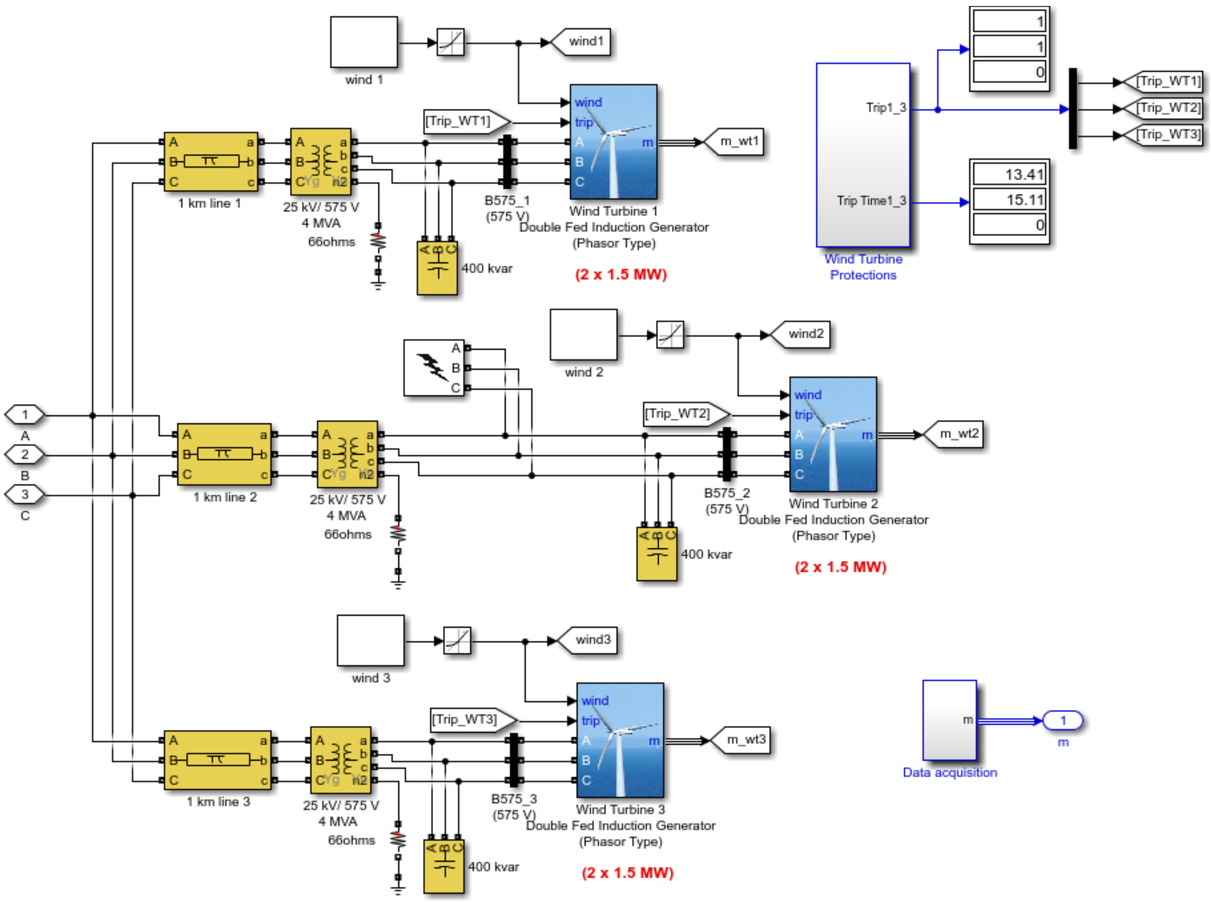


Fig 6.15 Simulink model of DFIG wind energy system without STATCOM at Fault condition

BUS VALUES			
TIME (SEC)	P(MW)	Q (MVAR)	V_PLANT POS.SEQ (P.U)
2	5.64	1.52	0.988
4	7.00	2.47	0.970
6	8.30	3.73	0.944
8	9.41	5.00	0.913
10	9.27	5.01	0.913
14	6.07	2.32	0.972
16	3.00	0.465	1.00
18	2.97	0.362	1.00
20	2.97	0.362	1.00

Table 6.9 Bus values of DFIG wind Power system, P-P fault condition without STATCOM

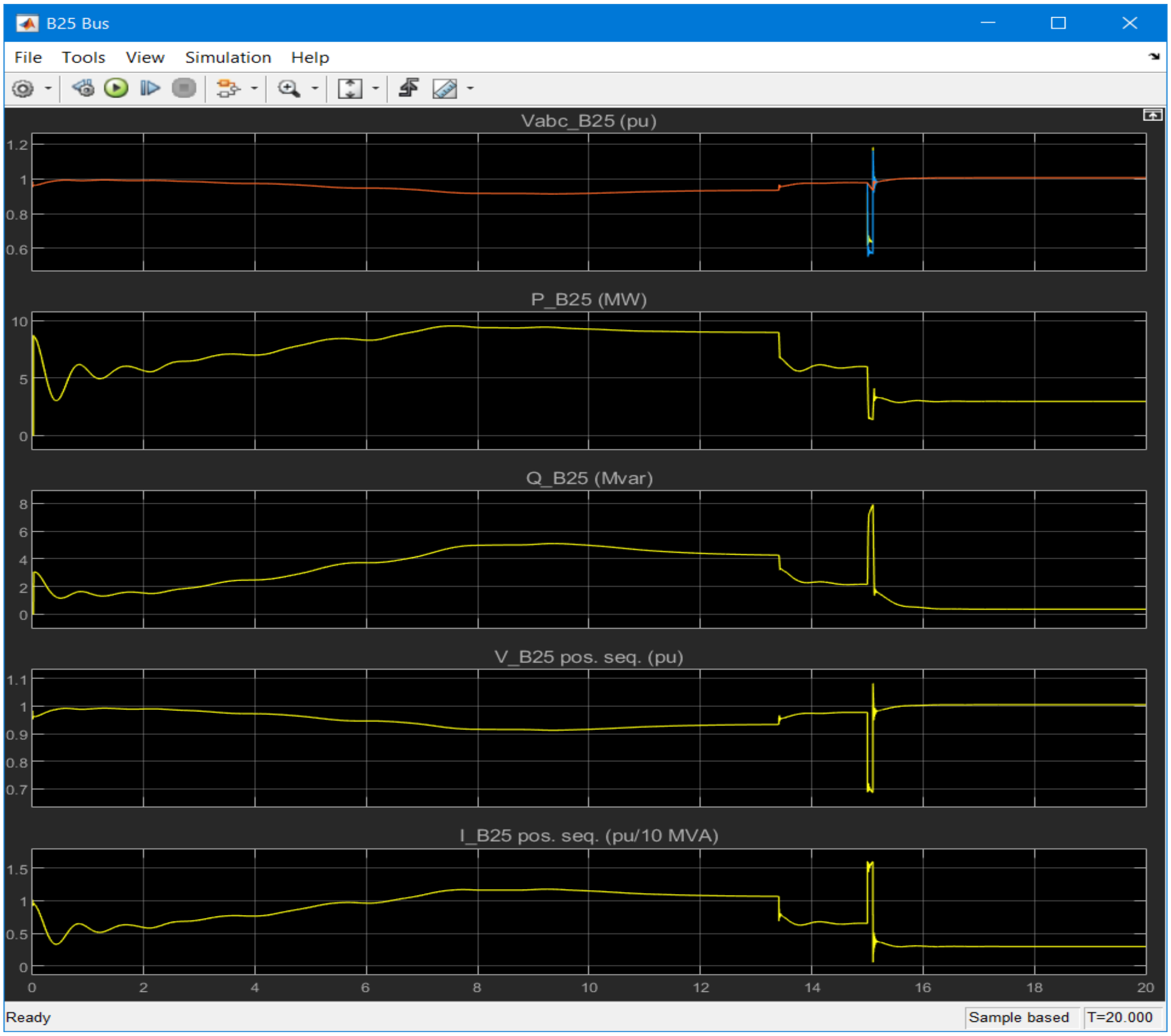


Fig 6.16 Bus Wave form of DFIG wind Power system, P-P fault condition without STATCOM

WIND TURBINE VALUES			
TIME(SEC)	GENARATED P(MW)	GENERATED Q(MVAR)	WIND SPEED (M/S)
2	1.89	0.848	8
4	3.17	1.62	10
6	3.24	1.72	11
8	3.05	1.66	11
10	3.01	1.67	11
14	-0.436	-0.228	11
16	-0.395	-0.145	11
18	-0.258	-0.28	11
20	-0.258	-0.28	11

Table 6.10 Wind turbine values of DFIG wind Power system, P-P fault condition without STATCOM

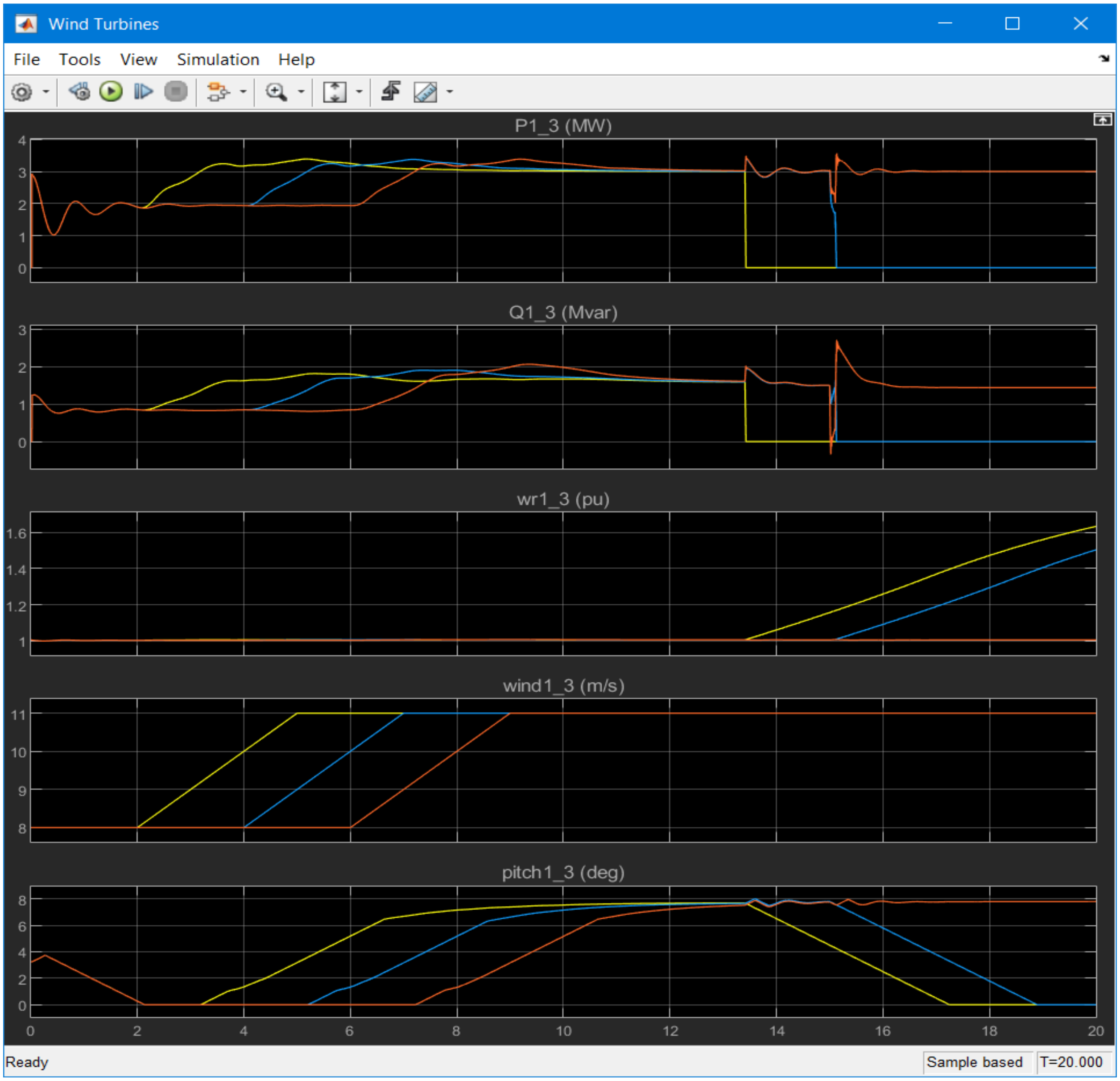


Fig 6.17 Wind Turbine Wave form of DFIG wind Power system, P-P fault condition without STATCOM

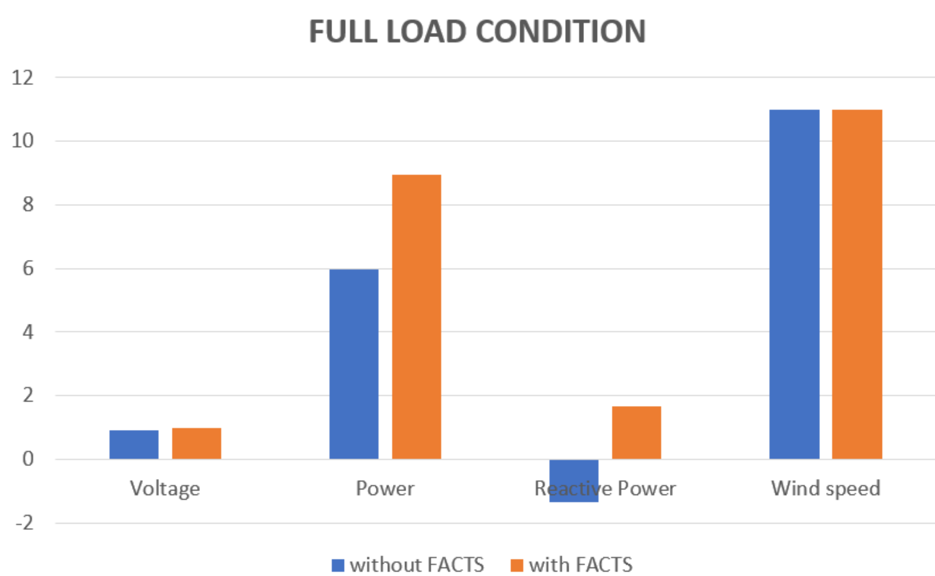
The objectives met by using STATCOM controller are as under:

1. The voltage waveform and reactive power at the bus shows an improvement
2. The Power, rotor speed, pitch angle and reactive power, shows an improvement in the Stability.
3. The Performance of different operating conditions shows the improvement in the Voltage and generated reactive power.

CONCLUSION

This work emphasizes the Stability analysis in grid interactive wind energy system. Stability improvement is observed with different operating conditions. FACTS devices like STATCOM are used to provide dynamic reactive power support leading to improvement in power system stability. The results obtained from simulation shows that of the compensation methods STATCOM is more effective in providing reactive power support, improving voltage profile and improving the system stability.

For illustration consider Full load condition Fig 6.16 which shows the improvement in Reactive power, plant voltages when we connect the STATCOM control system to the plant.



	without FACTS	with FACTS
Voltage	0.91	0.97
Power	5.96	8.95
Reactive Power	-1.34	1.65
Wind speed	11	11

Fig 6.18 Comparisons of parameters with and without FACTS

Hence, the study results encourage to use STATCOM in wind energy systems for effective reactive management, improved voltage profile and better stability of the system meeting the grid code requirements for connecting it with the grid.

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