REPORT

ON

EXPERIMENTAL SIMULATION OF A SMALL WIND TURBINE

BY

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Moreover, I am thankful to the institute for enabling me to take up this course and pursue this project.

This report is dedicated to all environmentally friendly mechanical engineers who go out of their way to ensure that minimal cost and efficiency is incurred in our daily life, and that the environment is safe for our habitation.

2 ABSTRACT SHEET

Course Number: ME-F366

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TITLE: Experimental Simulation of a Small Wind Turbine

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3 ABSTRACT

The issue of global warming and depleting non-renewable energy resources has brought up the need to find alternative sources of energy. Lot of research has been done in various fields to produce energy using renewable sources like solar, wind , geothermal , tidal etc.
Wind energy has emerged as a champion in all presently available renewable energy sources and new innovations are undergoing in this area.

Small Wind Turbines have been under research for a long time to generate energy for household , buildings and for various other small scale purposes. Simulations and experiments have been done for built-in environment installation of these machines which are capable of powering a household on its own.

It is hoped that this report will inform readers and researchers, the modelling and experimental simulations performed on small wind turbines.

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7 INTRODUCTION

In contrast to large commercial wind turbines, such as those found in wind farms, with higher individual power outputs, small wind turbines (also known as Micro Wind) are used for the micro-generation of electricity. The Canadian Wind Energy Association (CanWEA) describes "small wind" as varying from turbines of less than 1000 watts (1 kW) to turbines of 300 kW. For a cruise, caravan, or miniature cooling unit, the smaller turbines can be as small as a 50 watt auxiliary power generator. Small wind turbines are specified by the IEC-61400-2:2013 standard as wind turbines with a rotor sweep area of less than 200 m2, producing a voltage below 1000 Va.c. 1500 Vdc. [1]

The Small Wind World Report 2015 from WWEA reports that in early 2014, China alone produced 6,25,000 SWTs, followed by the USA with 6,25,000 SWTs. With 1,57,700. In the world, the installed capacity is about 755 MW and it is anticipated that this will rise by 2020 to 2 GW.

Smaller turbines are available for residential-scale use. Their blades are generally 1.5 to 3.5 metres (4 ft 11 in-11 ft 6 in) in diameter and produce 1-10 kW of electricity at their maximum wind speed.[7] In their construction, some units have been built to be very lightweight, e.g. 16 kilogrammes (35 lb), allowing sensitivity to small wind movements and a fast response to wind gusts commonly seen in urban settings and simple mounting, much like a TV. It is believed, and a few are accredited, that even a few feet (about a metre) beneath the turbine is inaudible.

8 OBJECTIVES AND PLAN OF REPORT

The report is an outcome of step by step strategic analysis of surveys ,literature ,designing, working and finally experimental data retrieved from simulation of a Small Wind Turbine.
Beginning with the relevant literature and surveys , moving to design of the Small Wind Turbine , the experimental set-up used , softwares aided and finally concluded with the results obtained through simulations performed. Figures and Tables have been included to give graphical insight and for better understanding of literature produced.

[1] https://en.wikipedia.org/wiki/Small_wind_turbine

9 SURVEY AND ANALYSIS

With global installed wind energy capacity close to 500 GW and projected to rise to 800 GW by 2020, there is a need to boost the performance of the wind farm. Wind farm performance is a function of many factors, including ambient conditions, geographic landscape, configuration of wind turbines, turbine spacing and electrical transmission.

9.1 SMALL WIND TURBINE CLASSIFICATION

Different ways of classifying SWTs exist. there are various meanings of small turbines for wind as well. There are other height restrictions in many countries when it comes to subsidy provision for wind power initiatives and projects. About IEC 61400-2 ed. 2 refers to wind turbines with a sweeping area of less than < 300 m^2 (generating at a sweeping area). voltage of below 1000 V ac or 1500 V dc) and extends not only to SWTs that are on the rated power base, but also on the basis of the swept area.

TABLE T.1 SWT CLASSIFICATION (IEC 61400–2)			
S.No	**Rated Power**	**Rotor Swept Area**	**Category**
1	Prated < 1 kW	A < 4.9 m^2	Pico Wind
2	1kW < Prated < 7 kW	A < 40 m^2	Micro Wind
3	7 kW < Prated < 50 kW	A < 200 m^2	Mini Wind
4	50 kW < Prated < 100 kW	A < 300 m^2	Small Wind

SOURCE: CIEMAT

Based on different criteria, other classifications of SWTs are as follows:
[2]

1. VAWT and HAWT
2. Drag and lift-based VAWTs
3. Upwind and downwind SWTs
4. Geared and direct-drive SWTs
5. Stall and pitch controlled SWTs

[2] Small Wind Turbines - Wind Power Technology: *Joshua Ernest , Stuthi Rachel*

6. Off-grid, on-grid and hybrid SWTs.

7.2 SWTs COMPONENTS

Irrespective of their rating, almost all SWTs consist of the following major parts:

- Rotor
- Electric generator/alternator
- Tail vane or yaw system
- Tower
- Control and protection systems
- Gearbox (in some SWTs).

9.1.1 Rotor

The rotor of a SWT could be a two-bladed, three-bladed or multi-bladed turbine (see Figure 1).[3] According to IEC 61400–2–Design Requirements for Small WindTurbines, they are to be designed to rotate in a clockwise direction to harness the energy from the wind. The blades are generally fixed to the hub at an appropriate angle of attack for the lift force to act upon and make them rotate. The blades are usually built of glass fibre reinforced plastic (GFRP) which are relatively lighter and durable than wood or metal.

Fig 1 Multi-bladed Small wind turbine[4]

[3] Rotor : Small Wind Turbines - Wind Power Technology: *Joshua Ernest , Stuthi Rachel*
[4] Image : https://www.beupp.com/wp-content/uploads/2019/03/Wind-Turbine-For-Home.jpg

9.1.2 Electric Generator

In SWTs, a variety of kinds of electric generators are used. The Results, The key factors for their selection are reliability and cost. A generator that the alternating current (AC) power generated is called an alternator.

1. DC Generator
2. PMSG
3. SCIG

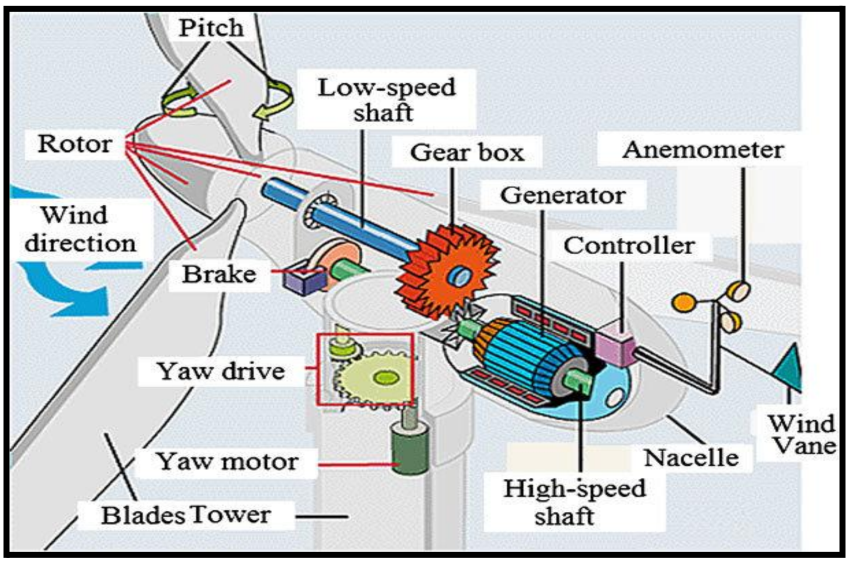

Fig 2 Five main parts of Wind Turbine[5]

9.1.3 Gearbox

Some SWTs use a gearbox to convert the rotation of the gearbox to a relatively slow rotation. A rotor to balance the electric generator 's high RPM. The gearbox between the gears Usually, the rotor and generator consist of two phases of helical / spur gears loaded with With oil for lubrication. The manufacturer, once every 2-3 years or as defined by the manufacturer. Contamination and moisture content should be checked for gearbox oil and altered, f asked. There should only be light oil used. Hypoid SAE oil is too dense, for instance, And 50 percent must be diluted with light engine oil if it is not possible to find lighter gear oil.

[5] Image:https://www.researchgate.net/figure/Parts-inside-the-wind-turbine_fig5_290094650

9.1.4 Control and Protection System

The control panel with the protection system is usually situated in the control room at the tower bottom. The output from the generator/alternator is variable (as the wind speed varies), requiring a control system to produce a stabilised constant output power. The sophistication of the control and protection system varies, depending on the application of the SWT and the energy system it supports. Inverters consume approximately 10% of the generated electricity (treated as a loss) when converting from DC to AC. A load is required to be connected to the output of the transformer. The transformer must be in a dry, clean, ventilated area, as it becomes quite warm when running at full power. For a typical home, properly-sized batteries can last 3 to 5 years. Deep discharge batteries are better, as they can safely discharge a significant amount daily and can be charged back by the next day.

9.1.5 Tail Vane (Yaw System)

Most micro and mini SWTs use a simple tail vane with a capacity of about 10 kW. At the rear of the horizontal axis, the SWT nacelle (see Figure 1.3) allows the turbine to work. The rotor will continue to face the storm. The forced yaw system, in the absence of the tail vane, Maintains the wind-facing rotor.

Fig 3 Small HAWT: Consists of the rotor, electric generator, tower and tail vane.[6]

[6] Courtesy: www.teroc.se

9.1.6 SWT Tower

Several different types of towers are available, depending upon the design and manufacturer. They could be free standing or guy wired. Standard tower lengths are 20 m and 30 m. It must be designed to withstand extreme winds and hail. Higher above the ground, the wind speed increases and the flow is more laminar. Electric power generation increases exponentially with the wind speed. For instance, installing a 10 kW SWT on a 30 m tower rather than an 18 m tower can result in 30% more power annually.

9.2 CFD SIMULATIONS

Understanding the behaviour of turbulence created by wind turbines and wind turbine wake dynamics will lead to more durable design of wind turbines, assist wind farm engineering and improve the performance of wind turbines. Computational fluid dynamics (CFD) has become a key component in the study of wind turbine wakes, and advances in wind energy technology can be directly attributed to research efforts using CFD in conjunction with wind tunnel experiments.

A great deal of literature is available on theoretical techniques for modelling wind turbine wakes and applying turbulence closure methods as they refer to horizontal-axis wind turbines (HAWT). Likewise, there are comprehensive publications on wind tunnel studies to research wake dynamics and wind turbine performance.

In 2011, a state-of-the-art analysis of CFD methods for simulating wind turbines was published by Sanderse et al.[1]. They classified the various numerical techniques used and distinguished between models unique to rotor simulation versus wake simulation. Kinematic and field models, previously discussed, are used for simulating the wake. The body forces in the momentum equations can be represented by an actuator disc (AD), actuator line (AL), or actuator surface (AS) for the simulation of the rotor.

Over the past decade , the number of wind tunnel experiments on small-scale wind turbines has grown. The development can be attributed to the need to research wake effects under controlled conditions and the need for CFD validation data to be provided. Depending on the size of the wind tunnel, instrumentation, and test target, the experimental setup varies.

9.3 IEC STANDARDS[7]

9.3.1 Introduction

Since January 1, 1997, IEC publications have been numbered from 60,000.
The committee has decided that the contents of this publication will remain unchanged until the maintenance date indicated on the IEC website under **"http://webstore.iec.ch"** in the data for the specific publication.
IEC 61400-23, Wind turbine generator systems - Part 23: Full-scale structural testing of rotor blades.
Indices: ave B design H hub max proj r shaft average blade input parameter for simplified helicopter design equations maximum projected hub height rotor shaft.
This annex provides information for the simplified design equations in this part of IEC 61400.
Some calculation inputs are defined for use in this part of IEC 61400: Vdesign is the design wind speed defined as 1.4Vave.
The term eccentricity assumes that the center of mass of the rotor is offset from the shaft by 0.005R, which causes a range of gravitational torque.

9.3.2 Design Considerations

Under this load assumption, the turbine has an orientation of ωyaw, max and the rotor turns at ωn, design.
In this load case the turbine is yawing with ωyaw, max and the rotor is spinning with ωn, design.
Extreme loading can occur if the rotor has an orientation error and the instantaneous wind positions the entire blade at the angle of attack for maximum lift.This load assumption is assumed to be dominated by the maximum rotational speed.For the shaft, only the bending moment of the shaft is considered, it is assumed that the rotor has an unbalance with the center of mass a of the rotor at the distance er from the center of the shaft.

Fixed rotors: Concerning the wind turbines which will be immobilized, the bending moment of the blade root outside the plane is dominated by the drag.
The formal decisions or agreements of IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested IEC National Committees.
The design load cases shall consist of a combination of these external conditions with wind turbine operational modes.Such conditions shall require wind turbine class S design.
At least the following extreme electrical power network conditions at the wind turbine terminals shall be considered in the design.The load cases shall be determined from the combination of

[7] Source : IEC 61400-2 , Design Requirements for Small Wind Turbine

specific assembly, erection, maintenance, and operational modes or design situations with the external conditions.

If a significant correlation exists between an extreme external condition and a fault situation, a realistic combination of the two shall be considered as a design load case.

Any fault in the control or protection systems, or internal fault in the electrical system significant for wind turbine loading shall be assumed to occur during power production.If it is likely that a turbine fault will occur at high wind speeds, this will be taken into consideration in this design load case.To determine the data required for the simplified load analysis or verify the aeroelastic model a test shall be performed to determine the following design data:Wind speed, power production and r.p.m. shall be measured at the nominal electrical load.The measurement load cases shall include all normal and critical operating and fault conditions, braking performance and yaw behaviour.Relevant wind turbine operational data including rotor speed, electrical power, yaw position and turbine status shall be measured.The mean, minimum and maximum values, as well as standard deviation of the appropriate load data shall be evaluated and included over the recorded wind speed and turbulence ranges and the relevant data included in the test report.For the purposes of this test, operational time fraction is defined as the measure of performance given by the ratio of time a wind turbine shows its normal designed behaviour to the test time in any evaluation period expressed as a percentage.Every electrical component selected on the basis of its power characteristics shall be suitable for the duty demanded of the equipment, taking into account design load cases including fault conditions.Consideration shall be given to the design loads arising from normal turbine maintenance including, climbing, raising and lowering the tower.The manufacturer shall provide a written manual shutdown procedure including a specification of a wind speed limit and other conditions in which the procedure may safely be carried out.The formal decisions or agreements of IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each the the technical committee has representation from all interested IEC National Committees.The design load cases shall consist of a combination of these external conditions with wind turbine operational modes.Such conditions shall require wind turbine class S design.At least the following extreme electrical power network conditions at the wind turbine terminals shall be considered in the design. The load cases shall be determined from the combination of specific assembly, erection, maintenance, and operational modes or design situations with the external conditions. If a significant correlation exists between an extreme external condition and a fault situation, a realistic combination of the two shall be considered as a design load case. Any fault in the control or protection systems, or internal fault in the electrical system significant for wind turbine loading shall be assumed to occur during power production.If it is likely that a turbine fault will occur at high wind speeds, this will be taken into consideration in this design load case.

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Wind speed, power production and r.p.m. shall be measured at the nominal electrical load.
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The manufacturer shall provide a written manual shutdown procedure including a specification of a wind speed limit and other conditions in which the procedure may safely be carried out.

9.3.3 IEC Standards Conclusions

For wind turbines with the rotor spinning at Ve50, one can expect that in a few places on rotor C1, max will occur on one of the blades due to variations in wind direction.
The helicopter's thrust coefficient is based on blade tip speed rather than wind speed.
Rotor rotating or immobilized, for the calculation of the mast loads, the pushing force must be combined with the drag exerted on the mast and the nacelle

10 WIND TURBINE MODEL

The number of wind tunnel studies on small-scale wind turbines has increased over the past decade. The development can be attributed to the need to research wake effects under controlled conditions and the need for CFD validation data to be provided. Depending on the size of the wind tunnel, instrumentation, and goal of research, the experimental configuration varies. The purpose of this research was to analyse the wake profile and turbulence downstream and between multiple small-scale turbines in the near-wake area where turbine spacing was considered. It was appropriate to use the experimental data for comparison with CFD simulations.

10.1 SWT (Unitron UE-6 650wt)

Unitron UE-6 650 wt, manufactured by Unitron Energy Systems Pvt. Ltd. was used in the study. UNITRON Energy Systems Pvt. Ltd. formerly 'UNITRON SYSTEMS', established in 1987, today boasts of an impressive growth rate from the start. With the growth in the products and Capacities Company changed its name to UNITRON Energy Systems Pvt. Ltd., as it is now known.
With the expertise of Mr.P.Ravindranath - Director , a few years back the Company diversified into forays of Renewable Energy Systems, such as small wind energy, which is still at a nascent stage in our country, especially the concept of 'MICRO WIND'.[8]

Fig.4 Unitron UE-6 650wt

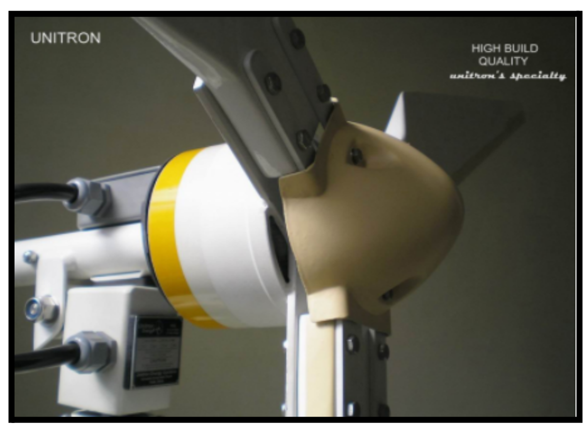

Fig.5 UE-6 650 wt build

[8] Source : https://www.unitronenergy.com/companyProfile.html

Table T.2 depicts the product specifications:

Model	UE-6
RATED OUTPUT	650W
RATED WIND SPEED m/s / mph	10.5 / 24
PEAK OUTPUT	750W
CUT IN m/s / mph	2.7 / 6
YAW SYSTEM	Passive by tail Vane
YAW / Tower Cable	N x 360° Freedom
GENERATOR	PM 3 phase alternator(variable speed)
Insulation Class & Efficiency	Class “H”, > 87%
Stator Skew	1 slot pitch
Max stator Core Temperature	180° C
POLES	10
RPM- 50hz/60hz	600 / 720
Over speed limit RPM / Hz	840/70
Monthly KWH 10mph / 4.5 m/s PLF %	72 kWh (18%)
Monthly KWH 12mph / 5.4 m/s PLF (%)	161 kWh (25%)
ROTOR DIAMETER	2.2m / 7.2 ft
NUMBER OF BLADES	3
BLADE MATERIAL & Cp	Carbon Fiber composite, ~ 0.37
SWEPT AREA	3.7 /43 Sq.m / sq.feet
Minimum Tip clearance cm / in	20 / 8
Tip Speed Ratio (TSR)	8.5
LATERAL THRUST (MAX)	1260 nts
GOVERNOR / over speed limit	Uptilt tilt
GOVERN SPEED	27mph
GOV. SHUT-DOWN / OPTIONAL STOP	Electro- dynamic Switch
UNIT WEIGHT (tower top)	23 kg to 39 Kg.
TOWER Top Pipe / Yaw adaptor	P 2.5” Shd, 40
VOLTAGE options	12 to 48 / 60 - 140 LV / HV
ELECTRONIC CONTROLLER	Incl. but separate
WARRANTY	2 yrs.
OPERATING LIFE	20 yrs.
SURVIVAL WIND	55 m/s
SUGGESTED. ROUTINE MAINTENANCE	Annual inspection

[9]

Table T.2 : Specifications of Unitron UE-6 650wt

[9] Source : https://www.unitronenergy.com/product-ue6.html#prettyPhoto

10.1.1 Sales and Distribution

Table T.3[10] below includes the name of clients of product Unitron UE-650:

S.No	Sector	Client	Project Capacity	Year of Installation
1.	Indian Navy	Bhuj	650 W	2013
2.	Indian Forest and Fisheries	Bhimashankar	650W	2013

Other clients of UNITRON Energy Systems Pvt. Ltd are from various sectors including:

1. Govt. Sector / Gram Panchayats
2. Indian Army
3. Indian Forest & Fisheries
4. Indian Railways
5. Schools/ Colleges / Universities
6. Banks
7. Builders / Housing Societies
8. Temple Trust / Social Organisations
9. Public Sector
10. Corporate Sector

[10] Source : https://www.unitronenergy.com/clientsList.html

10.2 Wind Tunnel Specifications

The wind tunnel in the Mechanical Engineering Laboratory at KK BIRLA BITS Pilani Goa Campus was used for experimental studies.
A three-axis traversing mechanism within the wind tunnel test segment .The top panel is fixed. To each one, stepper motors are connected Arm to enable precise placement of the hot wire probe Control. Command. Each stepper motor provides movement of 25.4 mm for Each 4000 revolutions on the location gives a resolution of 6.35 lm Of the probe of the hot wire. The stepper engines were powered by a Velmex VXM controller and data acquisition communication between The system and the controller were carried out using RS232. The Baseline Turbulence strength (empty tunnel) was assessed at 0.32 percent.(Randall et al. [2])

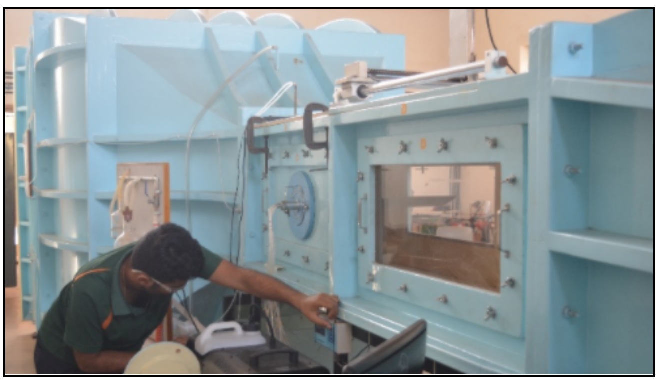

Fig. 6 Wind Tunnel at KK Birla BITS Pilani Goa Campus

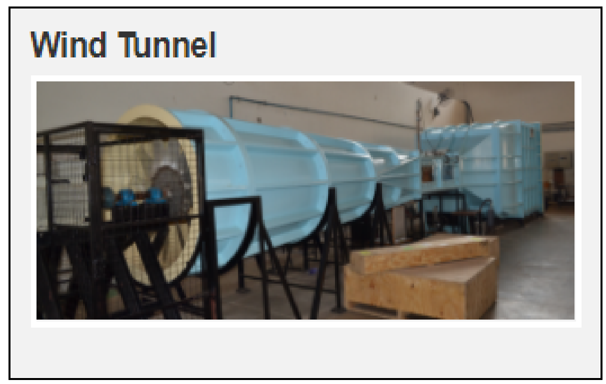

Fig.7 Wind Tunnel used in the experiment

Table T.4 [11]	**Description and specification of the Wind Tunnel at BITS Pilani Goa Campus**
Feature	**Specification**
Low Speed Wind Tunnel	Test Section: 0.6m x 0.6m square, 2.0m long with maximum speed of 50 m/s.
Entry	Square honeycomb entry followed by three wire-mesh screens and a 12:1 contraction, Operation: Open circuit, continuous low speed Suction tunnel.
Power	22 KW / 30HP AC motor, with speed control drive, Fan:12 blade low noise composite fan.
Flow Diagnostics	TSI Two-component LDV and Scanning Valve 10" H2O 16-channel Pressure module.

[11] *Courtesy : https://universe.bits-pilani.ac.in/goa/me/Research*

11 SIMULATION ENGINES

A simulation engine is the collection of components, features and support functions which are crucial to the implementation of an efficient discrete event simulation model. Furthermore, this model can be embedded in a larger application.
A lot of simulation engines are used worldwide for the computational as well as experimental simulation of turbines ranging from micro to large scale wind turbines.

WindoGrapher, WindSim, MeteoDyn, WindFarmer, which use the WAsP engine to perform wind assessments.(The WAsP software suite is the industry-standard for wind resource assessment, siting and energy yield calculation for wind turbines and wind farms.)

The Simulation engines used are FAST , AeroDyn and ADAMS2AD. These simulation engines are built by NREL. The National Renewable Energy Laboratory is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

11.1 FAST

FAST, now OpenFAST, is NREL's primary physics-based engineering tool for simulating the coupled dynamic response of wind turbines.[12]

FAST integrates aerodynamics models, hydrodynamics models for offshore structures, control and electrical system (servo) dynamics models and structural (elastic) dynamics models to allow non-linear aero-hydro-servo-elastic simulation in the time domain. The FAST tool enables the study of a variety of configurations of wind turbines, including two or three-blade horizontal-axis rotor, pitch or stall control, rigid or teeter core, upwind or downwind rotor and lattice or tubular tower. The wind turbine may be modelled on land or offshore on fixed or floating substructures. FAST is based on advanced engineering models derived from fundamental laws, but with necessary simplifications and assumptions, and complemented, where applicable, with computational solutions and test results.
Aerodynamic models use wind-inflow data and solve aerodynamic loads, including dynamic stall, for rotor-wake and blade-element effects. Hydrodynamics models simulate normal or irregular incident waves and currents and offer solutions for hydrostatic, radiation, diffraction and viscous loads on the offshore substructure. Control and electrical system models simulate the

[12] Source : FAST | Wind Research | NREL

logic of the controller, the sensors and actuators of the blade-pitch, generator-torque, nacelle-yaw and other control units, as well as the generator and power-converter components of the electrical drive. The structural-dynamic models apply control and electrical system reactions, apply aerodynamic and hydrodynamic loads, incorporate gravitational loads, and simulate the elasticity of the rotor, drive train and support structure. Coupling between all models is accomplished by means of a modular interface and a coupling (code of glue).

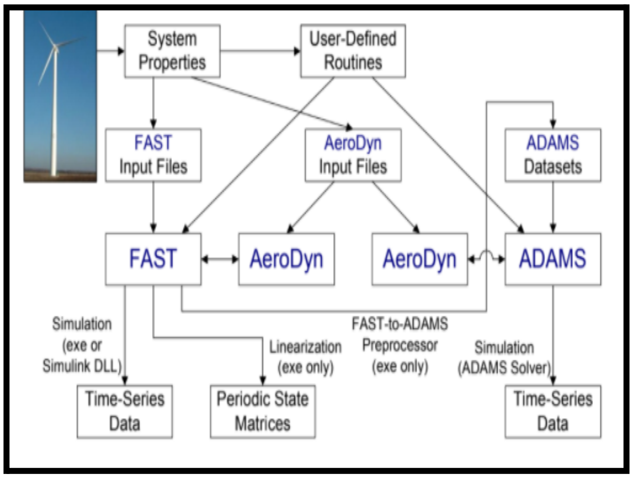

Fig.8 Modes of Operation (suggested by NREL)

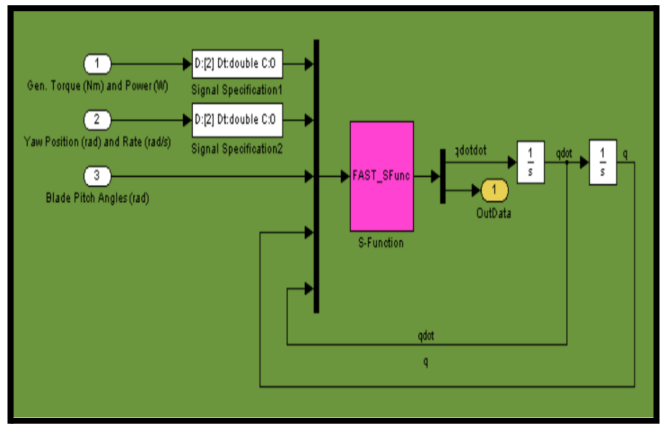

Fig.9 FAST Wind Turbine Block

11.1.1 FAST Input files

FAST uses a primary input file to describe the wind turbine operating parameters and basic geometry.However, the blade, tower, furling, and aerodynamic parameters and wind-time histories are read from separate files. Additionally, input parameters related toFAST linearization and parameters only necessary for creation of ADAMS datasets are read in from separate files. Descriptions of the individual inputs in the various files are provided below. Output Files are discussed in the Output Files chapter.

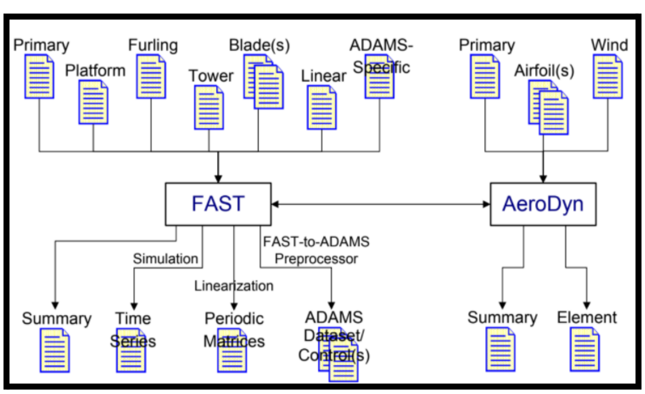

Fig.10 Input and Output Files (FAST)

Test Name	Turbine Name	No. Blades (-)	Rotor Diameter (m)	Rated Power (kW)	Test Description
Test01	AWT-27CR2	2	27	175	Flexible, fixed yaw error, steady wind
Test02	AWT-27CR2	2	27	175	Flexible, start-up, HSS brake shut-down, steady wind
Test03	AWT-27CR2	2	27	175	Flexible, free yaw, steady wind
Test04	AWT-27CR2	2	27	175	Flexible, free yaw, turbulence
Test05	AWT-27CR2	2	27	175	Flexible, generator start-up, tip-brake shutdown, steady wind
Test06	AOC-15/50	3	15	50	Flexible, generator start-up, tip-brake shutdown, steady wind
Test07	AOC-15/50	3	15	50	Flexible, free yaw, turbulence
Test08	AOC-15/50	3	15	50	Flexible, fixed yaw error, steady wind
Test09	UAE VI downwind	2	10	20	Flexible, yaw ramp, steady wind
Test10	UAE VI upwind	2	10	20	Rigid, power curve, ramp wind
Test11	WP 1.5 MW	3	70	1500	Flexible, variable speed & pitch control, pitch failure, turbulence
Test12	WP 1.5 MW	3	70	1500	Flexible, variable speed & pitch control, ECD event
Test13	WP 1.5 MW	3	70	1500	Flexible, variable speed & pitch control, turbulence
Test14	WP 1.5 MW	3	70	1500	Flexible, stationary linearization, vacuum
Test15	SWRT	3	5.8	10	Flexible, variable speed control, free yaw, tail-furl, EOG01 event
Test16	SWRT	3	5.8	10	Flexible, variable speed control, free yaw, tail-furl, EDC01 event
Test17	SWRT	3	5.8	10	Flexible, variable speed control, free yaw, tail-furl, turbulence

Table T.5 - Sample Models Provided with the FAST Archive.

11.1.2 FAST Output files

The program generates one or more output files based on settings in the input file. For time-marching analyses, the primary output file contains columns of time-series data. For linearization analyses, it provides the periodic state matrices of the linearized model. If ADAMSPrep is set to 2 or 3, FAST generates ADAMS dataset files corresponding to the model configuration and analysis settings specified in the FAST input file(s). See the ADAMS Preprocessor for more on this topic. When running FAST within Simulink, the output file names use the root name of the primary input file and append _SFunc to the name. A final file is generated only when the word "PRINT" is found on one or more of the lines defining the blade elements.

FAST certification test #1 for AWT-27CR2 with many DOFs.

Time (sec)	uWind (m/sec)	Azimuth (deg)	TeetDefl (deg)	RootMyc1 (kN·m)	RootMxc1 (kN·m)	RotTorq (kN·m)	YawBrMzn (kN·m)	TTDspFA (m)
10.000	1.039E+01	1.180E+01	1.031E+00	3.533E+01	2.039E+01	3.613E+01	-2.280E+00	4.922E-02
10.020	1.039E+01	1.831E+01	9.697E-01	3.642E+01	2.085E+01	3.558E+01	-1.996E+00	4.920E-02
10.040	1.039E+01	2.482E+01	8.946E-01	3.632E+01	2.235E+01	3.525E+01	-2.426E+00	4.920E-02
10.060	1.039E+01	3.134E+01	8.081E-01	3.538E+01	2.447E+01	3.514E+01	-3.286E+00	4.920E-02
10.080	1.039E+01	3.785E+01	7.116E-01	3.473E+01	2.672E+01	3.517E+01	-4.282E+00	4.918E-02
10.100	1.039E+01	4.436E+01	6.067E-01	3.503E+01	2.868E+01	3.526E+01	-5.124E+00	4.913E-02
10.120	1.039E+01	5.088E+01	4.943E-01	3.604E+01	3.011E+01	3.541E+01	-5.681E+00	4.906E-02
10.140	1.039E+01	5.739E+01	3.751E-01	3.707E+01	3.110E+01	3.565E+01	-5.993E+00	4.900E-02
10.160	1.039E+01	6.391E+01	2.498E-01	3.759E+01	3.191E+01	3.600E+01	-6.148E+00	4.897E-02
10.180	1.039E+01	7.042E+01	1.198E-01	3.769E+01	3.271E+01	3.642E+01	-6.184E+00	4.896E-02
10.200	1.039E+01	7.694E+01	-1.301E-02	3.777E+01	3.353E+01	3.684E+01	-6.121E+00	4.896E-02
10.220	1.039E+01	8.345E+01	-1.463E-01	3.813E+01	3.424E+01	3.720E+01	-5.908E+00	4.895E-02
10.240	1.039E+01	8.997E+01	-2.775E-01	3.868E+01	3.465E+01	3.745E+01	-5.546E+00	4.893E-02
10.260	1.039E+01	9.649E+01	-4.041E-01	3.916E+01	3.468E+01	3.764E+01	-5.027E+00	4.892E-02
10.280	1.039E+01	1.030E+02	-5.241E-01	3.939E+01	3.431E+01	3.777E+01	-4.365E+00	4.892E-02
10.300	1.039E+01	1.095E+02	-6.357E-01	3.942E+01	3.365E+01	3.787E+01	-3.590E+00	4.895E-02
10.320	1.039E+01	1.160E+02	-7.378E-01	3.945E+01	3.276E+01	3.791E+01	-2.757E+00	4.899E-02
10.340	1.039E+01	1.226E+02	-8.296E-01	3.959E+01	3.170E+01	3.791E+01	-1.938E+00	4.902E-02
10.360	1.039E+01	1.291E+02	-9.103E-01	3.985E+01	3.045E+01	3.788E+01	-1.210E+00	4.905E-02
10.380	1.039E+01	1.356E+02	-9.793E-01	4.009E+01	2.902E+01	3.783E+01	-6.359E-01	4.907E-02
10.400	1.039E+01	1.421E+02	-1.036E+00	4.028E+01	2.743E+01	3.777E+01	-1.897E-01	4.909E-02
10.420	1.039E+01	1.486E+02	-1.079E+00	4.039E+01	2.570E+01	3.772E+01	1.200E-01	4.912E-02
10.440	1.039E+01	1.551E+02	-1.107E+00	4.055E+01	2.384E+01	3.768E+01	2.992E-01	4.914E-02
10.460	1.039E+01	1.617E+02	-1.121E+00	4.054E+01	2.179E+01	3.762E+01	2.539E-01	4.917E-02

Fig.11 Sample output file.

11.2 AeroDyn

AeroDyn is an aerodynamics software library (module) for use by designers of horizontal-axis wind turbines.

AeroDyn is a time- domain wind turbine aerodynamics module that has been coupled into the FAST multi-physics engineering tool. The module equally applies to the hydrodynamics of marine hydrokinetic (MHK) turbines. AeroDyn calculates aerodynamic loads on both the blades and tower. It can also be driven as a standalone code to compute wind turbine aerodynamic response uncoupled from FAST. This documentation pertains to the newest release of AeroDyn version 15 and newer, which represents a complete overhaul from earlier versions of Aerodynamics. Aerodynamic imbalances are possible through the use of geometrical.

The aerodynamic models in AeroDyn include:

1. Rotor wake/induction
2. Blade airfoil aerodynamics
3. Tower influence on the fluid local to the blade nodes
4. Tower drag.

[13]

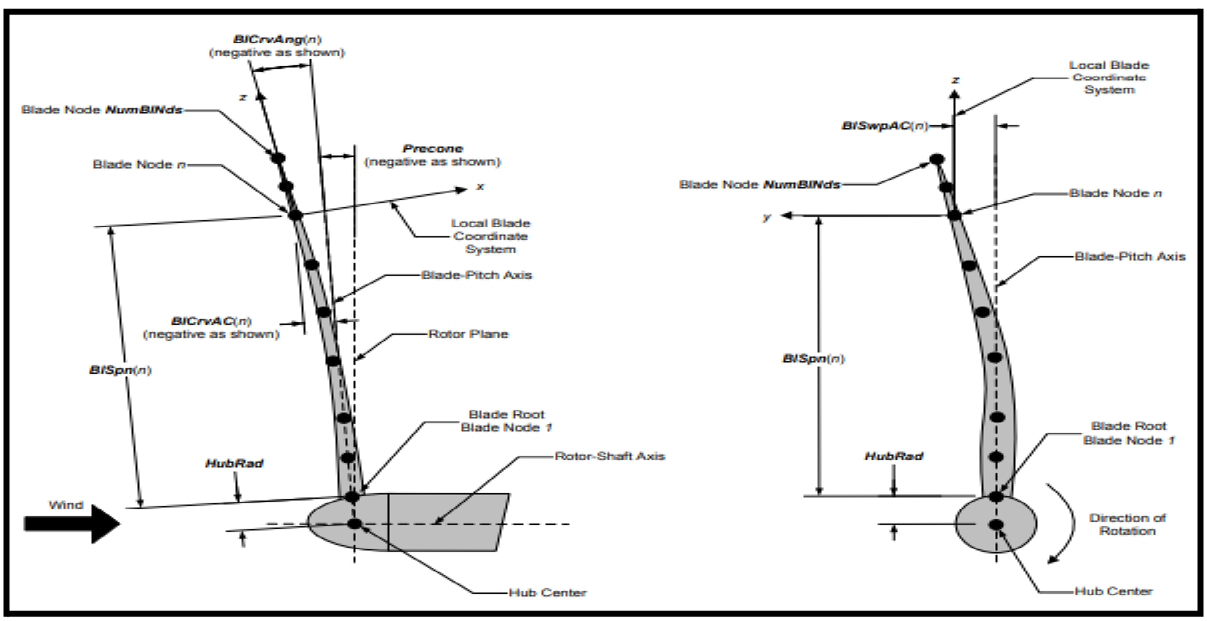

Fig.12 AeroDyn Blade Geometry – Left: Side View; Right: Front View (Looking Downwind)

[13] Source : [aerodyn-manual.pdf (nrel.gov)]

11.3 MATLAB/SIMULINK

Simulink® is a multi-domain simulation and model-based design environment. Dynamic and built-in systems. Provides an immersive graphical environment and Customizable set of block libraries that can be designed, simulated, implemented and tested A number of time-variable systems, including communications, sensors, signal processing, Video processing and processing of images. Add-on products to extend the Simulink programme Multiple modelling domains, as well as tools for design, implementation, and Tasks of verification and confirmation.Simulink is integrated with the MATLAB® system, providing Immediate access to a wide range of resources capable of designing, analysing and analysing algorithms. Visualize simulations, build scripts for batch processing, configure modelling Climate, and define signal, parameter, and test data. The MatLab Simulink Toolbox Applications for wind turbines have been built during the project. This toolbox includes Models for the main components of the wind turbine design. Figure.13 displays the MatLab data Toolbox and Wind Turbine Block Package v2.0 is the newest Wind Modeling Toolbox System.

The main libraries from this Toolbox are: Mechanical Components, Electrical Machinery, Power Converters, Common Blocks, Transformations, Measurements and Control. The Mechanical Components library contains: wind models, aerodynamic models of the wind turbine rotor, and different types of the drive train model. The Control library contains blocks such as: anti wind-up PI-controller, a maximum power point tracker block based on a look-up table obtained from a wind turbine characteristics.

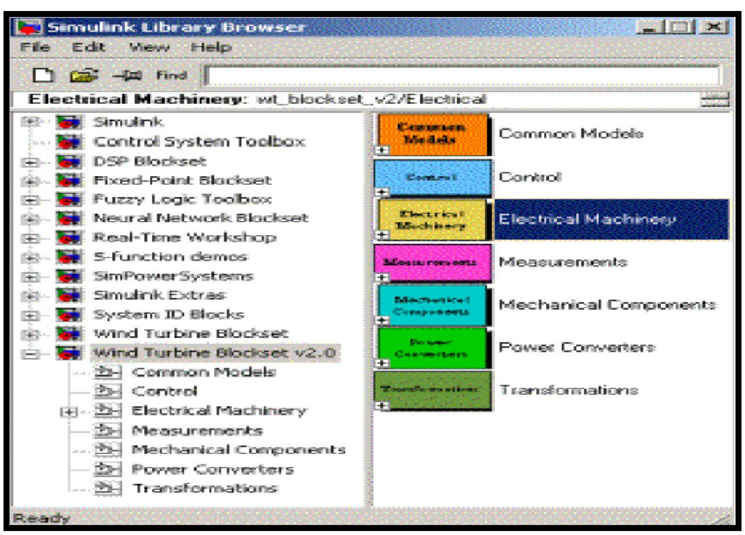

Fig.13 MATLAB/SIMULINK Toolbox (for Wind Turbine Simulation)

11.3.1 Wind Energy System Model And Component[14]

To develop the wind energy system above, MatLab Simulink Beta Wind toolbox was used. This toolbox has all components of the wind energy system which are wind turbine, drive train, voltage source, and induction machine as generator and P&Q measurement. Mat file block used as the input source in order to load the real data fromMat-file. Each component of the model has its own parameter by double clicking at each block component to set the parameter as needed. After simulating the model, the output power and waveform has been seen through the scope block. Figure 14 shows the wind energy system circuit designed using MatLab Simulink software.

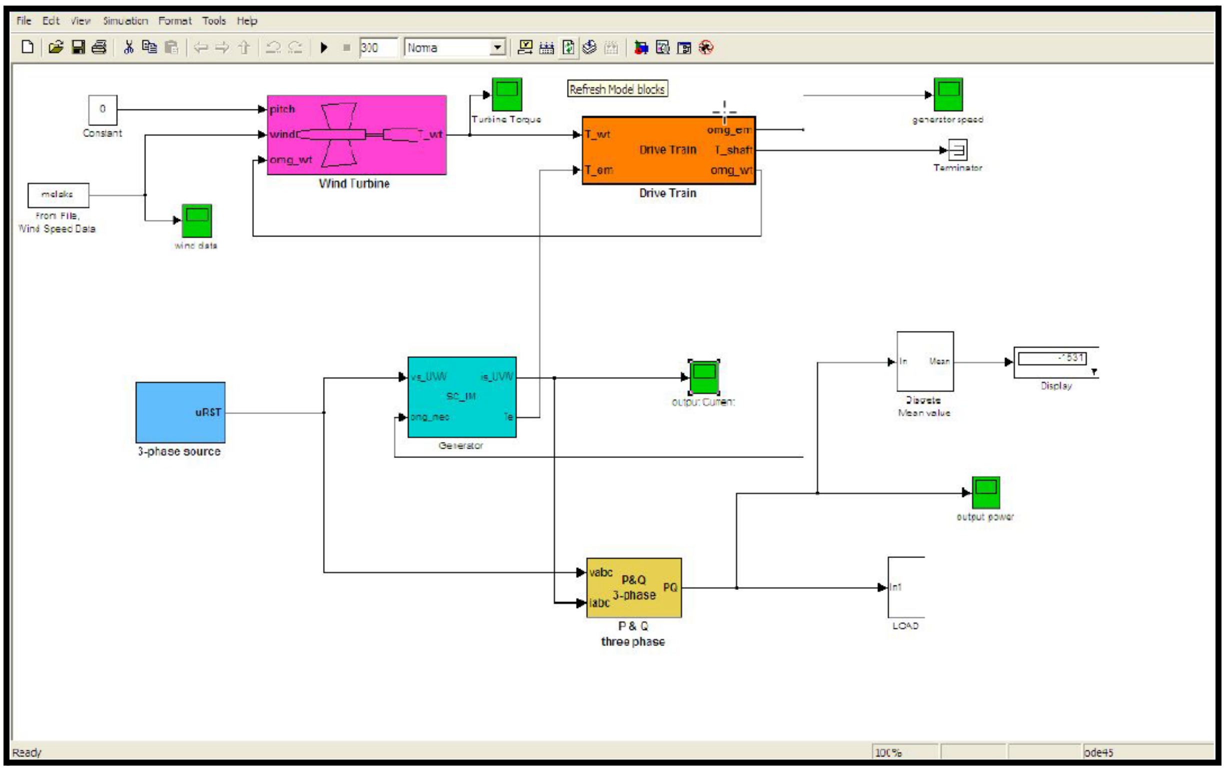

Fig.14 Wind system model

[14] Source : *Emezuru Uzor Steve*, "MODELLING OF SMALL WIND ENERGY SYSTEM"

Wind turbine components consist of parameters that can be set with their own value such as blade's radius, air density, cut in speed and cut out speed. The output produced from the wind turbine component is torque.

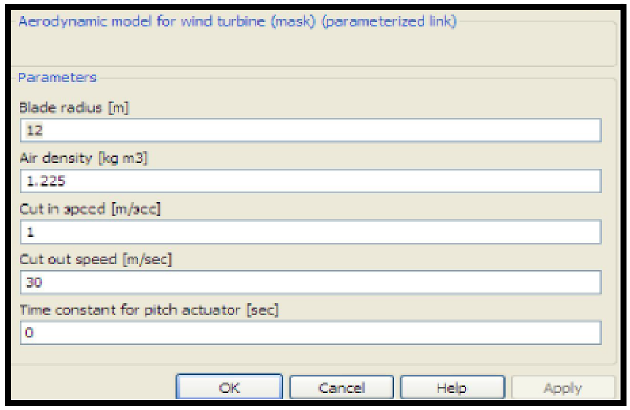

Fig.15 Wind Turbine Block

Drivetrain component used to produce speed for generators operate.Figure .16 shows drivetrain block and the parameter that can be set during the simulation process.

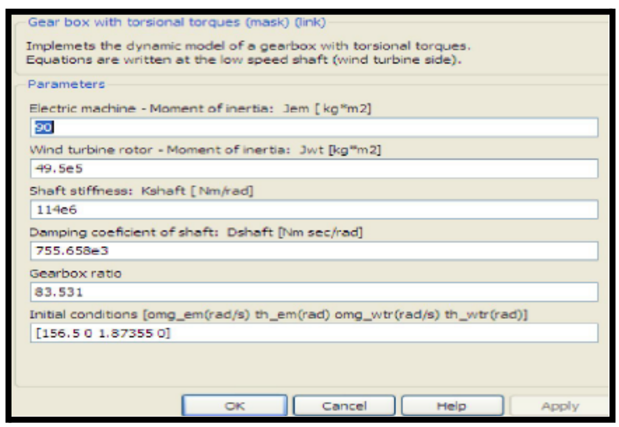

Fig.16 DriveTrain Block

Squirrel Cage Induction Machine operates as a generator or motor with delta or star connection and the output is the current and torque. This component needs 240V input voltage and speed generated by the drivetrain to operate. The block and parameter of this Induction Machine had to be set as a generator with delta connection.

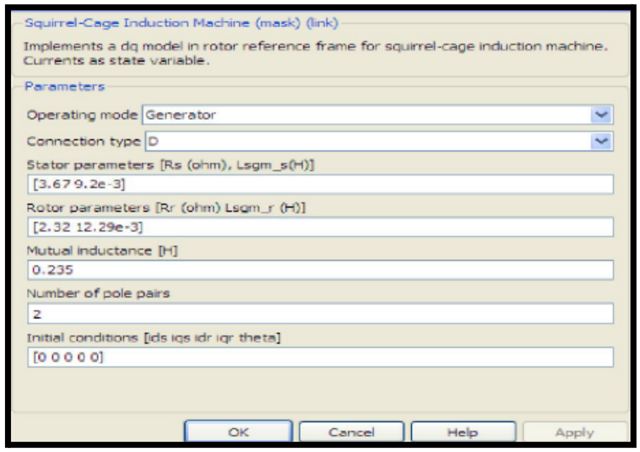

Fig.17 Squirrel Cage Block

P&Q block component used to measure the value of active power (P) and reactive power (Q) in three phases with input of three phase voltage and three phase current.

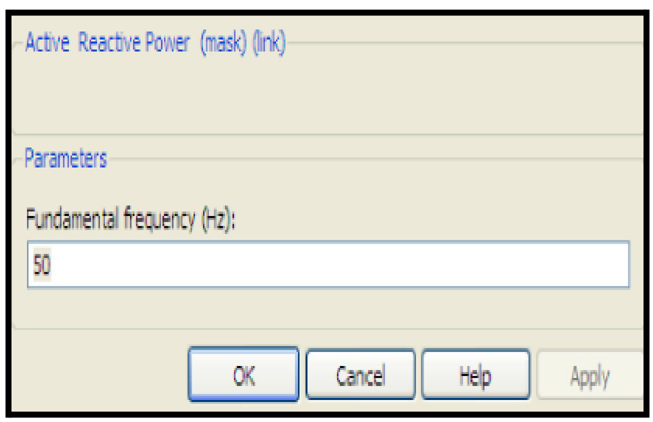

Fig.18 P&Q Block

All the components above were important in order to design a basic model of wind energy system. MatLab Simulink had been chosen as the suitable platform to model this wind energy system. All block already designed from complex math function and inorder to use this model, the value of parameter needs to be set using own value suitable with the model that would be simulated.

12 CONCLUSION

1. Data available at Unitron Energy Pvt. Ltd is enough to run a simulation on Simulation Engine , yet not complete to run full-scale simulation to predict performance on FAST or MATLAB.
2. Performance of the SWT was not available and is not included in the report.
3. Design Standards as described by IEC for Small Wind Turbines is important to take into account before designing and simulating a Small Wind Turbine.
4. FAST is a good platform for simulation of Wind Turbines with data available and to describe the performance of the SWT.
5. MATLAB/SIMULINK blocks are initial building steps of simulation of small wind turbines.
6. A fully functional Small Wind Turbine (with optimal performance) can be used to power a household/small-building.
7. Experimental simulation will be (after the situation gets better) performed for cross-verifying the simulation results.

13 GLOSSARY

- CAD - Computer Aided Design
- CAM - Computer Aided Machining
- CAE - Computer Aided Engineering
- HAWT - Horizontal Axis Wind Turbine
- SWT- Small Wind Turbine
- VAWT - Vertical Axis Wind Turbine
- DC - Direct Current
- AC - Alternating Current
- NREL - The National Renewable Energy Laboratory
- MHK - Marine HydroKinetic

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