A
Dissertation
Report On

HIGH ALTITUDE WIND TURBINE

Submitted in partial fulfillment of the requirements for the
degree **BACHELOR OF ENGINEERING** By

KHAN MOHD SARFARAZ
MANSURI MOHD MADNI
KHAN QAIS
HAJI ALTAMAS

Under the guidance of

MR. IFTEKAR PATEL

AFFILIATED TO
UNIVERSITY OF MUMBAI
ACADEMIC YEAR - 2018-2019

A Dissertation
Report On

HIGH ALTITUDE WIND TURBINE

Submitted to:
MR. IFTEKAR PATEL
Submitted by:

NAME	ROLL NO
KHAN MOHD SARFARAZ	16DEE60
MANSURI MOHD MADNI	16DEE64
KHAN QAIS	16DEE61
HAJI ALTAMAS	16DEE57

Prof.Mr.IFTEKAR PATEL
(GUIDE)

Prof. Mr S. KALEEM
(H.O.D)

Dr. A.R. HONNUTAGI
(DIRECTOR)

ACKNOWLEDGEMENT

The satisfaction and euphoria that accompany the successful completion of any task would be incomplete without the mention of the people who made it possible, whose constant guidance and encouragement crowned our efforts with success.
We consider it a privilege to express our sincere gratitude towards our guide, Prof. IFTEKAR PATEL for the help, guidance and encouragement, he provided during this project successfully and his suggestions.

We extend our thanks to Head of the Department Prof SYED KALEEM who have encouraged us throughout the course. We all are indebted to the entire team of the Department of Electrical Engineering. They supported us with scientific guidance, advice and encouragement, they were always helpful and enthusiastic and this inspired us all in this work.

Also, we would like to express our deep regards and gratitude to the director Dr ABDUL RAZAK HONNUTAGI who was a tremendous source of inspiration and of invaluable help in canalizing our efforts in the right direction. For providing us with the necessary facilities to carry out our project work.

CERTIFICATE

This is to certify that the report entitled “HIGH ALTITUDE WIND TURBINE” submitted by KHAN MOHD SARFARAZ, MANSURI MOHD MADNI, KHAN QAIS, HAJI ALTAMAS in partial fulfillment of the requirement for the award of Bachelor of engineering in “ELECTRICAL ENGINEERING” is an authentic work carried under my supervision and guidance.

Date:

DECLARATION

I declare that this written submission represents my ideas in my own words and where others' ideas or words have been included, I have adequately cited and referenced the original sources. I also declare that I have adhered to all principle so academic honesty and integrity and have not misrepresented or fabricated or falsified any idea/data/fact/source in my submission. I understand that any violation of the above will be cause for disciplinary action by the Institute and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been taken when needed.

DATE …………………….
PLACE…………………….

(NAME OF THE STUDENT)

KHAN MOHD SARFARAZ
MANSURI MOHD MADNI
KHAN QAIS
HAJI ALTAMS

TABLE OF CONTENTS

ABSTRACT

The concept of High Altitude Wind Power (HAWP) is to supply a clean energy at low cost and high capacity factor than the Conventional Wind Power (CWP) system. This is one of the new technologies deployed for harvesting high altitude wind power using air-borne wind turbine-cum electric generator supported by light gas filled blimp/aerostat has been proposed in the project. An air-borne wind turbine at high altitude extracts kinetic energy from high speed streamlined wind using buoyancy provided by the blimp. Using a suitable power electronic converter (PEC), harvested electrical power is transmitted to the ground by using a tether. Blimp is tethered to the ground and provides mechanical strength to hold the blimp and the

same tether consisting of electrical conductors is used for transmitting the generated electrical power.

The project out lines major components used for harvesting high altitude wind power. Transmission of the electrical power at medium voltage DC reduces the transmission loss and volume of the conducting cable. The optimal transmission voltage level that gives minimum weight of the tether has been calculated for a given power level. The proposed HAWP system requires high power density PEC, which converts low voltage AC to medium voltage DC in an air borne unit and a ground based PEC that transforms medium voltage DC to distribution level grid voltage. Further, it also proposes the ground based grid-side PEC for distributed grid interface. In addition, comparative study between conventional wind energy harvesting system and high altitude wind energy harvesting system shows that high altitude wind power is better in terms of capacity factor, Cost of Electricity (COE), ease of construction, and power density than conventional wind power generatingsystem.

CHAPTER 1.

INTRODUCTION

1.1 Overview of High Altitude Wind Power

Solar and wind have emerged as two major sources of renewable energy in the last two decades [1]. Solar power generating system has a lower power density (150-250 W=m^2) as compared to the power density of conventional thermal power generating system (1000-1200 W=m^2). Whereas, a conventional wind power (CWP) generating system requires huge civil constructions and suffers from low capacity factor (30-35%) [2] (Capacity factor is defined as the ratio of actual output energy over a period of time to potential output energy, if it were possible for it to operate at the rated power indefinitely) [3]. Due to these reasons, the penetration of renewable energy sources has not significantly increased in present power market [1]. However, true potential of wind power could be extracted using high altitude wind. The speed of wind increases with increase in the altitude from the ground surface was expressed in equation1.1 (a). In addition at higher altitudes, the wind flow is streamlined and consistent in nature. Since the wind power is proportional to the cube of the wind speed and directly proportional to turbine area, A_T, as mentioned in equation 1.1(a) a large amount of electrical power can be extracted with reduced turbine size.

$$P_{air} = \frac{1}{2}\rho C_P A_T v^3$$

$$v(h) = v_0 \left[\frac{ln(\frac{h}{z_0})}{ln(\frac{h_0}{z_0})} \right]$$

Equation 1.1 (a)

P_{air} is rated power of HAWP generating system, A_T is swept area of rotor blade in m^2, $_0$ is the known velocity of wind in m=s at earth surface, (h) is the speed of wind in m=s at an altitude h in m above sea level, $_0$ is the known wind speed in m=s at a known altitude h_0 above sea level in m, C_P is the coefficient of power extraction by the turbine, and z_0 is the Hellman's coefficient of the surface that depends on the terrain.

Power generated by the wind turbine is a function of power coefficient (maximum value of 59.3%), turbine swept area A_T and wind speed v. To increase the generated power in case of conventional wind energy generation, swept area of the turbine can be increased by increasing the diameter of turbine rotor. In contrast, velocity of wind increases with altitude above the earth surface as expressed in equation 1.1 (a). Velocity of wind reaches maximum of about 50m/s at an altitude of 9-10km above sea level. Since wind power is linearly proportional to turbine swept area and proportional to cubic power to velocity of wind, swept area of rotor can be significantly reduced to generate equal amount of power with slight increase in the wind speed. In contrast, velocity of wind increases with altitude above the earth surface as expressed in equation 1.1(a). Velocity of wind reaches maximum of about 50m/s at an altitude of 9-10km above sea level. Since wind power is linearly proportional to turbine swept area and proportional to cubic power to velocity of wind, swept area of rotor can be significantly reduced to generate equal amount of power with slight increase in the wind speed.

CHAPTER 2.

OBJECTIVE AND PROBLEM OVERVIEW

2.1 Objective

Winds at higher altitudes become steadier, more persistent, and of higher velocity. Because power available in wind increases as the cube of velocity (the velocity-cubed law), assuming other parameters remaining the same, doubling a wind's velocity gives $2^3=8$ times the power; tripling the velocity gives $3^3=27$ times the available power. With steadier and more predictable winds, high-altitude wind has an advantage over wind near the ground. Being able to locate HAWP to effective altitudes and using the vertical dimension of airspace for wind farming brings further advantage using high-altitude winds for generating energy.

High-altitude wind generators can be adjusted in height and position to maximize energy return, which is impractical with fixed tower-mounted wind generators.

In each range of altitudes there are altitude-specific concerns being addressed by researchers and developers. As altitude increases, tethers increase in length, the temperature of the air changes, and vulnerability to atmospheric lightning changes. With increasing altitude, exposure to liabilities increase, costs increase, turbulence exposure changes, likelihood of having the system fly in more than one directional strata of winds increases, and the costs of operation changes. HAWP systems that are flown must climb through all intermediate altitudes up to final working altitudes—being at first a low- and then a high- altitude device.

2.2 Problem Definition

- Wind power must still compete with conventional generation sources on a cost basis. Depending on how energetic a wind site is, the wind farm might not be cost competitive. Even though the cost of wind power has decreased dramatically in the past 10 years, the technology requires a higher initial investment than fossil-fueled generators.
- Good wind sites are often located in remote locations, far from cities where the electricity is needed. Transmission lines must be built to bring the electricity from the wind farm to the city. However, building just a few already-proposed transmission lines could significantly reduce the costs of expanding wind energy.
- Wind resource development might not be the most profitable use of the land. Land suitable for wind-turbine installation must compete with alternative uses for the land, which might be more highly valued than electricity generation.
- Turbines might cause noise and aesthetic pollution. Although wind power plants have relatively little impact on the environment compared to conventional power plants, concern exists over the noise produced by the turbine blades and visual impacts to the landscape.
- Turbine blades could damage local wildlife. Birds have been killed by flying into spinning turbine blades. Most of these problems have been resolved or greatly reduced through technological development or by properly siting wind plants.

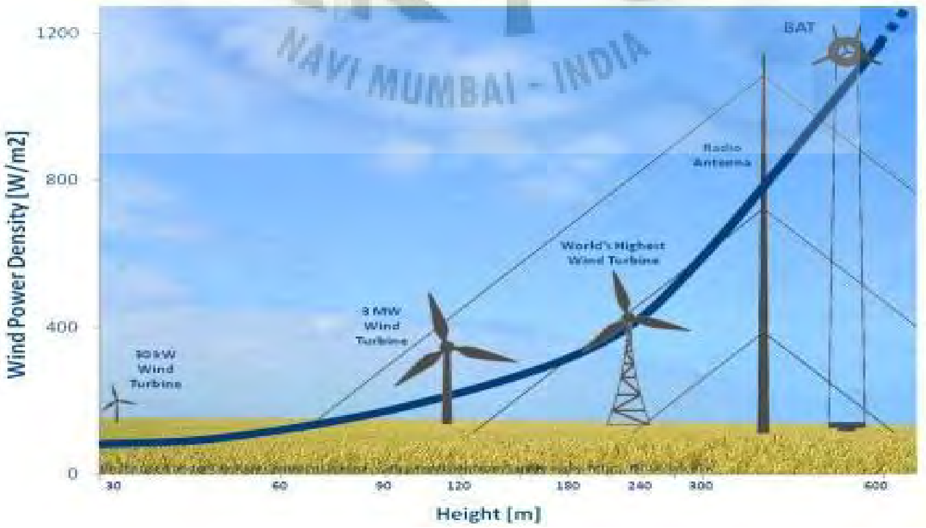

Figure 2.2 (a)

CHAPTER 3.

LITERATURE SURVEY

3.1 Introduction

As per the literature available the paper gives an alternative solution for the depleting energy sources on earth.

3.2 Literature Review

In this section various papers on High Altitude Wind Power are being reviewed.

Jeevan Adhikari, Student Member,IEEE, S.K.Panda, Senior Member, IEEE, Department of Electrical and Computer Engineering,National University of Singapore,Singapore, “Generation and Transmission of Electrical Energy in High Altitude Wind Power Generating System.” This paper represents a high altitude (HAWP) generating system supported by light gas filled blimp/ aerostat that extracts electrical energy from high altitudes streamlined wind. The optimal generation for increasing efficiency and transmission mechanism that gives suitable power to weight ratio (P/W) and the efficiency of the overall system is reviewed .The selected optimal electrical architecture simplifies electric system by transferring power electronic converter from the air borne unit to the ground based system and thereby improves the P/W ratio by a factor of 7% approximately.

Jeevan Adhikari, Student Member,IEEE, S.K.Panda, Senior Member, IEEE, Akshay Kumar Rathore, Senior Member, IEEE,Department of Electrical and Computer Engineering,National University of Singapore,Singapore,”Harnessing High Altitude Wind Power Using Light Gas Filled Blimp.” This paper presents a simple concept of harvesting high altitude wind power using air borne wind turbine cum eletric generators supported by light gas filled blimp / aerostat. Air wind turbine at high altitude extracts kinetic energy from the high speed streamlined wind using buoyancy provided by the blimp. Using a suitable power electronic converter (PEC) extracted electrical power is sent to the ground using a tether. Blimp is tethered to the ground and the same tether is used for electrical transmission as well. This paper outlines major components used for harvesting HAWP. In addition, comparitive study between conventional wind energy harvesting system and high altitude wind energy harvesting system shows HAWP is better in terms of capacity factor, cost of electricity (COE), ease of construction and power density than conventional wind power generation system.

Jeevan Adhikari, Student Member,IEEE, S.K.Panda, Senior Member, IEEE, Akshay Kumar Rathore, Senior Member, IEEE,Department of Electrical and Computer Engineering,National University of Singapore,Singapore,” Modelling, Design and Control OF Grid Connected Converter For High Altitude Wind Power Application.”This paper presents the power electronic converter (PEC) rated at 100 KW HAWP application that converters medium voltage DC to 3 phase distribution level grid voltage. Simulation of the proposed PEC and control of the inverter are carried out using software program PSIM - 9 and MATLAB. The design converter converts the 8 KV DC transmission voltage to 415V grid side voltage with current total harmonic distortion (THD) of about 1.2%.

CHAPTER 4.

BLOCK DIAGRAM

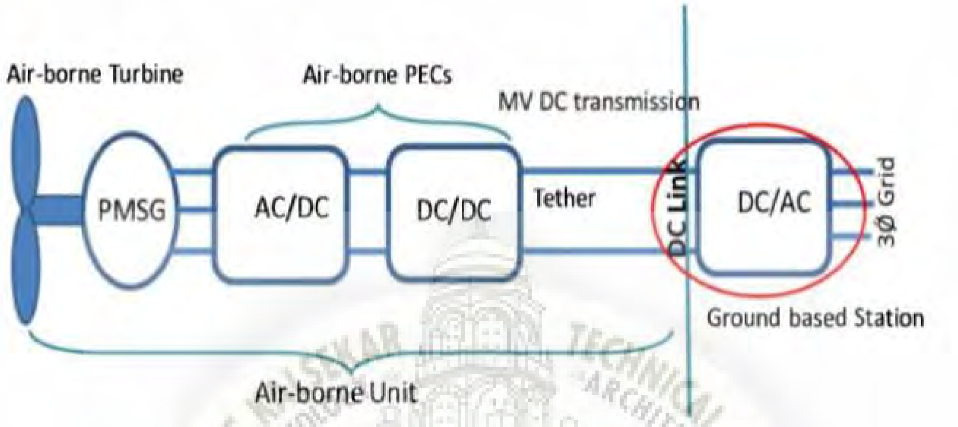

Figure 4

4.1 Air-borne Turbine

An airborne wind turbine is a design concept for a wind turbine with a rotor supported in the air without a tower,[5] thus benefiting from more mechanical and aerodynamic options, the higher velocity and persistence of wind at high altitudes, while avoiding the expense of tower construction,[6] or the need for slip rings or yaw mechanism. An electrical generator may be on the ground or airborne. Challenges include safely suspending and maintaining turbines hundreds of meters off the ground in high winds and storms, transferring the harvested and/or generated power back to earth, and interference with aviation.[7]

Airborne wind turbines may operate in low or high altitudes; they are part of a wider class of Airborne Wind Energy Systems (AWES) addressed by high-altitude wind power and crosswind kite power. When the generator is on the ground,[8] then the tethered aircraft need not carry the generator mass or have a conductive tether. When the generator is aloft, then a conductive tether would be used to transmit energy to the ground or used aloft or beamed to receivers using microwave or laser. Kites and helicopters come down when there is insufficient wind, kytoons and blimps may resolve the matter with other disadvantages. Also, bad weather such as lightning or thunderstorms, could temporarily suspend use of the machines, probably requiring them to be brought back down to the ground and covered. Some schemes require a long power cable and, if the turbine is high enough, a prohibited airspace zone. As of July 2015, no commercial airborne wind turbines are in regular operation.[9]

4.2 PMSG (Permanent Magnet Synchronous Generator)

A permanent magnet synchronous generator is a generator where the excitation field is provided by a permanent magnet instead of a coil. The term synchronous refers here to the fact that the rotor and magnetic field rotate with the same speed, because the magnetic field is generated through a shaft mounted permanent magnet mechanism and current is induced into the stationary armature.

Figure 4.2 (a)

In the majority of designs the rotating assembly in the center of the generator—the "rotor"— contains the magnet, and the "stator" is the stationary armature that is electrically connected to a load. As shown in the diagram, the perpendicular component of the stator field affects the torque while the parallel component affects the voltage. The load supplied by the generator determines the voltage. If the load is inductive, then the angle between the rotor and stator fields will be greater than 90 degrees which corresponds to an increased generator voltage. This is known as an overexcited generator. The opposite is true for a generator supplying a capacitive load which is known as an underexcited generator. A set of three conductors make up the armature winding in standard utility equipment, constituting three phases of a power circuit—that correspond to the three wires we are accustomed to see on transmission lines. The phases are wound such that they are 120 degrees apart spatially on the stator, providing for a uniform force or torque on the generator rotor. The uniformity of the torque arises because the magnetic fields resulting from the induced currents in the three conductors of the armature winding combine spatially in such a way as to resemble the magnetic field of a single, rotating magnet. This stator magnetic field or "stator field" appears as a steady rotating field and spins at the same frequency as the rotor when the rotor contains a single dipole magnetic field. The two fields move in "synchronicity" and maintain a fixed position relative to each other as they spin.[10]

4.3 Air-borne Power Electronic Converters

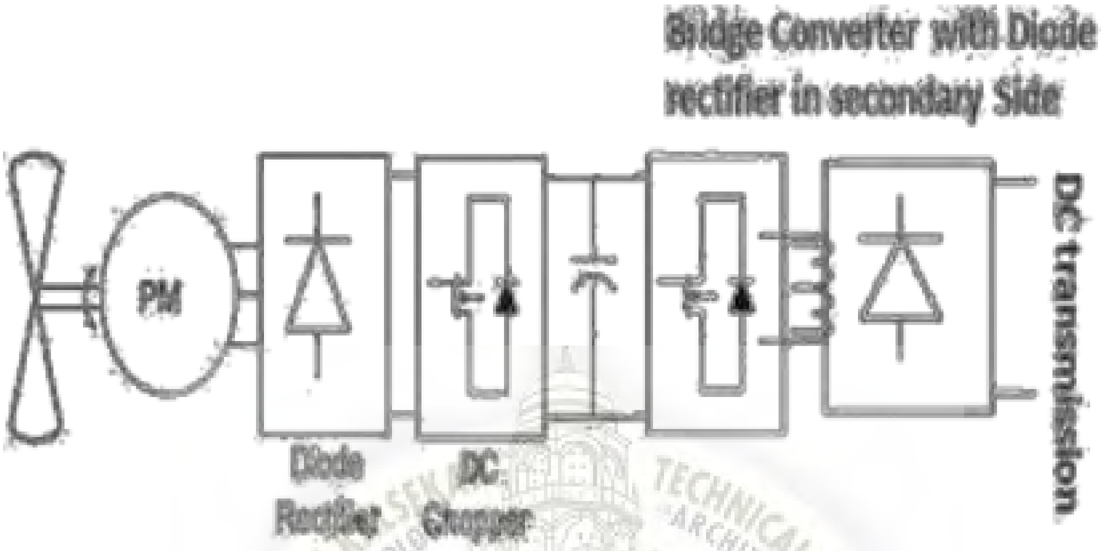

Figure 4.3 (a)

Permanent magnet synchronous generator (PMSG) gives better power to weight ratio in HAWP generating system [11]. The generated AC voltage needs to be converted into optimal medium voltage DC for efficient transmission. So, the power electronic converter is designed to convert low voltage AC to medium voltage DC efficiently. Flying electric generator supported by a blimp has an electric machine that works in generation mode only, so the bidirectional power flow is not a requirement. The proposed power electronic converter for harvesting HAWP consists of diode bridge rectifier, DC chopper at the generator side and full bridge isolated DC-DC converter in the transmission side shown in Fig. Since the transmission voltage is high, diodes are connected in series the secondary side of isolated DC-DC converter. Boost chopper is used here for extracting the maximum power from the given wind condition, controlling the power factor at the generation side (for single phase AC power generation) and maintaining a constant DC link voltage for DC-DC converter, that allows constant duty cycle switching of DC- DC converter.

Three phase rectifier gives rectified output to a DC chopper which is controlled using inductor current control. DC chopper cannot make unity power factor at generation side for three phase generation but diode rectifier output current is controlled to get maximum power from the given wind condition and also maintains constant DC link voltage at calculated reference value. Isolated DC-DC converter is used to step up constant DC link voltage to optimal medium voltage DC as calculated in earlier subsection. Output voltage for DC transmission as a function of HF transformer turns ratio is expressed in equation below :

$$V_o = nV_{dc} D_{eff}$$

Equation 4.3 (a)

Where V_{dc} is DC link voltage, n is transformer turns ratio and D_{eff} is effective duty cycle on square wave pulse. Stepped up DC voltage is transmitted through an electromechanical tether to the ground based power station and the ground based power station transforms the high altitude wind power to a suitable form.

4.4 Tether

Tether used for harvesting HAWP has two primary objectives:

1) To hold the blimp at a given altitude.
2) Transmit the power efficiently to the ground based station.

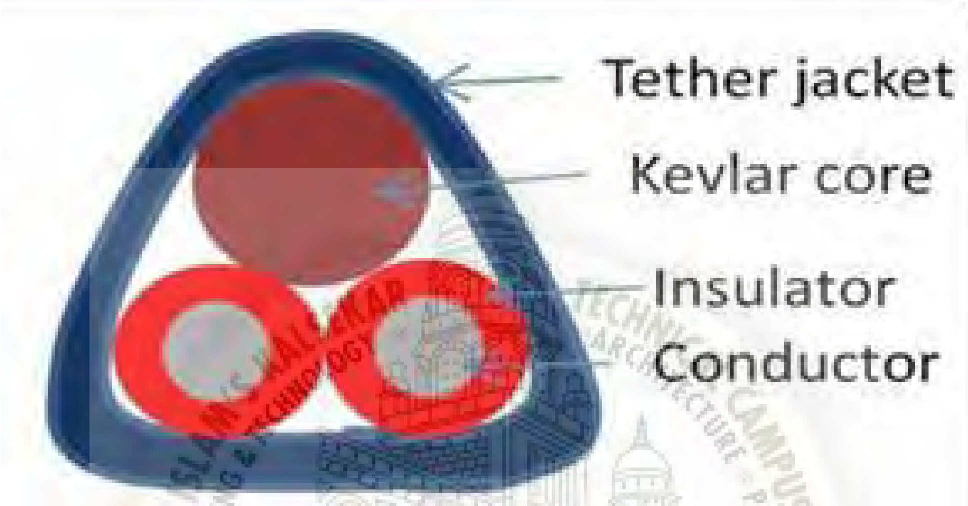

Figure 4.4 (a)

Fig shows the proposed tether for harvesting HAWP. The tether should have sufficient tensile strength and flexibility to support the air-borne unit. It is additionally used to drag the air-borne unit to the ground based station. Tether should offer minimum resistance to the electric current flowing through it to minimize the overall transmission loss. In addition, it should be physically resistant to radiation, humidity and other atmospheric pollution.

Major portion of the weight of an air-borne unit in HAWP system is contributed by tether. So, the weight of tether should be minimized without compromising the transmission efficiency. DC transmission gives better power to weight ratio than AC transmission and requires no compensation. So, DC transmission is always preferred over AC transmission for harvesting high altitude wind power [11]. In order to reduce the conductor weight, the transmission voltage is increased, but extra increment in transmission voltage may lead to increase in weight due to the increased thickness of insulation layer. So, optimal transmission voltage needs to be determined to get the minimum weighted tether. Equation below gives the relation of transmission voltage and conductor radius and equation provides the relation between transmission voltage and the thickness of dielectric.

$$r_c = \sqrt{\frac{P_{rated}L}{(1-n)\sigma_c \pi V^2}}$$

$$t_{ins} = r_c \exp[\frac{2V}{Sr_c}] - r_c$$

Equation 4.4 (a)

where r_c is conductor radius, P is power level of transmission system, L is length of tether, n is opted transmission efficiency, $_c$ is conductivity of the conductor and V is transmission volt-age level, t_{ins} is thickness of insulating layer, S is dielectric strength of insulator.

Overall weight of a cable depends on the weight of conductor and weight of dielectric used for insulator. Equation 4.4 (b) gives the weight of cable inside the tether as the function of transmission voltage.

$$W_{cab} = \rho_{con}\pi r_c^2 L + \rho_{di}\pi L t_{ins}(2r_c + t_{ins})$$

Equation 4.4 (b)

Where W_{cab} is the weight of a single cable, t_{ins} is the thickness of insulator, $_{con}$ and $_{in}$ are the density of conductor and insulator respectively.

4.5 Ground Based Station (Grid Side)

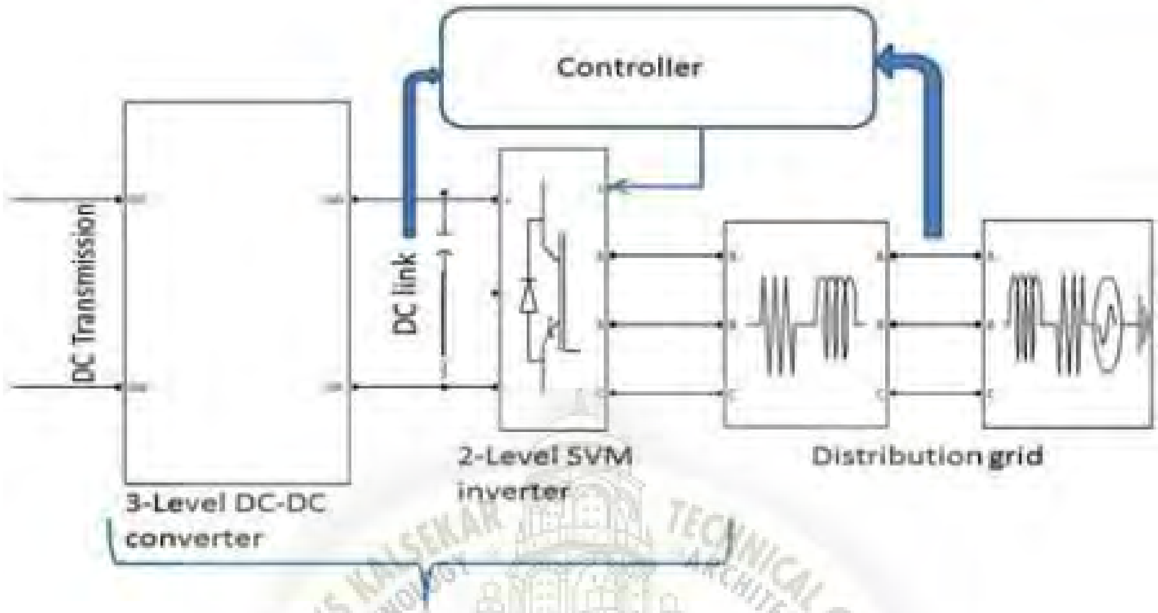

Figure 4.5 (a)

The schematic diagram of grid side converter is shown in Fig. Modelling of the grid side converter is carried out by modelling the DC link side and grid connected inverter.

DC link capacitor stabilizes the DC link voltage. Current flowing through the DC link capacitor is given by:

$$C\frac{dv_{dc}}{dt} = i_s - i_g$$

Equation 4.5 (a)

Where Vdc is DC link voltage, is current of DC link after buck converter, ig is current of DC link at the grid side and C is the DC link capacitance. Considering that the grid side inverter does not consume power.

Where Ps is generated output power by an air-borne electric generator which is equal to electromagnetic power (Pe = Tews), Te is electrical torque of the generator, Ws is angular frequency of rotation of the air-borne turbine. The voltage equation per phase between the inverter leg and the grid is given by :

$$C\frac{dv_{dc}}{dt} = \frac{P_s}{v_{dc}} - i_g$$

Equation 4.5 (b)

$$e_a = v_a + iR_a + L_a\frac{di_a}{dt}$$

Equation 4.5(c)

Where ea is grid side phase voltage, Va is output voltage of one of the leg of inverter, La and Ra are equivalent series inductance and resistance between grid and inverter leg per phase.

Similar voltage equations can be written for phase-b and phase-c as expressed in equation 4.5 (c). The stationary vectors are transformed into rotating d - q frame by park transformation. Three phase grid voltages (ea, eb and ec) are represented by single rotating voltage es, which rotates at angle e along the rotating frame. es is aligned along d-axis of rotating frame which results the q- axis component of rotating voltage zero. The d - q transformation of three voltage equations results the following equations:

$$v_d = L_d \frac{di_d}{dt} + R_s i_d - w_r L_q i_q + e_s$$

$$v_q = L_q \frac{di_q}{dt} + R_s i_q + w_r L_d i_d$$

Equation 4.5 (d)

Where V_d and V_q are quadrature axes voltages of the inverter, L_d and L_q are the inductances in d - q axes, id and i_q are the currents in d - q frame, Wr is angular frequency of grid.

Active power flow through the inverter is controlled by d- axis current control and reactive power is controlled by q-axis current. The equations for active (P) and reactive (Q) power are given by :

$$P = 1.5(V_d I_d + V_q I_q) = 1.5 V_d I_d$$

$$Q = 1.5(V_d I_q - V_q I_d) = 1.5 V_d I_q$$

Equation 4.5 (e)

Thus, P can be controlled by I_d and Q can be controlled by I_g.

CHAPTER 5.

Doubly Fed Induction Generator (DFIG)

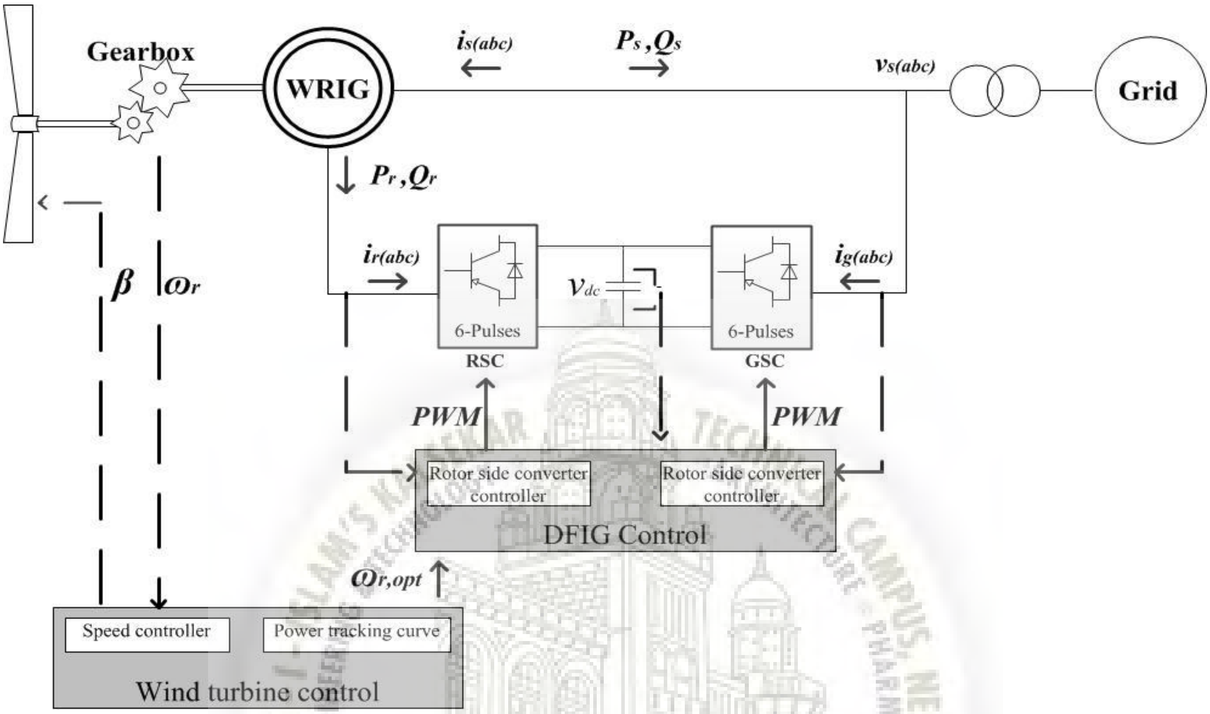

Figure 5

The doubly-fed induction generator (DFIG) system is a popular system in which the power electronic interface controls the rotor currents to achieve the variable speed necessary for maximum energy capture in variable winds. Because the power electronics only process the rotor power, typically less than 25% of the overall output power, the DFIG offers the advantages of speed control with reduced cost and power losses. This PLECS demo model demonstrates a grid-connected wind turbine system using all of PLECS' physical modeling domains. The system model includes a mechanical model of the blades, hub, and shaft, a back-to-back converter including thermal loss calculations, a magnetic model of the three-phase transformer, and the transmission line and grid.

5.1 Wind Profile Model

The basic wind profile is generally taken from meteorological department at 10 meters from the ground level. In this model, the basic wind profile can be estimated by power law profile as shown below :

$$v = v_o\left(\frac{h}{h_o}\right)^{\alpha(v_o,h_o)}$$

Equation 5.1 (a)

where v and vo are the desired and reference wind speed in meter per second. h and ho are the desired and reference elevation of wind tower horizontally in meters, and α is the power law exponent. α is a variable quantity and can be approximated using the correlation power law as a function of height and velocity as given below :

$$\alpha(v_o,h_o) = \frac{0.37 - 0.088 In(v_o)}{1 - 0.088 In\left(\frac{h_o}{10}\right)}$$

Equation 5.1 (b)

5.2 DFIG Model

The DFIG model uses wound rotor induction generator (WRIG), which controls the frequency and voltage amplitudes separately using rotor winding with back-to-back power converter, to maximize the variable speed operation. The stator winding is directly coupled with distributed power grid through a transformer The scaling of induction generator power follows the power turbine rating. To size the point of common coupling (PCC) of wind turbine, define the bus voltage level of the distributed power grid, and then select the appropriate capacity of the generator apparent power as stated in. In this model, the grid bus voltage is 230 V. DFIG electrical data are technically presented in result section.

5.3 Reactive Power Control Strategy

Voltage-reactive power control strategy is one of the main useful assessments for the power quality and power system stability issues. In order to eliminate the negative effect of absorbing reactive power produced from WTG, reactive power control is used for providing the appropriate amount of volt-ampere reactive (VAR) and to maintain steady voltage and power factor. In this paper, Back-to-Back power converter system is modeled for the reactive power compensation. The back-to-back control scheme of a DFIG-based wind generator system is comprised by DC link to enable bidirectional power flow. The two-level PWM converters (rotor side converter and grid side converter) control schemes are depicted in Fig and can be expressed as :

$$V_{s(abc)} = R_s i_{s(abc)} + \frac{d\psi_{s(abc)}}{dt}$$

$$V_{r(abc)} = R_r i_{r(abc)} + \frac{d\psi_{r(abc)}}{dt}$$

Equation 5.3 (a)

where $v_{s(abc)}$ and $v_{r(abc)}$ are the stator and rotor voltages, $R_{s(abc)}$ and $R_{r(abc)}$ are the stator and rotor resistance, $i_{s(abc)}$ and $i_{r(abc)}$ are the stator and rotor current, and ψs(abc) and $\psi_{r(abc)}$ is the stator and rotor flux linkage.

5.3.1 Rotor Side Converter (RSC) Control

The RSC controls the active and reactive power independently using space vector control. The space vector control applies synchronously rotating reference frame transformation (d-q axis) for controlling the inrush rotor current. The direct- quadratic axes use the stator-flux vector position to orient the reference frame of the rotor quantities. Therefore, the stator active (Ps) and reactive (Qs) power quantities are implemented in as shown .

$$Q_s = \frac{3}{2}\left(\frac{v_s^2}{L_s \omega_s} - \frac{v_s L_m}{L_s} i_{rd\_ref} \right)$$

$$P_s = -\frac{3}{2} v_s \frac{L_m}{L_s} i_{rq\_ref}$$

Equation 5.3.1 (a)

where i_{rd_ref} is the reference for the direct rotor current and i_{rq_ref} is the reference for the quadrature rotor current. According to eqn, the reactive power can be controlled via i_{rd_ref} whereas the active power control follows the power tracking operation, which uses optimum rotational speed via i_{rq_ref}.

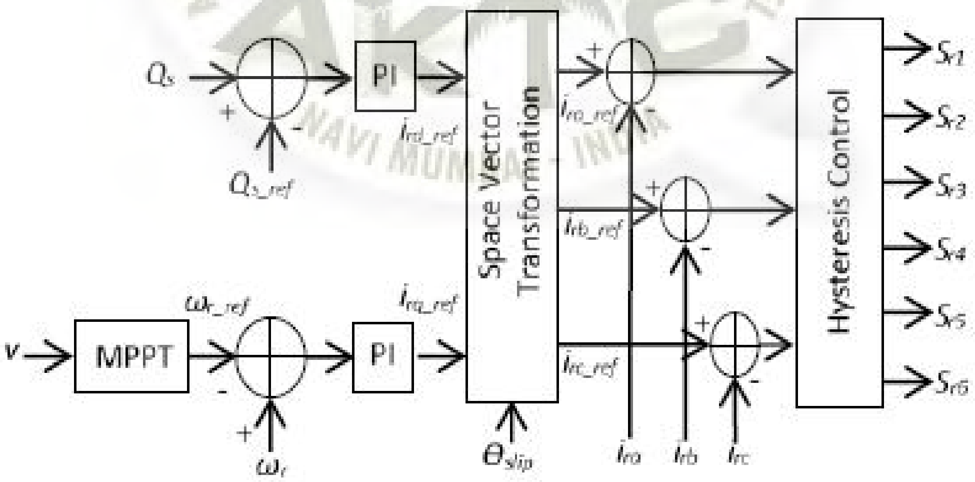

Figure 5.3.1 (a)

To established the three-phase reference rotor current ($i_{r(abc-ref)}$) for PWM RSC firing switches, PI controller is involved to eliminate the possible error between the generated rotor speed (ω_r) and reference rotor speed (ω_{r_ref}) as well as generated reactive power (Q_s) and reference reactive power (Q_{s_ref}). In addition, i_{rq_ref} and i_{rd_ref} require vector space transformation via slip angle (Θ_{slip}).

The reference $i_{r(abc-ref)}$ and actual $i_{r(abc)}$ rotor current are logically compared using hysteresis control in order to generate the PWM firing signals required for RSC as shown in Fig. As a result, the decoupling between the active and reactive power is fulfilled.

CHAPTER 6.

SIMULATION RESULT

This section evaluates and discusses about wind interaction point, control strategy performances, and steady state behavior. The control strategy represents results of the MPPT control and Back-to-Back converter system. The steady state behavior considers voltage magnitude profiles. The simulation is performed using PSCAD/EMTDC. The results obtained are plotted and explained accordingly.

Sr. No	Parameter Name	Expression
1.	Stator Frequency (Hz)	f = 50
2.	Rated Stator power (W)	Ps = 2e6
3.	Rated rotational speed (rev/min)	n = 1500
4.	Rated stator voltage (V)	Vs = 690
5.	Rated Stator current (A)	Is = 1760
6.	Rated Torque (N.m)	Tem = 12732
7.	Pole pair	p = 2
8.	Stator / Rotor turns ratio	u = 1/3
9.	Rated Rotor voltage (Non - reached) (V)	Vr = 2070
10.	Maximum slip	smax = 1/3
11.	Rated rotor voltage referred to stator	Vr_stator = (Vr*smax)*u
12.	Stator resistance (ohm)	Rs = 2.6e-3
13.	Leakage inductance (H)	Lsi = 0.087e-3
14.	Magnetizing inductance (H)	Lm = 2.5e-3
15.	Rotor resistance referred to stator side (ohm)	Rr = 2.9e-3
16.	Stator inductance (H)	Ls = Lm + Lsi
17.	Rotor inductance (H)	Lr = Lm + Lsi
18.	DC bus voltage referred to stator	Vbus = Vr_stator*sqrt(2)
19.	Sigma	sigma = 1- Lm^2/(Ls*Lr)
20.	Stator flux (Approx.) (Wb)	Fs = Vs*sqrt(2/3)/(2*pi*f)
21.	Inertia	J = 127
22.	Damping	D = 1e-3

Table 6 (a)

PI Regulators used in the simulation are :

- tau_i = (sigma*Lr)/Rr
- tau_n = 0.05
- wni = 100*(1/tau_i)
- wnn = 1/tau_n
- kp_id = (2*wni*sigma*Lr)-Rr
- kp_iq = kp_id
- ki_id = (wni^2)*Lr*sigma
- ki_iq = ki_id
- kp_n = (2*wnn*J)/p
- ki_n = ((wnn^2)*J)/p

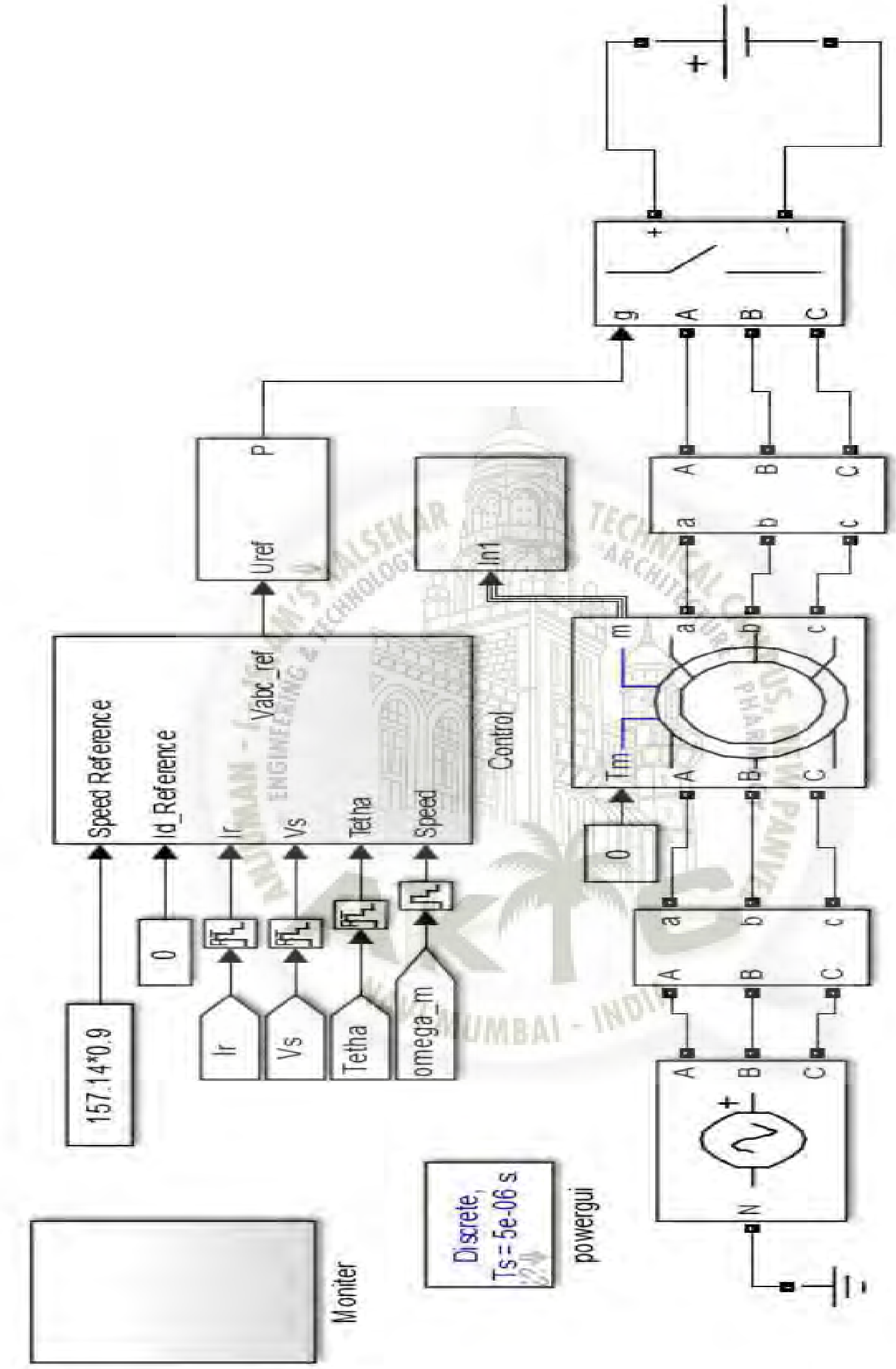
Speed Reference
Id_Reference
Ir
Vs
Tetha
Speed
Vabc_ref
Uref
P
In1
Control
Tm
m
A
B
C
a
b
c
g
+
-
157.14*0.9
0
0
Ir
Vs
Tetha
omega_m
N
Discrete,
Ts = 5e-06 s
powergui
Moniter

Figure 6 (a)

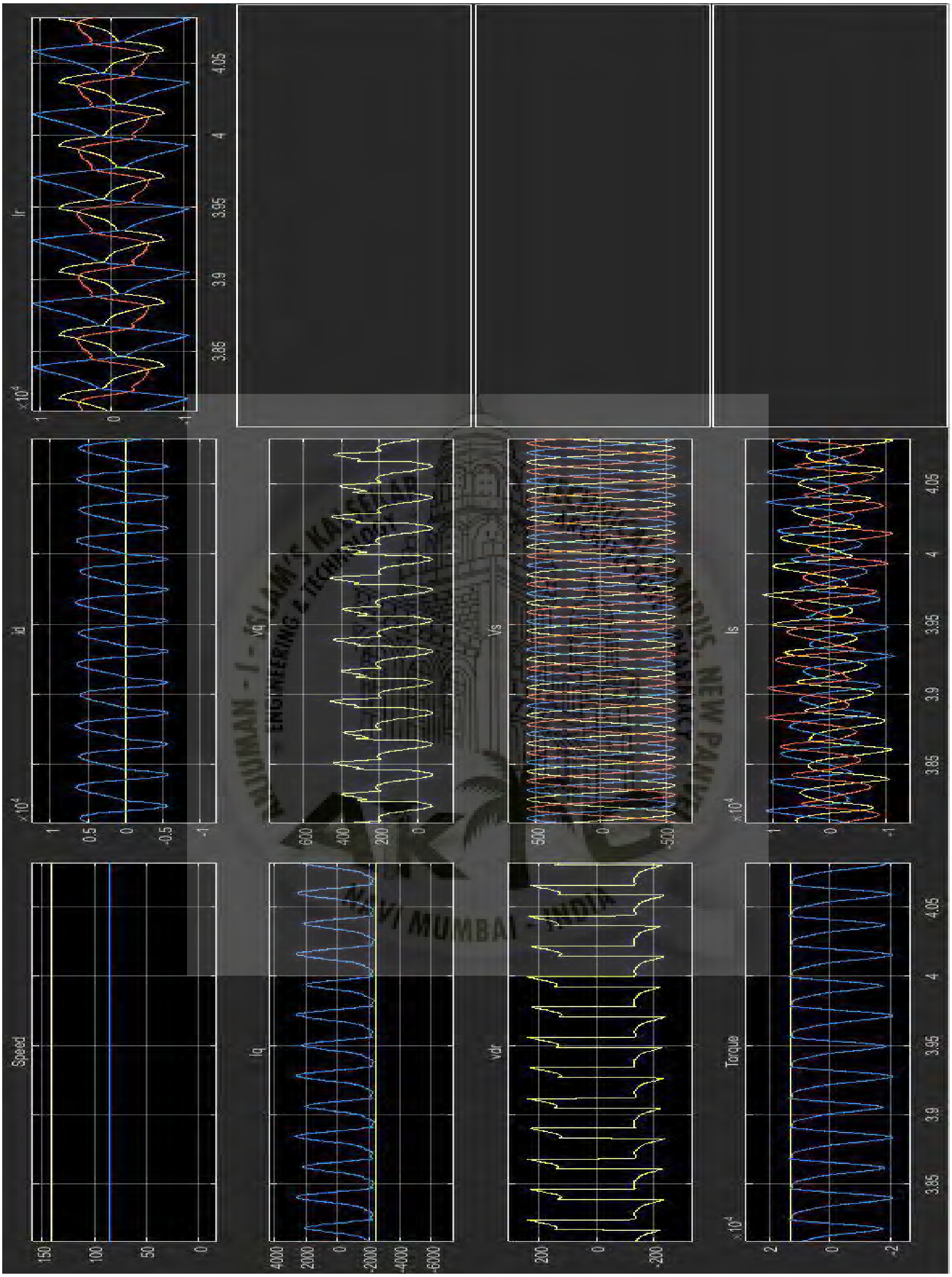
Speed
150
100
50
0
Iq
4000
2000
0
-2000
-4000
-6000
vdr
200
0
-200
Torque
×10⁴
2
0
-2
3.85
3.9
3.95
4
4.05
Id
×10⁴
1
0.5
0
-0.5
-1
vq
600
400
200
0
Vs
500
0
-500
Is
×10⁴
1
0
-1
Ir
×10⁴
1
0
-1

Figure 6 (b)

CHAPTER 7.

CONCLUSION

This project presents a simple concept to harvest high altitude wind energy using air borne wind generator supported by light gas filled blimp. A blimp is an aerostat that remains stationary at high altitude holding an air-borne wind turbine and the electric generator at a particular height. An electromechanical tether is used to transmit power to the ground based station. Optimal transmission DC voltage is determined in order to reduce the overall weight of tether. So, a simple and light weight PEC is designed which converts generated low volt-age AC to optimal medium voltage DC for efficient power transmission. The designed converter consists of a rectifier and an isolated DC-DC converter in the air-borne unit and a grid connected PEC in the ground station. Isolated DC-DC converter and ground based PEC are designed and simulated for 100 kW application in the paper. Using this concept of harnessing high altitude wind energy; on-grid power supply as well as off-grid power for underdeveloped countries, supply power during emergency condition can be provided with ease of tower construction. However, there are many challenges in harvesting high altitude wind energy using this concept. A blimp which uses light gas like Hydrogen and Helium for buoyancy is expensive. In addition, hydrogen is sensitive to ignition and Helium is a limited element in its existence on earth. Moreover, control of aerostat at high altitude to extract high energy is also challenging. Despite all these challenges, high altitude wind can be one of the best supplements to fulfill high energy demand in this decade for both on-grid, off-grid and emergency power requirements.

REFERENCES

1) J. Sawin, “Renewables global status report,” no. REN21.2012, Paris, France, Tech Rep. 2011 and 2012.
2) “G. m. masters, renewable and efficient electric power systems (wiley),” New York, NY, USA: Wiley 2004.
3) (2014,Aug.)Umas@ONLINE.[Online].Available http://www.umass.edu/windenergy/publications/published/communityWindFactSheets/RERL Fact Sheet 2a Capacity Factor.pdf
4) M. L. Loyd, “Crosswind kite power,” Journal of Energy, vol. 4, no. 3, ARTICLE NO. 80–4075, 1980
5) Elliot, Dave (2014-04-12). *"Flights of fancy: airborne wind turbines"*. Institute of Physics, Environmental Research Web.
6) Michael Specter, "Wind Power Takes Flight", The New Yorker May 20, 2013 behind paywall
7) Levitan, David (2012-09-24). *"High-Altitude Wind Energy:* Huge Potential — and Hurdles*"*. Environment 360. How do you safely suspend airborne turbines hundreds or thousands of feet off the ground? How do you keep them aloft for long periods of time in high winds without having to perform frequent, costly maintenance? And what about interference with aviation?
8) "Airborne Wind Energy Generation Systems".
9) Airborne Wind Energy Systems, a review of the technologies, A. cherubini, A. Papini, R. Vertechy, M.Fontana, Renewable and Sustainable Energy Reviews, 2015
10) Von Meier, Alexandra (2006). Electric Power Systems: A Conception Introduction. Hoboken, New Jersey: John Wiley & Sons, Inc. pp. 92–95. ISBN 978-0-471--17859-0.
11) Kolar, J.W.; Friedli, T.; Krismer, F.; Looser, A.; Schweizer, M.; Steimer, P.; Bevirt, J., ”Conceptualization and multi-objective optimization of the electric system of an

Airborne Wind Turbine," Industrial Electronics (ISIE), 2011 IEEE International Symposium on , vol., no., pp.32,55, 27-30 June 2011

12) Khaled Saleh Banawair, "DFIG Wind -Turbine Modelling With reactive power control Integrated to Large Distribution Network," 2014 IEEE International Conference Power & Energy (PECON)

13) Haitham Abu - Rub; Mariusz Malinowski, "Power Electronics for Renewable Energy systems, Transportation & Industrial Applications"

APPENDIX

1) Wind Power - Power obtained by harnessing the energy of the wind.
2) Swept Area - The swept area is the plane of the wind intersected by the generator.
3) Blade Solidity - Blade solidity is an important design parameter for the axial flow impeller andis defined as the ratio of blade chord length to pitch.
4) Fossil - Fueled Generator - Generators which produce electrical energy with the help of prime movers that run on fossil fuels.
5) Aesthetic Pollution - Visual pollution is an aesthetic issue and refers to the impacts of pollution that impair one's ability to enjoy a vista or view.
6) Depleting - Diminish in number or quantity.
7) Power to Weight Ratio - Power to weight ratio is a measurement of actual performance of a power source.
8) Buoyancy - The ability or tendency of something to float in water or other fluid or air.
9) Capacity Factor - Capacity factor is the unit less ratio of an actual electrical energy output over a given period of time to the maximum possible electrical energy output over that period.
10) Cost of Electricity - Cost of producing 1 KWH of energy.
11) Power Density - Power density (or volume power density or volume specific power) is the amount of power (time rate of energy transfer) per unit volume.
12) Air - Borne Turbine - An air borne turbine is a concept for a wind turbine with rotor supported in the air without a tower.
13) AWES - Among novel technologies for producing electricity from renewable resources, a new class of wind energy converters has been conceived under the name of Airborne Wind Energy Systems (AWESs). This new generation of systems employs flying tethered wings or aircraft in order to reach winds blowing at atmosphere layers that are inaccessible by traditional wind turbines.
14) Synchronocity - The simultaneous occurance of events which appear significantly related but have no discernible causal connection.
15) Blimp - A small airship or barrage ballon.