

Maximum Power Point Tracking For Wind Energy Conversion System

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Abstract— Modern wind turbine control system are slow, And they depend on design parameter of wind turbine and wind or rotor speed measurement for as control variable inputs. The Dependency on correctness on measurement devices makes the regulatory low credible. This system consists of a wind turbine, drive train, permanent magnet synchronous generator, diode bridge rectifier, buck/boost converter, inverter and control circuit for MPPT that commands dc to dc converter to control the generator for maximum power extraction. In this work aerodynamic characteristic of wind turbine and power conversion topology is explained. The maximum power tracking control algorithm with a hill climb search is introduced and the modeling and simulation of the wind turbine generator system using the MATLAB/SIMULINK software is presented, at least in principle, that the maximum power tracking algorithm developed is suitable for wind turbine generation systems.

These methods will increases reliability and efficiency of the system. And complexity of system decreased. This control System will base on the stiff system concept and provides a fast Response and dynamic solution to complicated aerodynamic system. This control scheme provides a quick response to wind Speed without knowledge of wind speed and turbine parameters.

Keywords— Turbine, Drive Train, Power electronics DC-DC Converter (Buck-Boost), MPPT, Simulation.

I. INTRODUCTION

Wind energy systems have been around for thousands of years. It is said that the first windmills on record were built by the Persians in approximately 900 AD [1]. These windmills were used for almost any mechanical task such as water pumping, grinding grain, sawing wood, and powering tools. These early windmills had four blades and were built on posts so that the windmill could be turn to face the wind. Prior to the industrial Revolution, wind was a substantial source of energy in Europe. Due to the inability to neither dispatch nor transport the energy produced by the windmills they began to lose its importance once the steam engine was invented. In addition, the use of coal to fuel the steam engine, which was used for the same mechanical work as wind energy, could be controlled to adjust the output power of the engine.

Even though wind energy popularity decreased after the Industrial revolution, many of these European windmills of the eighteenth Century included a number of features that were afterward incorporated into electricity generating wind turbines. Major improvements were made in the efficiency and operation of these windmills that would later benefit the generation of electricity. it was not until the end of the nineteenth century, in which the Electrical generator was invented, that people began using wind energy to produce electricity.

In the past several years wind energy is one of the fastest growing energy in the world. In the last two decades there have been many technological advances in wind power industry, making this source of energy more reliable and profitable. In present days, wind power generation can be commercialized and penetration in to the present power system is increasing. In addition wind power generation has been gaining acceptance from investors and more wind farms are being built because this industry has become more profitable. The cost of energy from wind has dropped to the point in which there are places that the prices of wind energy competitive with conventional sources of energy, even without incentives. Wind energy not only has economical impact on our society, but a big environmental and social impact as well. The use of wind energy reduces the combustions of fossil fuels and the consequent emissions. It also reduces our country dependence on foreign oil. On the other hand, it creates manufacturing, operation and maintenance jobs and construction jobs.

Modern wind turbine technology has been accomplished with help of many areas such as material science, aerodynamics, analytical methods, electrical machine, power electronics without help of this areas rapid development of new technology would not be possible. A relatively new area from wind turbine is power electronics. Power electronic system allows synchronization between winds turbine system and the utility grid and operate the wind turbine at variable speeds, increasing the energy production of the system. In addition, power electronics provide a means to transfer energy to and from storage units. This can allow the excess energy generation for later use.

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Wind turbine technology has improved significantly in the past 25 years. Modern turbine are reliable, efficient, cost effective and sound of turbines has been reduced significantly compared to their predecessors, although many improvements have been made, there needs to be more work done towards improving wind energy grid penetration, reducing the manufacturing and installation cost and improving turbine efficiency at all wind speeds. The development of new control strategies to maximize

power extraction from wind and increased turbine efficiency will make wind power generation more reliable source of energy in the future.

A) WIND TURBINE CONVERSION SYSTEM

1. MECHANICAL POWER EXTRACTION FROM THE WIND

The blades of a wind turbine extract the energy flow from moving air, which then converts this energy to rotational energy and delivers it via a mechanical drive unit to the rotor of an electric generator. The kinetic energy in air of an object of mass moving with speed v is equal to:

$$E = \frac{1}{2}mv^2 \text{ (N} \cdot \text{m)} \quad (1)$$

The power in the moving air, if we assume constant wind velocity, is:

$$P_{wind} = \frac{dE}{dt} = \frac{1}{2}\dot{m}v^2 \quad (2)$$

Where \dot{m} is the mass flow rate per second. When the air passes across an area A , such as the area swept by the rotor blades, the power in the air can be estimated:

$$P_{wind} = \frac{1}{2}\rho Av^3 \text{ (W)} \quad (3)$$

Where, ρ is the air density. The air density varies with air pressure and temperature, therefore $\rho = 1.225 \text{ kg/m}^3$ for the purpose of this work.

The equation above estimates how much power there is in the wind, but how much of this power can be extracted from the airstream with an energy converter? As demonstrated in [2], the mechanical energy which the converter extracts from the airflow will be equal to the power difference of the air stream before and after the converter:

$$P_{mech} = \frac{1}{2}\rho A_1 V_1^3 - \frac{1}{2}\rho A_2 V_2^3 = \frac{1}{2}\rho(A_1 V_1^3 - A_2 V_2^3) \text{ (W)} \quad (4)$$

Where A_1 and A_2 are the cross-sectional areas before and after the converter, and v_1 and v_2 are the wind speed before and after the converter. As the airflow passes through the converter the wind velocity behind the wind energy converter must decrease and the mass flow remains unchanged. Therefore,

$$\rho A_1 V_1 = \rho A_2 V_2 \left(\frac{kg}{s}\right) \quad (5)$$

$$P_{mech} = \frac{1}{2}\rho A_1 V_1 (V_1^2 - V_2^2) \text{ (W)} \quad (6)$$

from the equation (2.6) we can see that the maximum mechanical power occurs when V_2 is zero. If V_2 equals zero, the air was brought to a complete stop by the converter, which is not physically possible. If the outflow velocity behind the converter is zero, then the inflow velocity must be zero, which implies that there is no flow through the converter. Therefore, the mechanical power extracted from the air stream must be expressed from another equation. Using the law of conservation of momentum, the force exerted by the wind onto the converter is:

$$F = \dot{m}(V_1 - V_2) \text{ (N)} \quad (7)$$

And the extracted mechanical power is:

$$P_{mech} = FV' = \dot{m}(V_1 - V_2)V' \quad (8)$$

By comparing equation 2.4 and 2.8 we will be able to obtain the relationship for the flow velocity V' :

$$V' = \frac{1}{2}(V_1 + V_2) \left(\frac{m}{s}\right) \quad (9)$$

Thus the velocity of the airflow through the converter is equal to the average of V_1 and V_2 .

The mechanical power output of the converter can then be expressed as:

$$P_{mech} = \frac{1}{4}\rho A(V_1^2 - V_2^2)(V_1 + V_2) \quad (10)$$

if comparing this mechanical power output with the power in the air stream that flows through the same cross-sectional area A , the ratio between the mechanical power extracted by the converter and the power contained in the air stream that passes through the same area is called the "power coefficient" can be represented as follows:

$$C_p = \frac{P_{mech}}{P_{wind}} = \frac{\frac{1}{4}\rho A(V_1^2 - V_2^2)(V_1 + V_2)}{\frac{1}{2}\rho AV^3} \quad (11)$$

(10) the power coefficient can also be express in terms of the velocity ratio

$$C_p = \frac{P_{mech}}{P_{wind}} = \frac{1}{2} \left| 1 - \left(\frac{V_2}{V_1}\right)^2 \right| \left| 1 + \left(\frac{V_2}{V_1}\right) \right| \quad (12)$$

If we plot equation (11) we will see that the maximum ideal power coefficient happens when $\frac{V_1}{V_2} = \frac{1}{3}$, therefore C_p becomes

$$C_p = \frac{16}{27} = 0.593 \quad (13)$$

2. ROTOR POWER CHARACTERISTICS

$$P_R = \left(\frac{1}{2}\right) c_p V_w^3 \rho A \quad (14)$$

A = swept area of the rotor (m)

V_w = wind velocity (m/s)

C_p = rotor power coefficient

ρ = air density (kg/m)

P_R = rotor power (W)

The power coefficient can be obtained by data fields or look up tables or by approximating the coefficient using analytical function. In this thesis, the following power coefficient analytical function was used to model the wind turbine as demonstrated in [10]:

$$C_p(\lambda, \beta) = C_1 \left\{ C_2 \left(\frac{1}{\lambda_i} \right) - C_3 \beta - C_4 \beta^x - C_5 \right\} e^{-C_6 \frac{1}{\lambda_i}} \quad (15)$$

The coefficients $C_1 - C_6$ and x can be different for various turbines. They depend on the wind turbine rotor and blade design. The parameter $\frac{1}{\lambda_i}$ is defined as:

$$\frac{1}{\lambda_i} = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{\beta^3 + 1} \quad (16)$$

For simulation purposes the following values have been chosen for coefficients $C_1 - C_6$: $C_1 = 0.5, C_2 = 116, C_3 = 0.4, C_4 = 0, C_5 = 5, C_6 = 21$

Due to the fact that $C_4 = 0$ x will not be used.

From equation (16) we know that the mechanical power extracted from the wind is a function of the wind speed and the power coefficient. If we assume that the wind is constant, then the mechanical power only becomes a function of the power coefficient. The mechanical power can then be expressed as follows,

Where $P_0 = \frac{1}{2} \rho A V_w^3$ and it is constant.

Assuming the wind speed and the blade pitch angle are constant, and then the power coefficient becomes a function of the rotor speed .therefore the mechanical power can be expressed as

$$P_R = C_p(\omega_R) P_0 \quad (18)$$

B.DRIVE TRAIN

The rotational motion of the turbine rotor is transmitted to the electrical generator by means of a mechanical transmission called drive train. Its structure strongly depends on each particular WECS technology. Drive train as the mechanical system of a wind turbine consists turbine, generator and gear box. The major sources of inertia of this system lie in the turbine and generator. The tooth wheels of the gearbox contribute only a relatively small fraction

For this reason, the inertia of the gear is often neglected and only the transformation ratio of the gear system is included, but in this modeling gear ratio is taken to unity. For example, the turbines employing multipole synchronous generators use the direct drive transmission (the generator and the rotor are coupled on the same shaft). But most of the systems (e.g., those employing induction machines) employ speed multipliers (i.e.,gearboxes with a certain multiplying ratio) for the mechanical power transmission. Therefore, the electrical machine will experience an increased rotational speed and a reduced electromagnetic torque. The coupling between the two shafts can be either rigid or flexible.

$$T_{sh} = k_{sh} \theta_{t\omega} + D_t \frac{d\theta_{t\omega}}{dt} \quad (17)$$

Where

H_t = the inertia constant of the turbine H_g = the inertia constant of the pmsg

$\theta_{t\omega}$ = the shaft twist angle

ω_t = the angular speed of the wind turbine

ω_r = the rotor speed of the PMSG in p.u.

ω_{elb} = electrical base speed

T_{sh} = shaft torque

k_{sh} = shaft stiffness and

D_t = damping coefficient

C. DC/DC CONVERTERS

The dc-to-dc converters are often used in regulated switch-mode dc power supplies and in dc motor drives applications. Most of the time, the input to this converter is an unregulated dc voltage which can be obtained by rectifying an ac voltage source. This unregulated voltage will fluctuate due to changes in the line. In order to control this unregulated dc voltage into a regulated dc output we need to use a dc-to-dc converter. There are many dc-to-dc converters including the step-down (buck) converter, the step-up (boost) converter, the buck-boost converter and many others.

D. PERTURB AND OBSERVATION METHOD

Before explaining the maximum power tracking controller, it is important to understand the system. The generated mechanical power is given by,

$$P_{mech}(t) = T_{mech}(t) \omega_R(t) \quad (18)$$

For simplification, the generated electric power for a 1-phase generator is given by,

$$P_e(t) = V_a(t) i_a(t) \quad (19)$$

Assuming there are no losses in the system we can say that

$$P_{mech}(t) = P_e(t) \Rightarrow T_{mech} \omega_R = V_a i_a \quad (20)$$

The basic electrical and motion equations are

$$P = T \omega_R \quad (21)$$

$$i_a = \frac{v_a - e}{R} \quad (22)$$

$$e = k I_F \omega_e$$

$$i_a = \frac{v_a - k I_F \omega_e}{R} \Rightarrow T \quad (23)$$

$$\omega_e = \frac{2}{P} \omega_R$$

$$K I_F \left(\frac{v_a - k I_F \omega_e}{R} \right) \quad (23)$$

$$P_e = \frac{KI_F w_e}{R} (v_a - KI_F w_e)$$

$$P_e = \frac{KI_F w_e}{R} \left(\frac{\pi}{3\sqrt{3}} V_{dc} - KI_F w_e \right)$$

Therefore, to maximize power,

$$\frac{dP_e}{dV_{dc}} = 0 \Rightarrow V_{dc}(I_F, w_e)$$

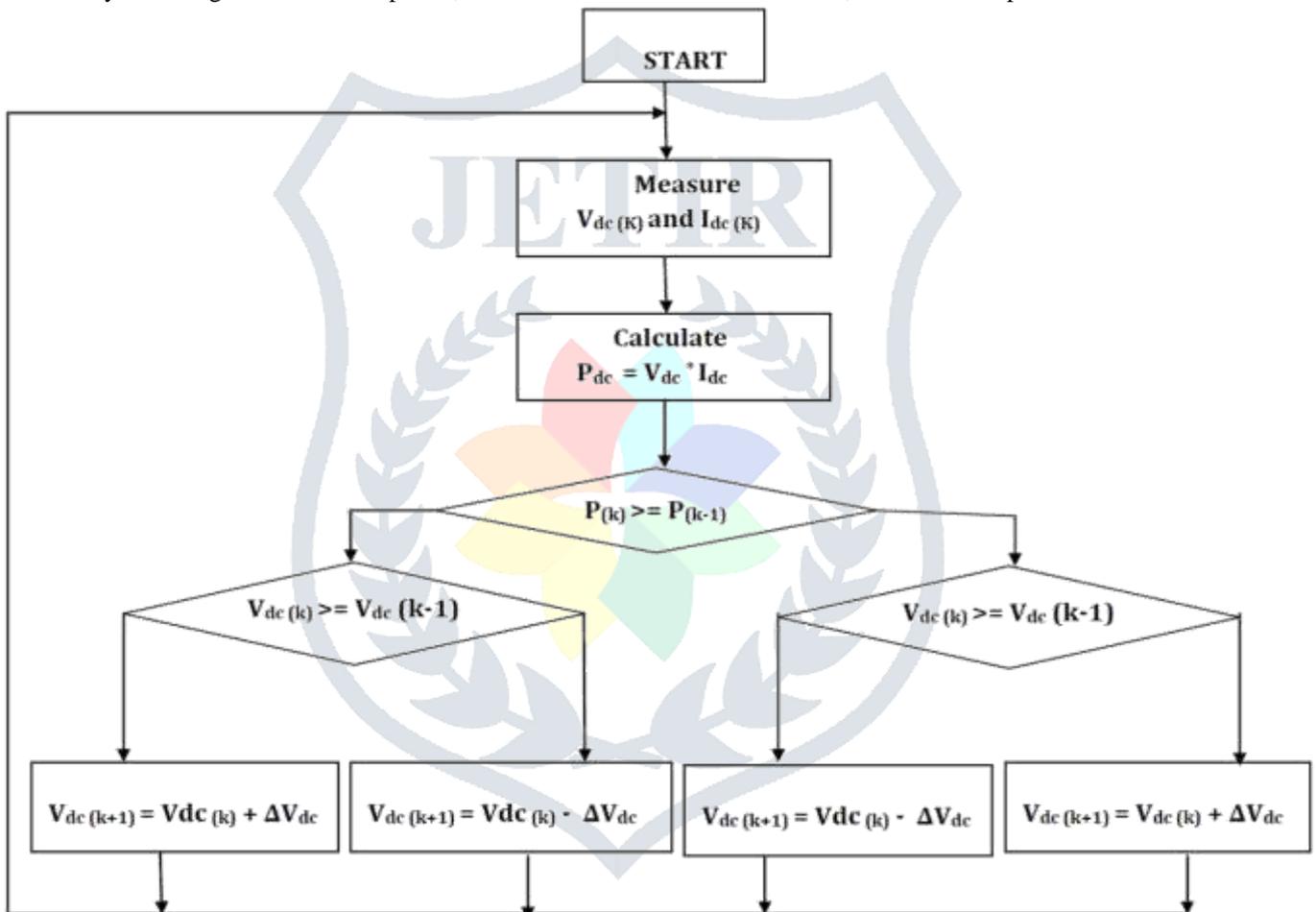
Equation shows that the power extracted from the wind can be controlled by varying the dc bus voltage, which is a function of I_F and w_e . Considering the wind turbine characteristics given in Fig, we know that the maximum power point is given when

$$\frac{dP_{mech}}{d\omega_R} = \frac{dP_{mech}}{dV_{dc}} \frac{dV_{dc}}{d\omega_e} \frac{d\omega_e}{d\omega_R} = 0 \quad (24)$$

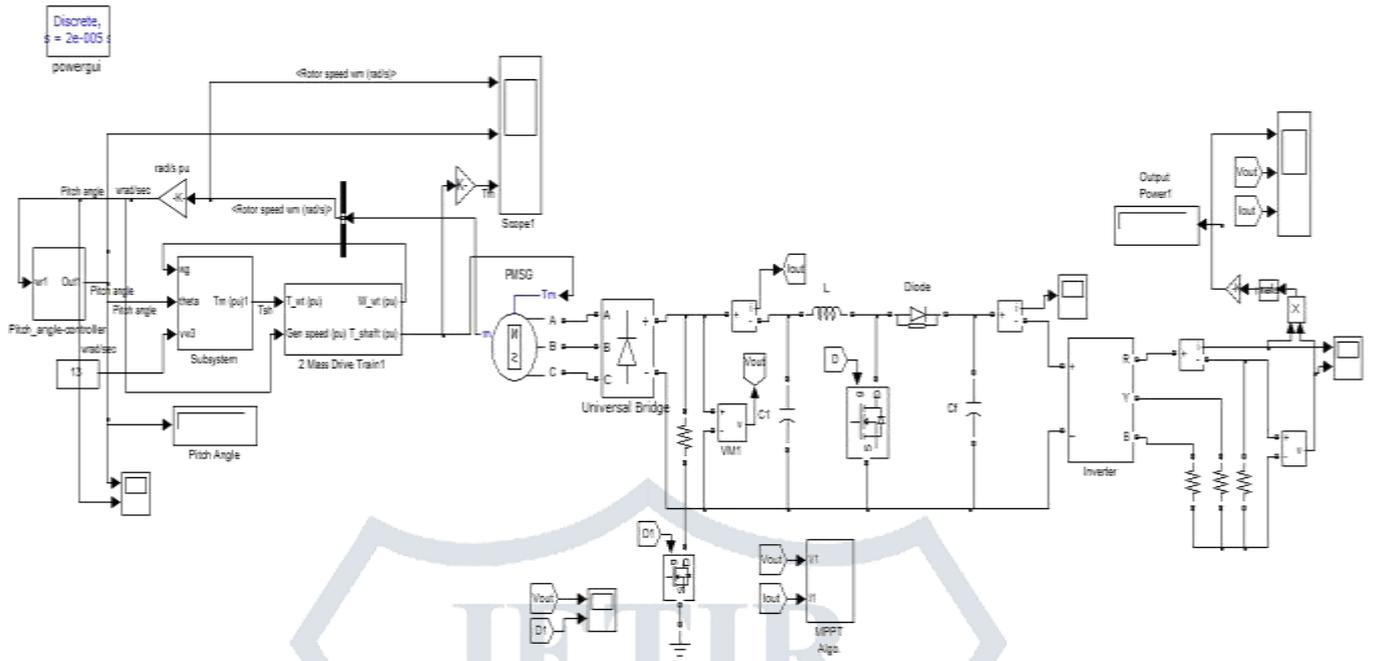
Where P_{mech} the mechanical power is generated, V_{dc} is the rectified dc voltage, ω_e is the electrical angular speed and ω_R is the rotor speed. Considering equation (4.13), it holds that,

$$\frac{dP}{d\omega_R} = 0 \Rightarrow \frac{dP}{dV_{dc}} = 0$$

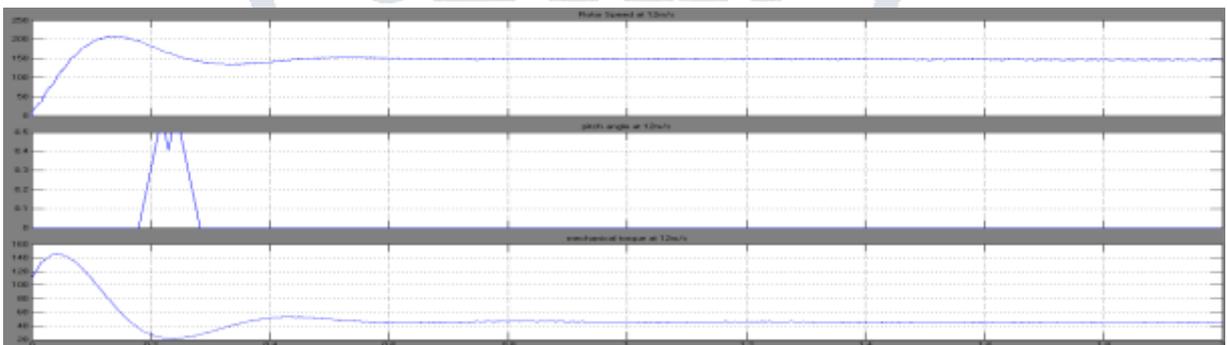
Then, the function $P(V_{dc})$ has a single point where maximum power extraction is achieved. It also means that the maximum power can be tracked by searching the rectified dc power, rather than environmental conditions, such as wind speed and direction.



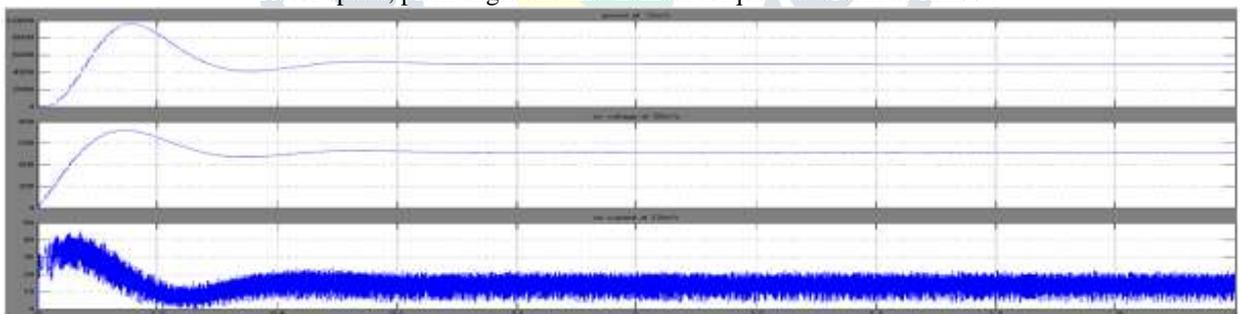
E.SIMULATION



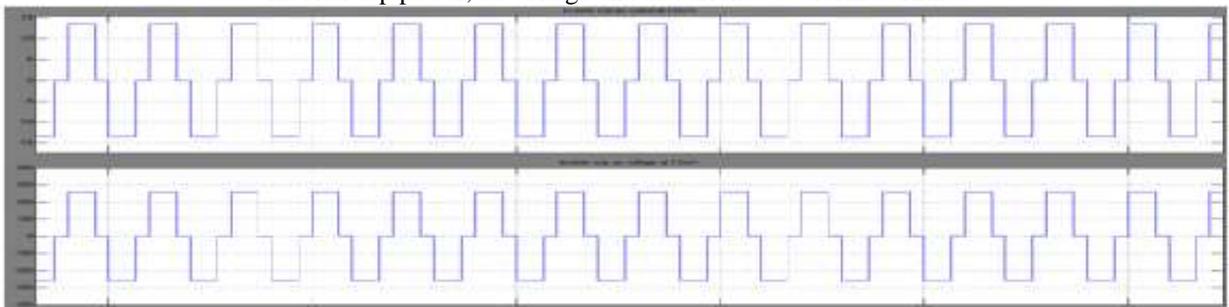
E.RESULT



Rotor speed, pitch angle and mechanical torque waveform at 12m/s



Inverter o/p power, dc voltage and dc current waveform at 12m/s



Inverter o/p current and voltage wave form at 12m/s

F.CONCLUSION

The above analysis and simulation have shown that the step and search algorithm developed is suitable for wind turbine generation systems. This algorithm is capable of extracting maximum power from the air stream at any wind speed without the knowledge of wind speed or rotor speed. In addition, the knowledge of the wind turbine aerodynamic characteristics is unnecessary

in order for the algorithm to work. It was shown that this control strategy can be easily implemented using semiconductor devices and that the system is capable of actively controlling power output. In conclusion this control strategy and system design can be easily implemented and will be able to improve the efficiency of wind turbine systems.

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