MPPT Control of Grid Connected PMSG Wind Turbines

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Abstract--Over the last years, with technological advancements wind power has grown rapidly and becomes the most competitive form of renewable energy especially for VS-WECS as compared to fixed velocity system. Most of system does not capture power at every wind speed, especially low wind speed. To achieve this outcome at variable speed wind energy conversion system (VS-WECS) here Permanent magnet Synchronous Generator (PMSG) is used which eliminates gear box. A simple Maximum Power Point Tracking (MPPT) control Scheme is used for PMSG with diode bridge rectifier and grid side inverter. The Power Conversion are Performed at unity power factor and DC link voltage is maintained constant. An Algorithm named Perturbation and Observation is developed at MPPT for maintaining constant voltage at output side in spite of variation in wind speed. Modeling and simulation of the grid side of the wind turbine system are performed. Results are verified through the MATLAB simulations.

Keywords-- Variable speed wind energy conversion system (VS-WECS), Permanent Magnet Synchronous Generator (PMSG), Perturbation and Observation Algorithm, Maximum Power Point Tracking (MPPT).

I.INTRODUCTION

Thederegulationofelectricmarketshasledtotheemergenceofdistributedgeneration(DG).Theseunitscompriserenewableandnon-renewablesources.Withtheincreased awarenessforenvironmentalpreservationandthedrivetoreducegreenhousegasemissions, therehasbeen a significantshift towardsrenewableenergy sources, leadingmost peopleto associatethe acronymDGwithsuch.Amongthose,windenergy,beingcleanandcommerciallycompetitive, hasbeenoneofthemostpopularchoices.AlargenumberofWindEnergyConversionSystems(WECS)arealreadyinoperationandmanynew systemsare beingplanned.AccordingtotheGlobalWindEnergyCouncil(GWEC),thetotalcapacityofwindpoweroperatingintheworldreached282.4GWin2012,anincreaseof48.4%from234.0GWin2011.[1] [4]Withmany governmentincentivesacrossmostofitsprovinces,itis expectedthatwindpowerinstallationwillexperiencesteadygrowthintheforthcoming years. The International Energy Agency (IEA) predicts that by 2030, the world's energy needs will be almost 60% higher than now. Two-thirds of this increase will occur in China, India and other rapidly developing economies; these countries will account for almost half of global energy consumption by 2030. For India and China OECD member states to cut their CO2 emissions by an average of 5.2% from their 1990 levels by 2013. Recently in Copenhagen accord, both India and China has voluntary agreed to cut their CO2 emissions by 20% in between 2005 to 2020. This leads to decrease in use of fuels and Exploiting renewable energy source including wind energy system. Global Wind Energy Council (GWEC) graphical view of wind power cumulative capacity since year 1996 to 2013.Wind power conversion differs from other conventional sources due to (1) the constructionofWECS,whichmostcommonlyusepowerelectronics-basedconverters,resulting intheapplicationofdifferenttopologies,(2)theunpredictablenatureofwindpower,whichisintermittentanduncertain,and(3)thechangefromapassivedistributionnetworkintoanactive onewithmultipleenergysourcesandbidirectionalpowerflow.Duetothesefactorsassociated withwindpower,itinteractsdifferentlywiththepower systemnetwork[3].

In this paper Permanent Magnet Synchronous Generator, (PMSG), is an interesting solution which is based on variable-speed operation. With permanent magnets there is no need for a DC excitation system. With a multipole synchronous generator it is possible to operate at low speeds and without gearbox. Therefore the losses and maintenance of the gearbox are avoided. In order to operate with low speeds, a high number of poles is used in PMSG wind turbines. Instead of electrical DC excitation the magnetic rotor field is provided by permanent magnets. The use of permanent magnets eliminates the DC excitation system, which means a reduction of losses.The proposed MPPT strategy is based on directly adjusting the dc-dc converter duty cycle according to the result of the comparison of successive WTG output power measurements. The control algorithm uses a "Perturbation and Observation" (P&O) iterative method that proves to be efficient in tracking the MPP of the WECS for a wide range of wind speeds.[9] The WECS MPPT algorithm operates by constantly perturbing, i.e. increasing or decreasing, the rectified output voltageof the WTG and thuscontrolling the rotational speed of the turbine rotor via the dc-dc boost converter duty cycle and comparing the actual output power with the previous perturbation sample . If the power is increasing, the perturbation will continue in the same direction in the following cycle so that the rotor speed will be increased, otherwise the perturbation direction will be inverted. This means that the WTG output voltage is perturbed every MPPT iteration cycle k at sample inte

II WIND ENERGY CONVERSION SYSTEM

WECSproduceelectricitybyusingthepowerofwindtodriveanelectricalgenerator.Theconversionofthekineticenergyoftheincomingairstreamintotheelectricalenergytakes placeintwosteps:theextraction device,i.e.,thewindturbinerotorcapturesthewindpower movement by means of aerodynamically designed blades, and converts it into rotatingmechanicalenergy,whichdrivesthegenerator rotor.[2]Theelectricalgeneratorthenconvertsthisrotatingmechanicalpowerintoelectricalpower.Agearbox maybeusedtomatchtherotationalspeedofthewindturbinerotorwithonethatisappropriateforthegenerator.Theelectricalpoweristhen transferred tothegrid throughatransformer. The connectionof thewind turbine tothegridispossibleatdifferentlevelsofvoltage,witha commonlevelbeing600-700V.[5]Powerelectronics converters can also be usedfor enhanced power extraction and variable speedoperationofthewindturbine.

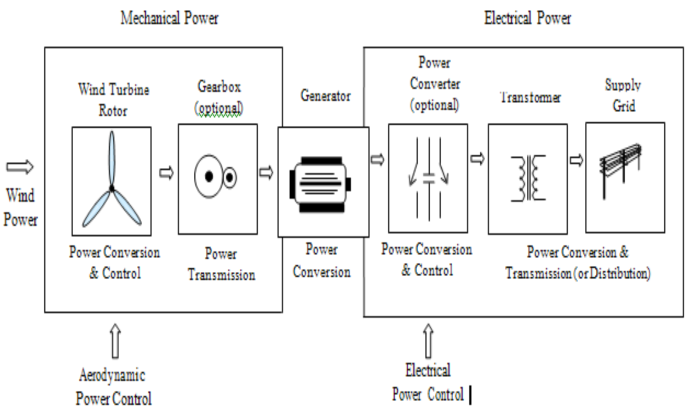


Fig 2.1 AgenericWindEnergyConversionSystem

2.1 Wind turbine modeling

The aerodynamic power at the rotor of the turbine is given by the following equation [4]:

$$P_t = \frac{1}{2}\rho\pi R_t^2 V^3 C\rho(\lambda,\beta) \qquad (2.1)$$

where ρ (kg.m-3) is the air density, Rt (m) is the turbine radius, v (m.s-1) is the wind speed and $Cp(\lambda,\beta)$ is the power coefficient which represents the aerodynamic efficiency of the turbine and also depends on speed ratio λ and the pitch angle β. The speed ratio λ, is given by :

$$\lambda = \frac{Rt\Omega t}{V} \qquad (2.2)$$

Ωt is the mechanical turbine speed (rad/s).

The mechanical torque produced by the turbine is expressed as follows:

$$C_t = \frac{1}{2}\rho\pi R_e^3 V^2 C_m(\lambda,\beta) \qquad (2.3)$$

$Cm(\lambda,\beta)$ is the torque coefficient :

$$C_m(\lambda,\beta) = \frac{Cp(\lambda,\beta)}{\lambda} \qquad (2.4)$$

For different values of β, the $Cp(\lambda,\beta)$ curves are shown in Fig.2.2

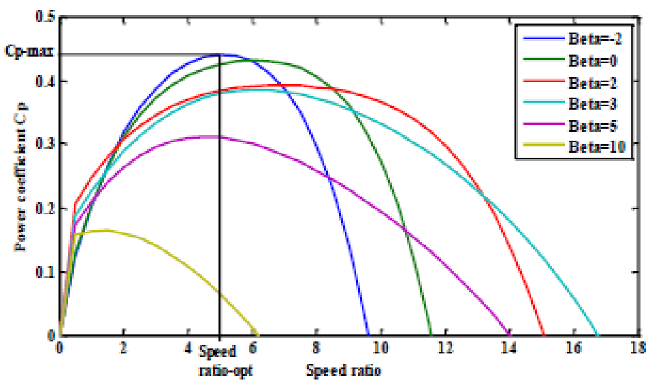


Fig 2.2Power coefficient values at different speeds

We note the existence of the maximal value of power coefficient *Cpmax* corresponding to the optimal value of the speed ratio $\lambda optimal$ for each value of pitch angle β. The maximum value of Cp, that is $Cpmax$=0.44, is achieved for β=-2° and for λ=5.[1] This particular value λopt results in the point of optimal efficiency where the maximum power is captured from wind by the wind turbine.

2.2 Mechanical shaft modeling (Two mass drive train)

2.2.1Components in the drive train:

The drive train consists of the following components:

1. Rotor shaft with bedding
2. Gear box (direct drive turbines have none)
3. Brake(s) and coupling
4. Generator.

2.2.2 Two Mass Drive Train Model:

In a comparative study of wind turbine generator system using different drive train models, it has been shown that the two-mass model is suitable for transient stability analysis [8]. Fig.2.3 shows a two-mass model for the direct drive train wind turbine system considered in this work**.**

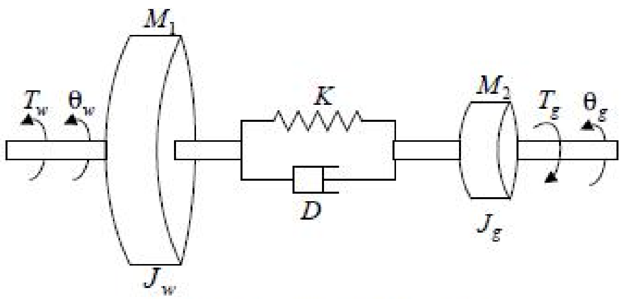


Fig 2.3 Two Mass Drive Train Model

Jw- the equivalent wind turbine inertia.
Jg- generator inertia.
Tw - aerodynamic torque of the wind turbine.
Tg -generator loading torque.
Θw- wind turbine.
θg – Generator Angle.
K - elastic characteristic of the shaft
D - mutual damping between the two masses.

2.3 Pitch angle control

The pitch angle control system is primarily used to limit the aerodynamic power above rated wind speed in order to keep the turbines' speed constant without overspeed The inertia of the MW-level wind turbines' blades turned by the drive is large and the pitch actuator angle can not change immediately, but only at a finite rate. The maximum rate of change of the pitch angle is in the order from 3 to 10 degree per second, depending on the size of the wind turbine.[10] The pitch angle control system with firstorder actuator model in this paper. The actuator is modeled in closed loop with saturation of the pitch rated limitation. In case of generator rotor speed *ωg* below *ω*max,active power is regulated according to the maximum power tracking characteristic. When the maximum generator speed *ω*max is exceeded, the pitch angle control system starts acting driving the generator speed back to the maximum permitted value so as to keep the active power constant [6].

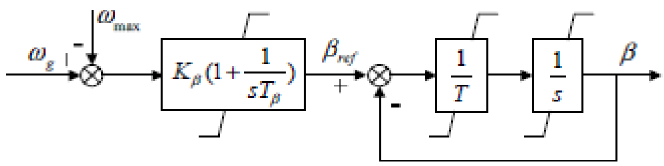


Fig 2.4Pitch Angle Control Block Diagram

The pitch angle is kept constant at zero degree until the speed reaches rated speed. Beyond rated speed the pitch angle is proportional to the speed deviation from rated speed. The SIMULINK model for the pitch angle controller is illustrated in the following figure 2.4.

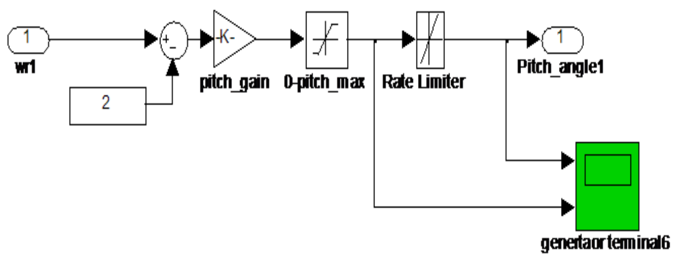


Fig 2.5Simulink Model of Pitch Angle Controller

Here in the figure given below the graph of pitch angle vs wind speed has been ploted which shows variation of speed of wind with respect to the change in angle of pitch.

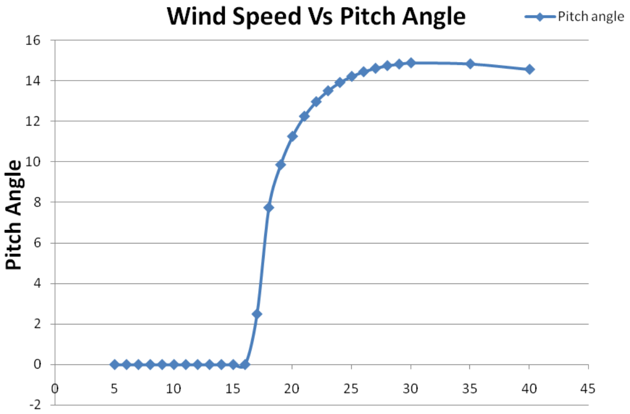


Fig 2.6Graphical view of pitch angle with different wind speed

III PERMANENT MAGNET SYNCHRONOUS GENERATOR

In order to operate with low speeds, a high number of poles is used in PMSG wind turbines. Instead of electrical DC excitation the magnetic rotor field is provided by permanent magnets. Due to the equal distribution of the surface mounted magnets and a permeability of the magnet material µm approximately as big as the airgap permeability the reactances in d- and q-axis differ by only a few percent , so that surface mounted PMSGs can be considered as round rotor machines (xd = xq). Because the multipole PMSG is a converter connected low speed application (in contrast to high dynamic drives) no damper winding is necessary. The use of permanent magnets eliminates the DC excitation system, which means a reduction of losses (high field ampere turns in multipole generators) and the omission of slip rings and thus maintenance requirements.[10]

3.1Construction of PMSG

Similar to the construction of induction generator, the PMSG has a stator and a rotor.A typical figure of PMSG is shown in figure 3.1 Since the stator construction is similar to that of the induction generator. Usage of permanent magnets for flux production makes the PMSG a brushless machine; this highly reduces the maintenance cost. Due to the absence of rotor windings, achieving a higher power density is possible through reduced weight and size of the machine. With zero or negligible winding loss, the thermal stress on the rotor is highly reduced. The main drawback of PMSG is the usage of highly expensive permanent magnets that are prone to demagnetization.[10] Based on the mounting of permanent magnets, the PMSG can be classified into two types: surface-mounted and inset PM generator.

Fig 3.1Model of PMSG

IV. MPPT CONTROL ALGORITHM

The proposed MPPT strategy is based ondirectly adjusting the dc-dc converter duty cycleaccording to the result of the comparison of successiveWTG output power measurements. The controlalgorithm uses a "Perturbation and Observation" (P&O)iterative method that proves to be efficient in trackingthe MPP of the WECS for a wide range of wind speeds.The WECS MPPT algorithm operates byconstantly perturbing, i.e. increasing or decreasing, therectified output voltage *Vg(k)* of the WTG and thuscontrolling the rotational speed of the turbine rotor viathe dc-dc boost converter duty cycle and comparing theactual output power *Pg(k)* with the previous perturbationsample *Pg(k-1)*. If the power is increasing, theperturbation will continue in the same direction in thefollowing cycle so that the rotor speed will be increased,otherwise the perturbation direction will be inverted.This means that the WTG output voltage is perturbedevery MPPT iteration cycle k at sample intervals *Ts*.Therefore, when the optimal rotational speed of the rotor for a specific wind speed is reached, the P&O algorithm will have tracked the MPP and then will settle at thispoint but oscillating slightly around this..According to Maximum Power Transfer theorem, the power output of a circuit is maximum when the Thevenin impedance of the circuit (source impedance) matches with the load impedance. Hence our problem of tracking the maximum power point reduces to an impedance matching problem. In the source side we are using a boost convertor connected to PMSG in order to enhance the output voltage. By changing the duty cycle of the boost converter appropriately we can match the source impedance with that of the load impedance.

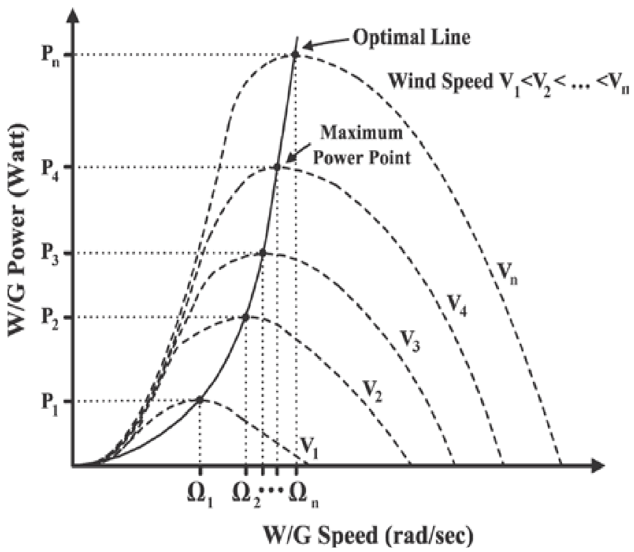


Fig 4.1 wind speed v/s wind Power

The principle of P&O is to perturbation by acting decrease or increase on the PWM duty cycle of boost converter and then observing the direction of change of wind output power. If at any instant j the output wind power P (j) & voltage V (j) is greater than the previous computed power P (j−1) & V (j-1), then the direction of perturbation is maintained otherwise it is reversed. The flow chart of algorithm has 4 cases as shown and can be detailed as following:

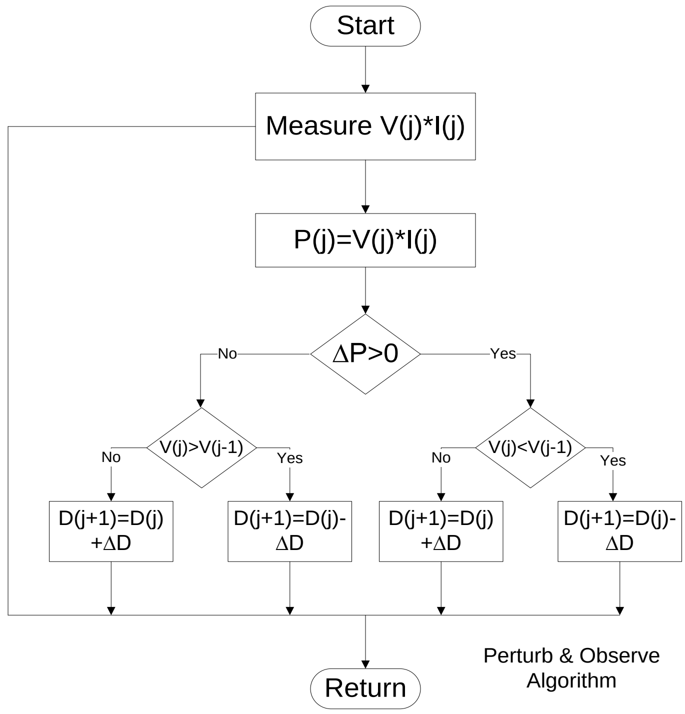


Fig 4.2Perturb and Observe Algorithm

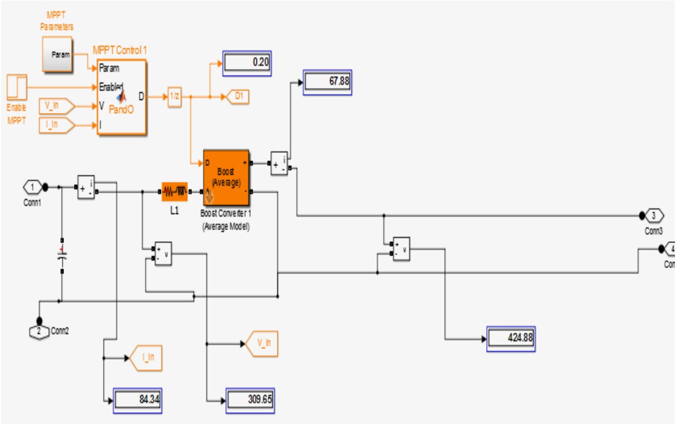
When ΔP <0 & V(j)>V(j-1), this yields to D (j+1) = D (j) – DWhen ΔP <0 & V(j)<V(j-1), this yields to D (j+1) = D (j) + DWhen ΔP >0 & V(j)<V(j-1), this yields to D (j+1) = D (j) – DWhen ΔP >0 & V(j)<V(j-1), this yields to D (j+1) = D (j) + D

Despite the P&O algorithm is easy to implement it has mainly the following drawbacks:

(1)Cannot always operate at the maximum power point due to the slow trial and error process, and thus the maximum available wind energy cannot be extracted all the time.2. The wind system always operates in an oscillating mode which leads to the need of complicated input and output filters to absorb the harmonics generated.

V.SIMULATION AND RESULTS

The Simulations and results have been given in the following figures. All the simulation have been done in MATLAB which shows us that by applying us the input to the system one can get it through boost converter and thus the boost converter converts it into the system with respect to MPPT algorithm which has been explained it in the flowchart given in above chapter. When the wind speed changes it controls the input and thus maintains the system stability by controlling the wings of wind angle and if the speed exists within it one can get the output stabled. Figure 5.1 shows the main simulation of MPPT.



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Results given in Fig 5.2 shows us the waveforms of wind at different wind speeds and thus get it Feedback Vout voltage.

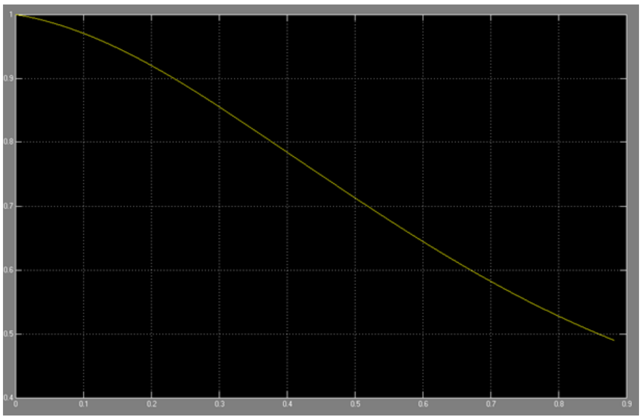

Fig 5.1 Simulations of MPPT and Boost Converter

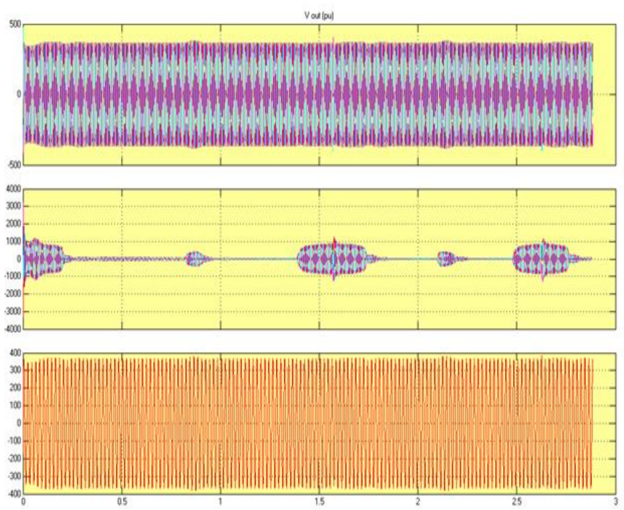

Fig 5.2 Waveforms of wind at different wind speed

Fig 5.3Two Mass Drive output voltages

Result analysis of Figure 5.3 and 5.4 show us that one can get that Two Mass Drive can be achieved through this and thus one can get this waveforms and thus it initially increasesgets high voltage and thus as the voltage is increased the Two Mass Drive output is decreased. In Figure 5.4 also the Generator Terminal Voltages are shown at different voltages and also at Power absorption to it as initially it absorbs high voltage and then at constant value of voltages one can get the peak value of it and thus there is also a constant output and which derives maximum output at a particular point and thus maximum value is derived in it through the results. And also one can get the tracking point where optimum power line is been derieved and thus they remains output of it and values of them are given in feedback voltage at particular wind speed of it. The offset time is been set to 0 and thus we gets the following outputs.

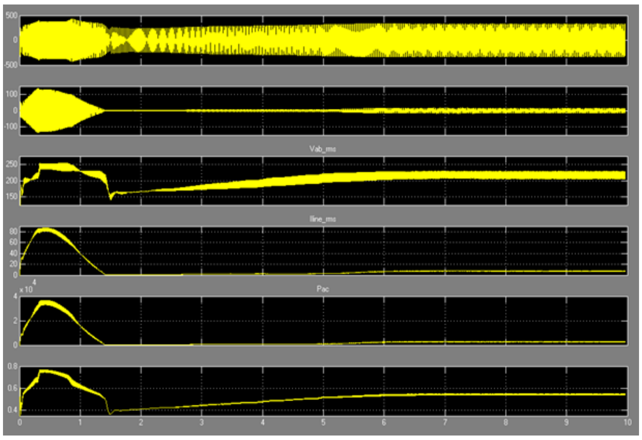

Fig 5.4Generator Terminal voltages and power outputs

VI CONCLUSION

The simulation model of the PMSG-based variable speed wind turbine system is built using MATLAB/SIMULINK. In addition, The two-mass model of drive train is incorporated in order to get a clear picture of wind turbine dynamics. It can be concluded that,

The reliability of the variable speed wind turbine can be improved Significantly using a direct drive-based permanent magnet synchronous generator (PMSG). PMSG has received much attention in wind energy applications because of its self-excitation capability, leading to a high power factor and high efficiency operation. It is observed that, for each wind speed, there exists a specific point in the wind turbine output power versus rotating-speed characteristic where the output power is maximized. The control of the wind turbine results in a variable-speed wind turbine operation, such that maximum power is extracted continuously from the wind below the rated wind speed.The pitch angle control system is primarily used to limit the aerodynamic power above rated wind speed in order to keep the turbines' speed constant without over-speed.The system analyzed is a variable speed wind turbine based on a multi-pole PMSG. Due to the low generator speed, the rotor shaft is coupled directly to the generator, which means that no gearbox is needed. It should be noted that the mechanical torque transmitted to the generator is the same as the aerodynamic torque, since there is no gearbox. It implies that the gearbox ratio is I. A three phase grid connected wind energy conversion system, incorporating a maximum power point tracker (MPPT) has been presented. This model has proposed a simple MPPT control scheme utilizing for a small sized wind turbine PM synchronous generator system with a diode bridge rectifier.The advantages of the proposed MPPT method are as follows: 1) no knowledge of the WG optimal power characteristic or measurement of the wind speed is required and 2) the WG operates at variable speed and thus suffering lower stress on the shafts and gears compared to constant-speed systems.

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