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Maximum Power Point Tracking System for Wind Generator Using MATLAB.

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ABSTRACT:The purpose of this work is to develop a maximum power tracking control strategy forvariable speed wind turbine systems. Modern windturbine control systems are slow, and they depend on the design parameters of the turbine and use wind and / or rotor speed measurements as control variable inputs. The dependence on the accuracy of the measurement devices makes the controller less reliable. The proposed control scheme is based on the stiff system concept and provides a fastresponse and a dynamic solution to the complicated aero dynamic system. This control scheme provides a response to the wind changes with out the knowledge of wind speed and turbine parameters.

The system consists of a permanent magnetsynchronous machine (PMSM), a passive rectifier, adc/dcboost converter, acurrent controlled voltages our ceinverter, and a micro controller that commands the dc/dcconverter to control the generator for maximum power extraction. The microcontroller will also be able to control the current output of the three-phaseinverter. In this work, the aerodynamic characteristics of wind turbines and the power conversion system topology are explained. The maximum power tracking control algorithm with avariable stepestimat or is introduced and the modeling and simulation of the wind turbine generator system using the MATLAB/SIMULINK® software is presented and its results show, at least in principle, that the maximum power tracking algorithm developed is suitable for wind turbine generation systems.

Keywords-MPPT, PMSG, WECS, HCS, PSF, TSR, WEGS.

1INTRODUCTION:

Inthepastseveralyears,windenergy hasbeenoneofthefastestgrowingenergy sourcesintheworld. Inthelasttwodecadestherehavebeenmany technological advancesinthewindpowerindustry,makingthissourceofenergy morereliableand profitable. Inpresentdays,windpower generationcanbe commercializedand penetration into thepresentpowersystemsisincreasing.In addition,wind power generation hasbeengaining acceptancefrominvestorsandmorewindfarmsarebeing builtbecausethisindustryhasbecomeprofitable. Thecostofenergyfromwindhas dropped to the point in which there are places that the price of wind energy is competitive with conventional sources ofenergy,even withoutincentives.

Windenergy notonly haseconomicimpactonoursociety,butithasabig environmentalandsocialimpactaswell.

Theuseofwindenergy reducesthe combustionsoffossilfuelsandtheconsequentemissions. ItalsoreducestheUnited Statesdependence onforeignoil. On the other hand,itcreates manufacturing, operation and maintenancejobsand construction jobs.

Modernwindturbinetechnology hasbeenaccomplishedwiththehelpofmany areas,suchasmaterialscience,computerscience,aerodynamics,analyticalmethods, testing, and power electronics. Without thehelpofthese areas therapid development of newtechnologieswouldnotbepossible.

Arelativelynewareaforwindturbinesis powerelectronics. Powerelectronicsystemsallowsynchronizationbetweenthewind turbinesystemandtheutility gridandoperatethewindturbineatvariablespeeds, increasingtheenergy productionofthesystem. Inaddition,powerelectronicsprovidea meanstotransferenergytoandfromstorageunits,whichcanallowthestorageof excess energygeneration for lateruse.

Wind turbine technology has improved significantly in the past 20 years. Modern turbines are more reliable, efficient, cost-effective, and the sound of the 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 the wind and increase turbine efficiency will make wind power generation a more reliable source of energy in the future.

2 WIND ENERGY CONVRESION AND PRINCIPLE

2.1 Relations between Speed and Power:

The power in moving air is nothing but the flow rate of kinetic energy per second therefore:

$power\ = \frac{1}{2}\rho A v^3$(2.1)

P= mechanical power in moving air

ρ= air density in Kg/m^3

A= The area swept by the rotor blades in m^2

v= velocity of the air in m/s

2.2 Power Extracted from the wind

The actual power extracted by the rotor blade is the difference between the upstream wind power and the downstream wind powers.

Po=$\frac{1}{2}$ (Mass flow rate per second).$\{V^2 - Vo^2\}$(2.2)

Where Po= Mechanical turbine output power,V = Upstream wind velocity at the starting of the rotor blades,V_o= Downstream wind velocity at the leaving of the rotor blades.

By multiplication of air density and average velocity, the mass flow rate of air through the rotating blades is calculated

Mass flow rate = ρ.A.$\frac{V+Vo}{2}$ (2.3)

The mechanical power extracted by the rotor, which is actually driving the electrical generator is,

Po=$\frac{1}{2}\left[\rho.A.\frac{V+Vo}{2}\right].(V^2 - Vo^2)$

After Rearranging ,

Po=$\frac{1}{2}$ ρ.A.V^3.$\frac{\left(1+\frac{Vo}{V}\right)\left[1-(\frac{Vo}{V})^2\right]}{2}$ (2.4)

The extracted power from the rotor is expressed in a fraction of the upstream wind power as follows:

Po= $\frac{1}{2}$ ρ.A.V^3.Cp (2.5)

Where, Cp=$\frac{\left(1+\frac{Vo}{V}\right)\left[1-(\frac{Vo}{V})^2\right]}{2}$

The value of Cp depends on the ratio of the downstream wind speed to the upstream wind speeds, i.e. (Vo/V) for a given upstream wind speed.

When the ratio of (Vo/V) is one-third then 0.59 has the maximum value. When the downstream wind speed equals at one-third of the upstream wind speed then at this condition the extracted maximum power is extracted from the wind as.

Po=$\frac{1}{2}$ρ.A.V^3 ∗0.59 (2.6)

Where, Po is the power in W, ρ is air density in kg/m^3, Cp is a dimensionless factor called power coefficient, A is area swept by the rotor blades in meter square (A =πR^2, where R is the rotor blade radius) and V is the wind speed in m/s. The power coefficient is depends upon the tip speed ratio λ and rotor blade pitch angle θ.

In aerodynamic model, the mechanical torque on the wind turbine shaft gives a formula as follows.

Tmech=$\frac{\text{Wind turbine mechanical power}}{\text{Shaft speed on high or low speed}}$= $\frac{Pm}{WT}$

Tmech=$\frac{Pm}{WT}$== $\frac{1}{2WT}$ ρ .A. Cp (θ, λ).V^3 (2.7)

In the book of “Wind power in power systems” the author Thomas Ackermann explained that in an individual wind turbine, the power curves are same as per Manufacturer documentation. Therefore for the different constant speed in wind turbines we do not assume using different approximations for the Cp (λ) curve. For that a general approximation can be used Instead of this. For describing the rotor of constant and variable speed wind turbines we can be using general approximate equation. And for energy yield calculations for financial purposes we do not consider for other types of calculation.

Cp (λ, θ)

=C1$\left(\frac{C2}{\lambda i} - C3\theta - C4\theta^{C5} - C6\right)\exp\left(\frac{-C7}{\lambda i}\right)$(2.8)

Where,λi = $\left[\left(\frac{1}{\lambda+C8\theta}\right) - \left(\frac{C9}{\theta^3+1}\right)\right]^{-1}$(2.9)

The ratio between tip rotor speeds of the blade and actual wind velocity is called Tip speed ratio (TSR) λ.

$$\lambda = \frac{Wr,Rr}{Vw} \qquad (2.10)$$

Wr- is rotational speed of the turbine.
Rr- is the radius of the rotor
Vw_is The wind velocity.

Heier originates the structure of this equation in 1998. However, for better result, the C1 to C9 constant values changes slightly. The difference between the ideal manufacturer documentation and the curve we obtained by using Equations (2.9) and (2.10) can be minimizing by applying optimization technique of multidimensional. We can include both the ideal parameters and the used parameters here.

$$P = 0.5\ \rho.A.Vw^3.Cp \qquad (2.11)$$

By comparing the values of heier ,constant speed wind turbine, variable speed wind turbine ,the standard values of C1 to C9 used in equation (3.10) and (3.11) as.

$$Cp\ (\lambda,\ \theta) = 0.73\left(\frac{151}{\lambda i} - 0.58\theta - 0.002\theta^{2.14} - 13.2\exp - 18.4\lambda i\right) (2.12)$$

Where, $\lambda i = \left[\left(\frac{1}{\lambda - 0.02\theta}\right) - \left(\frac{0.03}{\theta^3 + 1}\right)\right]^{-1}$ (2.13)And

$$\lambda = \frac{Wr,Rr}{Vw} \quad (2.14)$$

3 THE PROPOSED SCHEME:

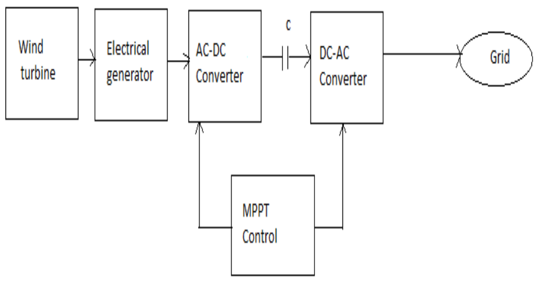


Fig 3.1: Grid connected system Block diagram of MPPT.

In Fig. 3.1 shows a diagram of MPPT wind energy conversion system for grid connection. The power generated in wind turbine is forwarded through the AC-DC rectifier and DC-AC inverter. The HCS algorithm interfaces the PMSG and AC-DC-AC converter to achieve maximum power point tracking with the help of different wind velocities and by using MPPT control. The rectifier and inverter consisting of three arm bridges switch which are an IGBT.

4 **CONCEPT OF MAXIMUM POWER POINT TRACKING:**

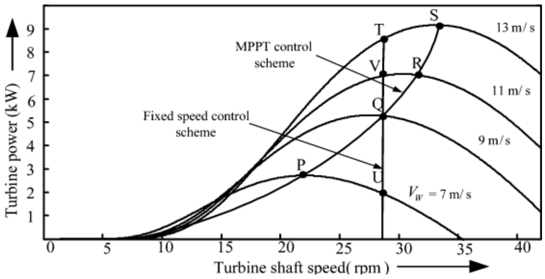


Fig: 4.1: Turbine power (Kw) vs. turbine shaft speed (rpm) for wind velocities of various values.

The fig 4.1 shows that the turbine power in Kw in y axis and turbine speed in x axis with reference to the different wind velocities such as 7m/s, 9m/s, 11m/s, 13m/s as an increasing order of conversion system of wind energy with the help of a constant speed. The capturing energy from wind converted in to electrical energy by using generator and that generating power is transferred to the grid or load with the help of suitable power electronics device .but the main disadvantage of the system is its less efficiency because it do not track maximum power point. As the change in wind velocity, the segment T-V-Q-V is dissipated by this situation shown in fig. At 9 m/s the MPP point Q can be set for a constant speed .therefore for other wind velocities points like U, V and T results, and they are long away with respect to the actual points P, R, and S respectively for other wind velocities. For there is necessary requirement is to run the system at the point of MPP. For getting these result high power electronics device with high variable speed used therefore WEGS has effective to operate .i.e. fig. shows that the point P, Q, R, and S can be represented by this system. In this case, for the wind system the extracted amount of energy is higher with reference to the fixed speed system.

5 Hill climb searching algorithm or Perturb and observe (P & O) algorithm:

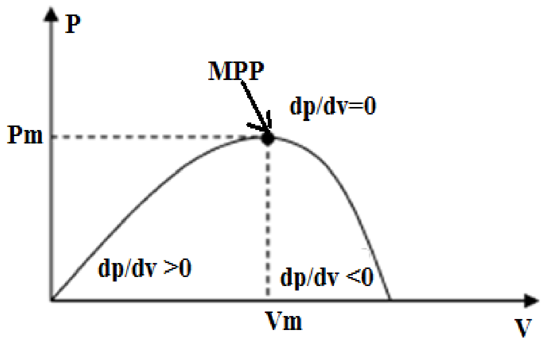


Fig 5.4: Hill Climb searching

Fig.showspower vs. speed characteristics and according to that MPP can be checked. For that we use hill climb searching algorithm, for that we check the sign of dp/dv .first of all when dp/dv>0 .i.e. shaft speed can be decremented and when dp/dv<0 it can be incremented .but at that point dp/dv=0,the MPP get tracked .At dp/dv>0 and dp/dv<0 these two curves are reversed to each other .i.e. this method can search peak power of the variable wind velocity according to that MPP point can be tracked ,this algorithm is independent on the turbine characteristics and wind speed measurement and it is useful to various wind turbine.Advantages:1) turbine characteristics knowledge is not necessary.2) It is useful to any wind turbine.Disadvantages: 1) this proposed algorithm is depending upon the system parameters.

6 Mathematical Expression of MPPT:

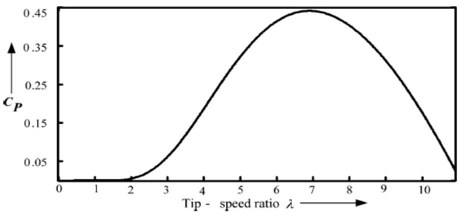


Fig 6.1: Cpversus tip speed ratio curve

With reference from the above fig. Which shown that the power coefficient versus tip speed ratio curve. From this waveform when at the crest point of curve, without considering wind velocity, the capturing power from the wind is maximum. For this purpose, the speed of turbine should be changed in such a way that the tip speed ratio corresponding to MPP.

The output power of the wind turbine is given by

Po= $\frac{1}{2}$ ρ.A.V^3.Cp (6.1)

Cp (λ, θ) =$0.73\left(\frac{151}{\lambda i} - 0.58\theta - 0.002\theta^{2.14} - 13.2\exp{-18.4\lambda i}\right.$(6.2)

Where, $\lambda i = \left[\left(\frac{1}{\lambda - 0.02\theta}\right) - \left(\frac{0.03}{\theta^3+1}\right)\right]^{-1}$ (6.3)

And $\lambda = \frac{Wr,Rr}{Vw}$ (6.4)

Differentiating equation (6.1) w .r. t. turbine speed & equating to zero. Assume air density is zero. Differentiating equation (6.2) w .r. t. λi keeping pitch angle θ is constant. Differentiating equation (6.3) w .r. t. Wr. And Rearranging equation result in PMPP $= 2.10 \times 10^{-3}$ ρRr^5 Wr^3 mpp(6.5)

At this MPP point, β is a new variable created and defined β=Wr^3/P. At MPP the value of β corresponding to that MPP is given by

BMPP $= \frac{Wrmpp^3}{PMPP} = \frac{476.20}{\rho Rr^5}$ (6.6)

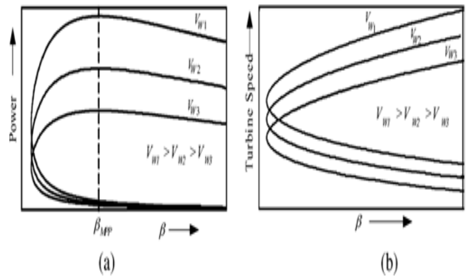


Fig.6.2 :(a) Power versus β curves with considering variable wind velocities. (b)Turbine speed versus β curves with considering various wind velocities.

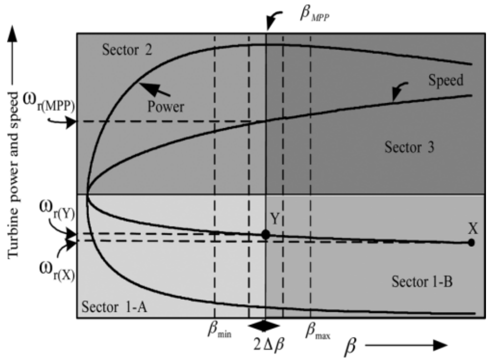


Fig 6.3: Turbine power and speed versus β curves (approximate scale). Different shades show different operating sectors.

The values from equation (6.6) are constant of a wind turbine system for a related values and it can be calculated from a specification of turbine. For practical system the value of β_{MPP} can be calculated for a particular system.

The fig 6.2 (a) shows the curve of output power vs. β and fig 6.2(b) shows that the turbine speed vs. β respectively with variable wind velocities. fig 6.2(a) shows that when the wind velocity increases the power also increase and the value of β at MPP is constant irrespective of changes in the wind speed.

These fig .6.2 (a) and (b) are compared at different wind speed and a new set off curves are created shown in fig.6.3. Three sectors are created from the complete working area just like sector 1, 2 and 3.these sector are small and for more clarity the sector 1 can be divided in to subsectors like section 1-A and 1-B shown in fig. As per the graph shown in fig. We can easily concluded that at MPP point related to βmpp is lies at the junction of sector 2 and 3 .some also may concluded that the junction 1 A and 1 B is also related to βmpp but it is not true result ,because its slope negative in both the curve. In sector 2 and 3 the slope is positive of both the curve, but the main result shows that, in sector 3, the slope is negative in the power vs β curve .whereas it has positive slope in speed vs. β curve. By work out this proper techniques and observation a rapid MPPT algorithm is developed.

7 Proposed MPPT algorithms

(1). At stator terminal of PMSG, read the speed of wind turbine. For that do not considers stator voltage, stator current, and stator frequency(.2)Calculate the present turbine output power p_k,β_k,ΔP_k,,$\Delta\omega_k$,$\Delta\beta_k$,when the present and reference frequency are equal.(3) By observing the value of $\Delta P_k / \Delta\beta_k$ and $\Delta\omega_k / \Delta\beta_k$, identify the operating sector. if sector is 1 then both values are negative and if both are positive then the sector is 2, and if $\Delta P_k / \Delta\beta_k$ is negative but $\Delta\omega_k / \Delta\beta_k$ is positive then the sector is 3.(4). There is need for equating the reference frequency and the actual frequency, i.e. F_k=f_k. The operating sector is 2 or 3 when the value of $\beta_k$lies band between the "$\beta_{MPP}\pm\Delta\beta$". (5) If the current sector is 1 and $\beta_k > \beta_{MPP}$, set the reference frequency $F_k=f_k+ f_{min\ 1}$.and if this condition is not satisfied then set the reference frequency $F_k=f_k+ f_{min\ 2}$. (6.) If the current sector is 2 and $\beta_k < \beta_{min}$, set the reference frequency $F_k=f_k+ (\beta_{MPP}- \beta_k)\ G_f$, and if the condition is reverse then set the reference frequency $F_k=f_k- f_{min3}$. (7) If the currents sector is 3 and $\beta_k > \beta_{max}$, set the reference frequency $F_k=f_k+ (\beta_{MPP}- \beta_k)\ G_f$,and if no then set the reference frequency $F_k=f_k+ f_{min3}$(8) Again goes in to the step no 1.in this way, continuously repeat this procedure to search the maximum power with different wind velocity.

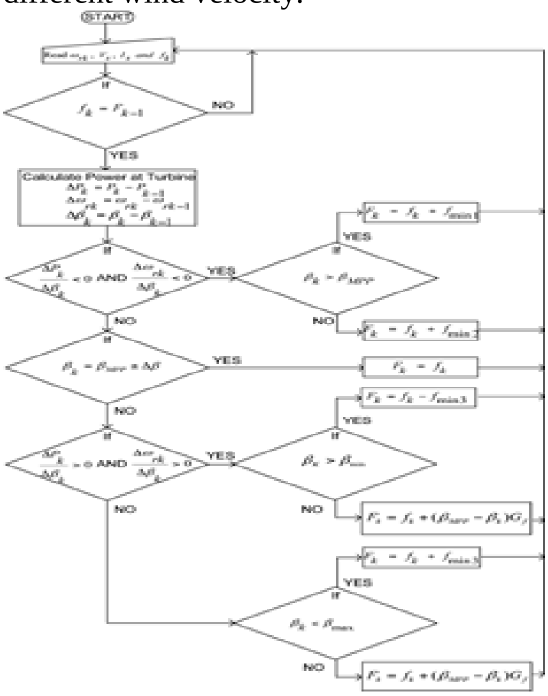


Fig.7.1: Flow chart of the proposed algorithm

Fig.7.1 shows the flowchart with reference from the corresponding algorithm, the operating point can be determined from previous fig.on which sector operating point lies completely on stator frequency. If in sector 1 when the operating sector lies (i.e.1-B) and βk> βMpp, then Fmin1 is used to drive the operating point i.e. Fk=fk+ Fmin1.and if βk< βMpp, then fmin2 is used to drive the operating point i.eFk=fk+ Fmin2 is in sector 1-A.but the βk value is in between the βmin and βmax then Fmin3 is used for driving the operating point. The Fmin1 and Fmin2 is totally depends on the parameter of WECS and wind speed at that location. Suppose that for starting the algorithm approximate values are used. Let assuming that on speed vs β curve, the point X which is longest one and if we choose Fmin for that point"X" then the turbine speed must be in between ωr (Y) and ωr (MPP).the Fmin1 and Fmin2 are the frequencies used for that to need the fine tanning at the time of installation and for obtaining MPP Fmin3 is a very fine frequency used. If in the sector 2 and 3 the operating point lies then the change in stator frequency is decided by Gf(βMpp-βk), where Gf is the gain factor of frequency and it is used to reduce the number of step for achieving the MPP. also for achieving MPP at a minimum time, the value βmin and βmax are tuned .similarly the difference of (βmax-βmin) is a very small then the system oscillates between sector 2 and 3 before entering the (βmax-βmin) band. So that at the time of selecting βmin and βmax there has a relation between MPPT and system stability. But in actual case it is very difficult to achieve the exact βMpp points. For that it is necessary a computational error Δβ around the βMpp. This Δβ represents the small tolerance error.

8 RESULTS AND DISCCUSSION

8.1 simulation model for MPPT

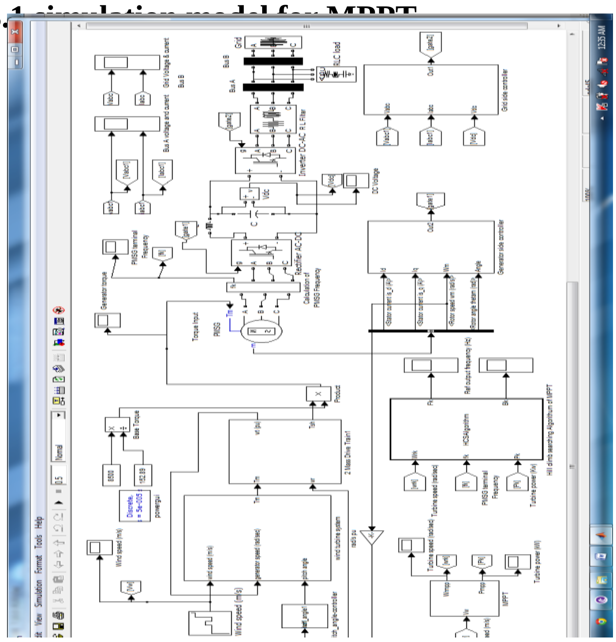
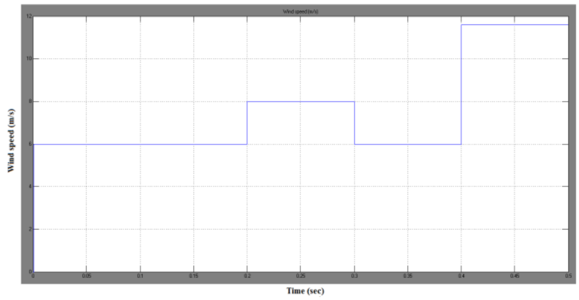
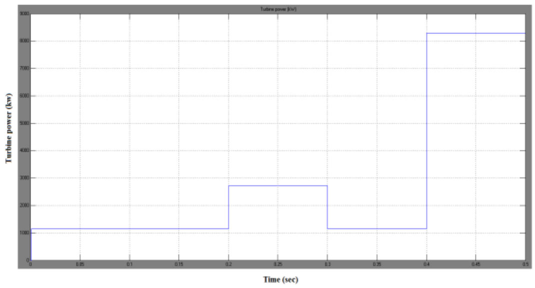


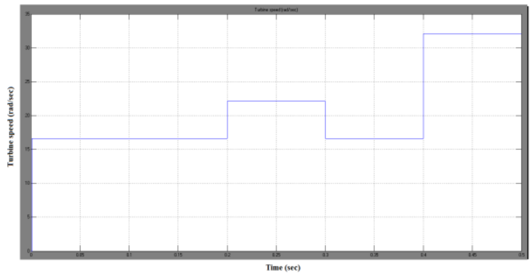
Fig 8.1: Main block of MPPT



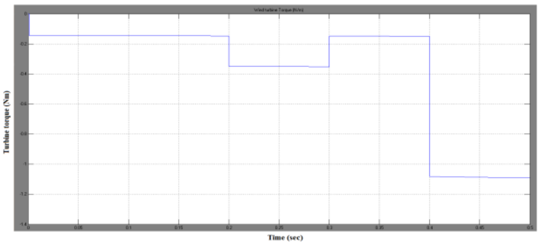
(a) Variable wind speed profile.



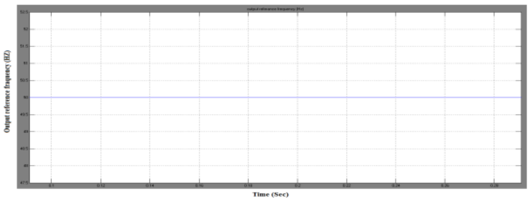
(a) Turbine Power (Kw).



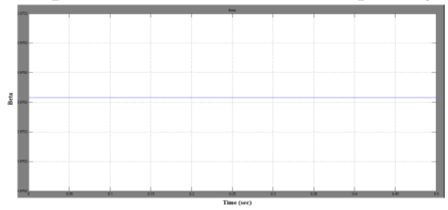
(b) Turbine speed (rad/sec).



(c) Turbine torque (Nm).

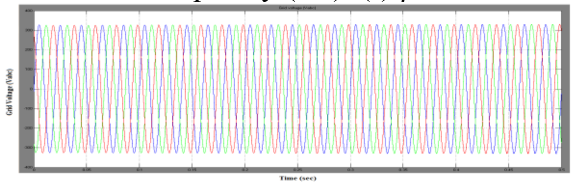


(d) Output reference frequency (Hz).

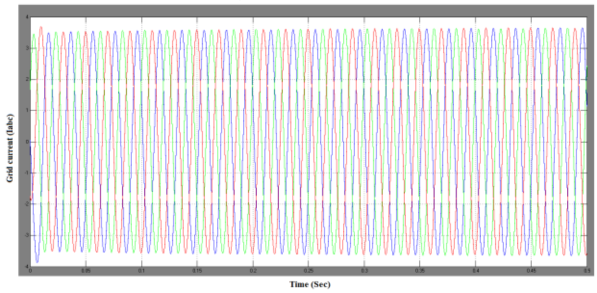


(f) β

Fig 8.2: Curves obtained during the tracking of the MPP using the proposed MPPT algorithm. a) Wind speed. b) Turbine Power (Kw). (c)Turbine speed (rad/sec). (d)Turbine torque (Nm.) (e) Output reference frequency (Hz). (f) β



(a) Grid Voltage



(b) Grid Current

Fig 8.3: Simulation result (a) Grid voltage and (b) Grid current

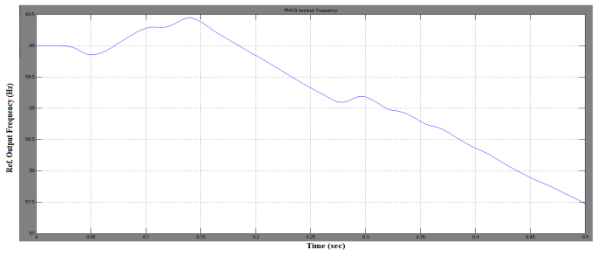


Fig.8.4: Frequency (fk) at stator terminals of the PMSG

8.2 Comparison Results without MPPT and with MPPT

Table No 8.1:Comparison result without MPPT and with MPPT turbine power.

Wind speed (m/s)	**Turbine Power Without MPPT (kW)**	**Turbine Power With MPPT (kW)**	**Difference (kW)**
0	0	0	**0**
1	5.288	5.3047	**0.0167**
2	41.824	42.438	**0.6142**
3	142.77	143.22	**0.45**

7	1813.78	1819.54	**5.76**
11	7038.32	7060.67	**22.35**
12	9137.66	9166.67	**29.01**
20	42304	42438.33	**134.33**

9 Conclusions

In this dissertation work, for the WECS a new MPPT technique has been created and actually implemented for grid connected system with the help of AC-DC-AC conversion. Now a day, for the MPPT purpose different algorithms are used but in this the most frequently used algorithm is Hill climb searching algorithm at variable wind speed.

In this, algorithm has been published, represented and in actual case it is practically implemented on power grid connected system for this energy conversion of wind system. The proposed algorithm was tested under different wind conditions including constant wind speed, abruptly changing wind speed, and randomly varying wind speed. In all the scenarios, the power extraction from the turbine was at the peak with respect to the wind curves for the turbine. The reduced ripple in power and increased efficiency are the biggest achievements of the Hill climb searching algorithm.

• By using this Hill climb searching algorithm (new P and 0), capturing power for any wind speed is high i.e. power is maximum at this condition. But the required time for taking to reach is smaller as compared to P and O algorithm so to decrease the large amount of loss of power, for the tracking of MPP this algorithm used.

• The exact MPP is tracked using this hill climb searching algorithm, extra hardware equipment are not required or measurable part are required as compared to the other algorithm like calculation based, Anemometer- based, Tip speed ratio control , Power signal feedback control etc. hence the cost is not increased.

• This algorithm does not required information of turbine characteristics and wind speed measurement. It can be apply to any wind turbine system. Also this algorithm implementation in practical is simple as compared to other algorithm.

10 Future scopes

The Future scopes which relates to proposed new algorithm could be summarized as below:

1) Low power wind turbine can be used for Experimental verification of the proposed algorithm.

2) For providing better control, various methods for converter of power can be implemented Such as matrix converter etc.

3) Actually this algorithm depending upon the system parameters of the wind. This is useful research on further research.

4) The value of PI controller in generator side controller and grid side controller can be found out optimization technique.

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