HILL CLIMBS SEARCHING METHOD FOR WIND GENERATOR OF MAXIMUM POWER POINT TRACKING SYSTEM

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ABSTRACT
This project is specially developed for permanent magnet synchronous generator (PMSG) for the purpose of maximum power tracking (MPP) of variable wind power system. And this is specially based on wind energy conversion system (WECS). Also in this project, for its implementation purpose practically, we can proved this is a mathematical equation and Hill climb searching (HCS) algorithm are also used for tracking of maximum power point. Wind turbine inertia is taken account for this algorithm. This new proposed techniques are used for the tracking of optimal operation point of wind turbine system of fluctuating wind condition of less time and minimum losses. This developed algorithm of maximum power for extraction provides the capability of initial power demand based on error driven control and to search maximum power at variable wind speeds, constructing an intelligent memory and applying the intelligent memory data to control the inverter for wind power extraction without knowing the knowledge characteristics of wind turbine or the measurement of mechanical quantities such as wind speed and turbine rotor speed. By using MATLAB/SIMULINK this algorithm can be effectively proposed as various result getting with or without MPPT.

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

1. INTRODUCTION
At this condition, we have seen that, the non-renewable sources are reducing day by day also there cost increases rapidly and in other side the requirement of electric energy is also increases in large percentage, so we need renewable energy sources like wind, solar, fuel cell etc. In this thesis wind energy is used because of its advantages and right now this is attractive and economical option. In wind power plants wind turbine converts rotating energy in to kinetic energy and electric generator converts this in to electrical energy. This energy is transferred entirely to an appropriate power grid with the help of various power electronic convertor devices and power transmission network. As we know that velocity of does not remain constant continuously, it changes very rapidly up and down, and because of this under such condition we do not get the maximum power. So for resolving this problem we need to use the method or algorithm of maximum power point tracking (MPPT) for the variable wind velocity condition so that maximum energy will be generated.

2. WIND ENERGY CONVERSION 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:

\[ \text{power} = \frac{1}{2} \rho A v^2 (2.1) \]

Where \( \rho \) = mechanical power in moving air \( \rho \) = 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.

\[ P_o = \frac{1}{2} \text{(Mass flow rate per second)}, \{V^2 - V_o^2\} (2.2) \]

Where \( P_o \) = 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

\[ \text{Mass flow rate} = \rho A \frac{V + V_o}{2} \quad (2.3) \]
The mechanical power extracted by the rotor, which is actually driving the electrical generator is,

\[ P_o = \frac{1}{2} \left( \rho A \frac{V + V_o}{2} \right) (V^2 - V_o^2) \]

Rearranging the above expression algebraically,

\[ P_o = \frac{1}{2} \rho A V^3 \left( \frac{1 + \frac{V_o}{V}}{1 - \left(\frac{V_o}{V}\right)^2} \right) \tag{2.4} \]

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

\[ P_o = \frac{1}{2} \rho A V^3 \cdot Cp \tag{2.5} \]

Where, \( Cp = \frac{1 + \frac{V_o}{V}}{1 - \left(\frac{V_o}{V}\right)^2} \)

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

When the ratio of (\( V_o/V \)) 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.

\[ P_o = \frac{1}{2} \rho A V^3 \cdot 0.59 \tag{2.6} \]

Where, \( P_o \) is the power in W, \( \rho \) 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 (\( A = \pi R^2 \), 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 \( \lambda \) and rotor blade pitch angle \( \theta \). In aerodynamic model, the mechanical torque on the wind turbine shaft gives a formula as follows.

\[ T_{mech} = \frac{P}{2} \frac{V^3}{\omega} \cdot Cp \tag{2.7} \]

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.

\[ Cp (\lambda, \theta) = 0.73 \tag{3.14} \]

Where, \( \lambda_i = 2.15 \) And \( \lambda = \frac{1}{\omega + 0.025} \)

3. THE PROPOSED SCHEME

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 \( Cp (\lambda) \) 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.

\[ Cp (\lambda, \theta) = C1 \left( \frac{C2}{\lambda1} - C3\theta - C4\theta^2 - C5 - C6 \right) \exp \left( \frac{-C7}{\lambda1} \right) \tag{2.8} \]

Where, \( \lambda_i = \left( \frac{1}{\omega + C8\theta^2} \right) \left( C9 \right) \tag{2.9} \)

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

\[ \lambda = \frac{W_{br}}{V_{br}} \tag{2.10} \]

\( W_{br} \) is rotational speed of the turbine.

\( R_{br} \) is the radius of the rotor

\( V_{br} \) 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.

\[ P = 0.5 \rho A V^3 \cdot Cp \tag{2.13} \]

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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

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](image)

Fig. 5.4: Hill Climb searching

Fig. shows power 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: Cp versus tip speed ratio curve](image)

Fig 6.1: Cp versus 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
$P_o = \frac{1}{2} \rho A V^3 C_p$ \hspace{1cm} (6.1)

$C_p (\lambda, \theta) = 0.73 \left( \frac{151}{\lambda_1} - 0.58 \theta - 0.002 \theta^2 + 14 - 13.2 \right) \exp \left( \frac{-18.4}{\lambda_1} \right)$ \hspace{1cm} (6.2)

Where, $\lambda_i = \left[ \left( \frac{1}{\lambda} - 0.25 \right) - \left( \frac{0.03}{\theta^2 + 1} \right) \right]^{-1}$ \hspace{1cm} (6.3)

And $\lambda = \frac{W_{r_{\text{max}}}}{V_w}$ \hspace{1cm} (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. $\lambda_i$ keeping pitch angle $\theta$ is constant. Differentiating equation (6.3) w.r.t. $W_r$ and rearranging equation result in

$P_{\text{MPP}} = 2.10 \times 10^{-5} \rho R \tau^5 W_{r_{\text{max}}} \text{mpp}(6.5)$

At this MPP point, $\beta$ is a new variable created and defined $\beta = \frac{W_{r_{\text{max}}}}{P}$. At MPP the value of $\beta$ corresponding to that MPP is given by

$BMPP = \frac{W_{\text{mpm}}^3}{P_{\text{MPP}}} = \frac{476.20}{\rho R \tau^5} \hspace{1cm} (6.6)$

![Fig.6.2](a) Power versus $\beta$ curves with considering variable wind velocities. (b) Turbine speed versus $\beta$ curves with considering various wind velocities.

![Fig.6.3](a) Turbine power and speed versus $\beta$ 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 $\beta_{\text{MPP}}$ can be calculated for a particular system.

The fig 6.2 (a) shows the curve of output power vs. $\beta$ and fig 6.2(b) shows that the turbine speed vs. $\beta$ respectively with variable wind velocities. fig 6.2(a) shows that when the wind velocity increases the power also increases and the value of $\beta$ 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 sector 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 $\beta_{\text{mpm}}$ 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 $\beta_{\text{mpm}}$ 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 $\beta$ curve whereas it has positive slope in speed vs. $\beta$ 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 $P_k$, $\beta_k$, $\Delta P_k$, $\Delta \omega_k$, $\Delta \beta_k$, 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 “$\beta_{\text{MPP}}=\Delta \beta$”. (5) If the current sector is 1 and $\beta_k < \beta_{\text{MPP}}$, set the reference frequency $F_k = f_k + f_{\text{min1}}$. and if this condition is not satisfied then set the reference frequency $F_k = f_k + f_{\text{min2}}$. (6) If the current sector is 2 and $\beta_k > \beta_{\text{MPP}}$, set the reference frequency $F_k = f_k + (\beta_{\text{MPP}}-\beta_k) G_k$, and if the condition is reverse then set the reference frequency $F_k = f_k - f_{\text{min3}}$. (7) If the currents sector is 3 and $\beta_k > \beta_{\text{MPP}}$, set the reference frequency $F_k = f_k + (\beta_{\text{MPP}}-\beta_k) G_k$, and if no then set the reference frequency $F_k = f_k + f_{\text{min8}}$. (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 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 \( \beta_k > \beta_{Mpp} \), then \( F_{min1} \) is used to drive the operating point i.e. \( F_k = F_k + F_{min1} \).and if \( \beta_k < \beta_{Mpp} \), then \( F_{min2} \) is used to drive the operating point i.e \( F_k = F_k + F_{min2} \) is in sector 1-A. but the \( \beta_k \) value is in between the \( \beta_{min} \) and \( \beta_{max} \) then \( F_{min3} \) is used for driving the operating point. The \( F_{min1} \) and \( F_{min2} \) 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 \( \beta \) curve, the point X which is longest one and if we choose \( F_{min} \) for that point“X” then the turbine speed must be in between or (Y) and \( \omega_r \) (MPP).the \( F_{min1} \) and \( F_{min2} \) are the frequencies used for that to need the fine tanning at the time of installation and for obtaining MPP \( F_{min3} \) 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 \( G_f(\beta_{Mpp} - \beta_k) \), where \( G_f \) 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 \( \beta_{min} \) and \( \beta_{max} \) are tuned .similarly the difference of \( (\beta_{max} - \beta_{min}) \) is a very small then the system oscillates between sector 2 and 3 before entering the \( (\beta_{max} - \beta_{min}) \) band. So that at the time of selecting \( \beta_{min} \) and \( \beta_{max} \) there has a relation between MPPT and system stability. But in actual case it is very difficult to achieve the exact \( \beta_{Mpp} \) points. For that it is necessary a computational error \( \Delta \beta \) around the \( \beta_{Mpp} \). This \( \Delta \beta \) represents the small tolerance error.

8. RESULTS AND DISCUSSION

8.1 simulation model for MPPT:
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) $\beta$

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

Fig 8.4: Frequency ($f_k$) 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.

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<tr>
<th>Wind Speed (m/s)</th>
<th>Turbine Power Without MPPT (kW)</th>
<th>Turbine Power With MPPT (kW)</th>
<th>Difference (kW)</th>
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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 O), 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 applied 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.

REFERENCES