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Maximum Power Point Tracking (MPPT) Algorithm in Wind Energy Conversion System

Aupendu Kar
UG Student
Department of Electrical Engineering
Kalyani Government Engineering College, Kalyani, WB, India

Abstract

This thesis presents some methods or algorithms to find the maximum value of the power coefficient of the wind power model with respect to the tip-speed ratio. The various algorithms implemented in the thesis are Gradient, Steepest Decent and Conjugate Gradient methods. The necessary theoretical & mathematical foundations have been analyzed and presented systematically to find the maximum wind power. These algorithms are implemented using MATLAB software. Necessary simulation results are presented to validate the proposed concepts & their performances are also compared.
Keywords: Power coefficient, Gradient, Steepest Decent, Conjugate Gradient

I. INTRODUCTION

Wind turbines can be used to harness the energy available in airflows. Current day turbines range from around 600 kW to 5 MW of rated power. Since the power output is a function of the cube of the wind speed, it increases rapidly with an increase in available wind velocity. Recent advancements have led to aero foil wind turbines, which are more efficient due to a better aerodynamic structure. Here section II describes theoretical background of the wind power characteristics with various relevant characteristics. Section III is devoted to represent the use of Gradient, Steepest Decent and Conjugate Gradient methods to obtain maximum power coefficient. Section IV presents the simulation results and their comparison is presented in section V. The conclusion is presented in section VI.

II. THEORY OF WIND POWER MODEL

The power available in the blowing wind is given by $P_w = \frac{1}{2}\rho_a A_T V^3$

Where P_w is the wind power, ρ_a is the air density, A_T is the cross-sectional area of the rotor and V the wind velocity.

The power extracted from the wind by a wind turbine is given by: $P_w = \frac{1}{2}\rho_a A_T V^3 C_p$

Where P_T is the power produced by the wind turbine and C_p is the power coefficient.

The power coefficient, C_p, is the most important parameter in the case of power regulation. C_p is a function of the tip speed ratio, λ and the blade pitch angle β in degrees as

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

$$\frac{1}{\alpha} = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{1+\beta^3}$$

Here the values of the co-efficient C_1-C_6 and x depends on turbine type. B is defined as the angle between the plane of rotation and the blade cross section chord. For a particular turbine type the values of the constants are given as C_1=0.5, C_2=116, C_3=0.4, C_4=0, C_5=5, C_6=21

Albert Betz was a German physicist who calculated that no wind turbine could convert more than 59.3% of the kinetic energy of the wind into mechanical energy turning a rotor. This is known as the Betz Limit. Good wind turbines generally fall in the 35-45% range.

λ is called the tip speed ratio of the wind turbine. The blade tip speed in meters per second can be calculated from the rotational speed of the turbine and the length of the blades used in the turbine. TSR (tip-speed ratio) which means how many times the speed of the tip of the turbine blade is grater then the wind speed.

Pitch angle in bevel gears is the angle between an element of a pitch cone and its axis. Normally for a wind energy system Pitch angle, β =2 degree.

The power coefficient, Cp, is the most important parameter in the case of power regulation. Cp is a function of the tip speed ratio and the blade pitch angle in degrees. Although the theoretical maximum value of Cp is 0.59, in practical designs, the maximum achievable Cp is below 0.5 for high-speed, two-blade turbines, and between 0.2 and 0.4 for slow speed turbines with more blades.

Here the plot between power coefficient & tip-speed ratio for a pitch angle β =0 degree is plotted below.

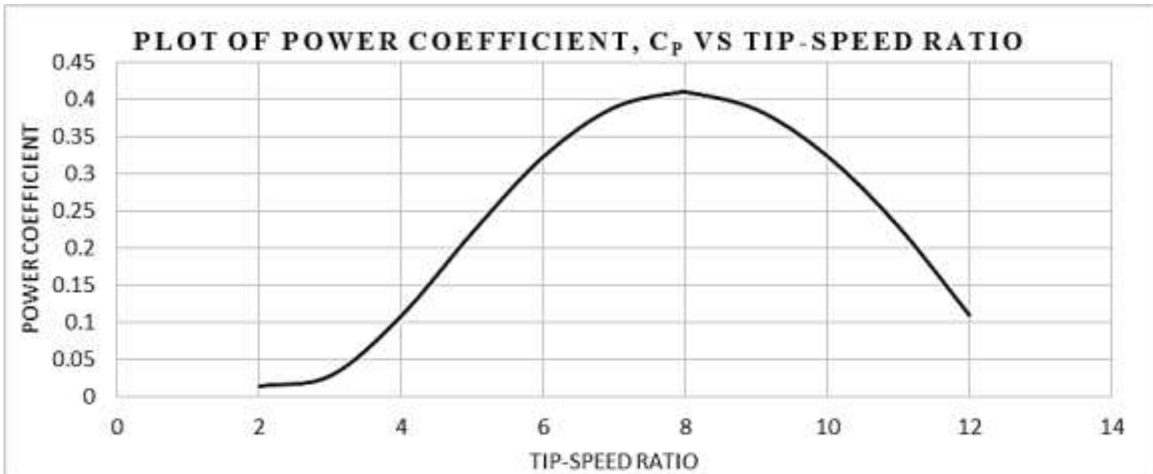

Fig. 1: Plot of Power Coefficient, Cp VS tip-speed ratio

III. MPPT ALGORITHMS

Maximum power generated by wind turbine depends upon the value of power co-efficient, Cp. Here Cp is a nonlinear function of tip-speed ratio, λ & pitch angle,β. Normally Pitch angle β is considered as constant & its typical value is almost taken as near about zero degree in this zone of power characteristics. Now Cp becomes the non-linear function of only λ. In this thesis, the maximum value of Cp & the corresponding value of λ will be obtained for a wind energy system by application of the following four algorithm as

- Gradient Search Method.
- Steepest Descent Method.
- Conjugate Gradient Method.
- Steepest Descent & Conjugate Gradient

In this context of maximum power point tracking algorithm, the necessary analysis of these four methods will be described in the subsequent subsections. Here the algorithms are used to get the maximum or peak value of power coefficient, Cp. Here a new method by punching steepest descent & conjugate gradient method is introduced to get the fastest response in this model. The complete description of these algorithms with necessary flow charts is presented as follows.

A. *Gradient Method:*

Gradient method is a first-order optimization algorithm. Gradient method is used to find the minimum & maximum point of a function.

In this gradient method, let $f(x_{n*1})$ needed to minimize. Now to get the minimum point of this function, we can use gradient method to get the minimum value.

Let $x^{(0)}, x^{(1)}, x^{(2)}, x^{(3)}, x^{(k)}$ is generated by following equation,

$$x^{k+1} = x^k + \lambda_k d^k \text{ Where } \lambda_k \text{ is constant } \& \; d^k = -grad(f(x^k)) \text{, Here } \lambda_k > 0$$

Thus by several iterations we can reach the minimum point of a function & also can get the maximum value (some modification needed) of a function. Here, this method is used to get the maximum value of power co-efficient, Cp with respect to tip-speed ratio for the wind power system. As this method is used for minimization of a function, we have taken the function Cp as negative to get maximum value using this method. Here in the wind power system Cp is a nonlinear function of tip-speed ratio, λ & pitch angle, β. Here we have taken β as a constant. So now Cp is a nonlinear function of tip-speed ratio, λ.

In this wind power system, $d^k = -grad(Cp(\lambda^k))$ & $\lambda^{k+1} = \lambda^k + Cd^k$ Here C is constant step size.

B. *Steepest Decent Method:*

Steepest Descent Method is used to get optimal minimization of a function. In the gradient method constant step size, C is kept constant. But in this method this step size is optimized to get the optimum solution of a function. Here in this method step size C is optimized in each iteration & help to reach the minimum or maximum point faster than the gradient method. In this method, let $f(x_{n*1})$ needed to minimize. Now to get the minimum point of this function, we can use this method to get the minimum value.

Let $x^{(0)}, x^{(1)}, x^{(2)}, x^{(3)}, x^{(k)}$ is generated by following equation, $x^{k+1} = x^k + \lambda_k^* d^k$

Here $\lambda_k = \lambda_k^*$; λ_k^* is the optimal step size & $d^k = -grad(f(x^k))$

Hence the optimal value of $\lambda_k^* = -\dfrac{grad^T f(x(k))\, d_k}{d_k^T grad^2 f(x(k))\, d_k}$

Here we have used this method to reach the peak value of Power Coefficient Cp of a wind power system & respective value of tip-speed ratio. As this method is used for minimization of a function, we have taken the function Cp as negative to get maximum value using this method.

Now, here in this wind power system, $d^k = -grad(Cp(\lambda^k))$ & $\lambda^{k+1} = \lambda^k + C^k d^k$

Now C is optimized into C^k. And Value of $C^k = \dfrac{1}{grad^2(Cp(\lambda^k))}$.

Now C^k is optimized in each iteration.
Steepest Decent method has much faster convergence than Gradient method.

C. *Conjugate Gradient Method:*

Conjugate Gradient Method is almost same as the Steepest Descent Method. In this method, only the equation for the optimal step size is modified. In this gradient method, let $f(x_{n*1})$ needed to minimize. Now to get the minimum point of this function, we can use gradient method to get the minimum value.

Let $x^{(0)}, x^{(1)}, x^{(2)}, x^{(3)}, x^{(k)}$ is generated by following equation, $x^{k+1} = x^k + \lambda_k^* d^k$

Here $\lambda_k = \lambda_k^*$; λ_k^* is the optimal step size.

Hence the optimal value of $\lambda_k^* = -\dfrac{grad^T f(x(k))\, d_k}{d_k^T grad^2 f(x(k))\, d_k}$

Here the value of the d^k modified as $d^k = -grad(f(x^k)) + b^k d^{(k-1)}$
Here the new coefficient b^k is used & some value from the previous iteration is used.

$$b^k = \frac{grad(f(x^k))\, grad(f(x^k))}{grad(f(x^{k-1}))\, grad(f(x^{k-1}))}$$

Here we have used this method to reach the peak value of Power Coefficient Cp of a wind power system & respective value of tip-speed ratio. As this method is used for minimization of a function, we have taken the function Cp as negative to get maximum value using this method. Now, here in this wind power system, $d^k = -grad(Cp(\lambda^k))$ & $\lambda^{k+1} = \lambda^k + C^k d^k$

Now C is optimized into C^k. And Value of $C^k = \dfrac{1}{grad^2(Cp(\lambda^k))}$.

Here the value of $b^k = \dfrac{grad(Cp(\lambda^k))\, grad(Cp(\lambda^k))}{grad(Cp(\lambda^{k-1}))\, grad(Cp(\lambda^{k-1}))}$ Now C^k is optimized in each iteration.
Conjugate gradient makes the convergence rate faster.

D. *Steepest Decent & Conjugate Gradient:*

Here in order to get the maximum value of power coefficient, Cp of a wind turbine model, we have punched two algorithms steepest decent & conjugate gradient to get the faster convergence in this model. It is observed that conjugate gradient reaches faster near peak value but settle the peak value slower than steepest decent method in the wind turbine model. So we have used both the method to reach the peak value. Conjugate gradient method is used to reach near the peak value & steepest decent is used to settle near peak value.

Conjugate gradient is used until it crosses the peak point first time during the iteration. When the gradient d^k becomes negative, it means that it crosses the peak point & previous point was near to the peak point, so the algorithm comes back to the previous value and start iteration with the help of steepest decent method.
This type of algorithm gives fastest convergence in the wind turbine model to find the peak of the power coefficient, Cp.

IV. RESULT

Program based on this algorithm is written in MATLAB and the necessary results regarding it is written in the table given below. No of iteration to find the maximum value of Cp w.r.t. λ is given for various value of pitch angle.

Gradient Method					
Value of Beta	*Step Size*	*Minimum Error*	*No of Iteration*	*Results*	
				Maximum Value of Cp	*Value of Lambda at Maximum Value of Cp*
0	*30*	1×10^{-21}	*1313*	*0.4110*	*7.9540*
1	*30*	1×10^{-21}	*632*	*0.2286*	*6.8038*
2	*30*	1×10^{-21}	*326*	*0.1514*	*6.3019*
Steepest Decent Method					
Value of Beta		*Minimum Error*	*No of Iteration*	*Results*	
				Maximum Value of Cp	*Value of Lambda at Maximum Value of Cp*
0		1×10^{-21}	*21*	*0.4110*	*7.9540*
1		1×10^{-21}	*20*	*0.2286*	*6.8038*
2		1×10^{-21}	*18*	*0.1514*	*6.3019*
Conjugate Gradient Method					
Value of Beta		*Minimum Error*	*No of Iteration*	*Results*	
				Maximum Value of Cp	*Value of Lambda at Maximum Value of Cp*
0		1×10^{-21}	*25*	*0.4110*	*7.9540*
1		1×10^{-21}	*14*	*0.2286*	*6.8038*
2		1×10^{-21}	*11*	*0.1514*	*6.3019*
Steepest Decent & Conjugate Gradient					
Value of Beta		*Minimum Error*	*No of Iteration*	*Results*	
				Maximum Value of Cp	*Value of Lambda at Maximum Value of Cp*
0		1×10^{-21}	*10*	*0.4110*	*7.9540*
1		1×10^{-21}	*10*	*0.2286*	*6.8038*
2		1×10^{-21}	*10*	*0.1514*	*6.3019*

V. COMPARISON

Method	*No. of Iteration*	*Complexity*
Gradient	*High*	*Easy*
Steepest Decent	*Low*	*Moderate*
Conjugate Gradient	*Low*	*High*
Steepest Decent & Conjugate Gradient	*Very Few*	*Very High*

VI. CONCLUSION & ANALYSIS

All the three methods of minimization techniques are used to get the maximum value of the power coefficient of the wind turbine model. Using these techniques, the MATLAB program has been written & all the details of the programs & results are written above.

The gradient method is simple & easy to implement but no of iteration is very high. So convergence rate is slow. In this gradient method step size is a important factor. We have to choose this value wisely unless the convergence will not occur.

The steepest decent method is comparatively complicated but convergence rate is high. Here the step size is optimized in each iteration.

The conjugate gradient method has faster convergence than steepest decent. But in the wind power model, steepest decent gives a good result than conjugate gradient. In the conjugate gradient one extra term is added with gradient of the function. This extra term depend upon the previous value of the iteration. In this iteration the process is very complex & hard to implement but convergence rate is high.

Here a new process is implemented by punching the steepest decent & conjugate gradient which gives the best result. Very little iteration is needed to reach the peak point in this iteration. Conjugate gradient method is used to reach near the peak value & steepest decent is used to settle near peak value. This process needs little iteration but complexity is very high.

Therefore, the methodologies presented in this thesis will be useful for implementation of sensor less MPPT algorithm in connection with the wind power generation.

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