Wind Farm Micrositing Optimization by Stackelberg Game Theory Model

(1) Ramin Farajifijani, (2) Ehsan Ghotbi

(1) Rf8@Alfred.edu, (2) Ghotbi@Alfred.edu

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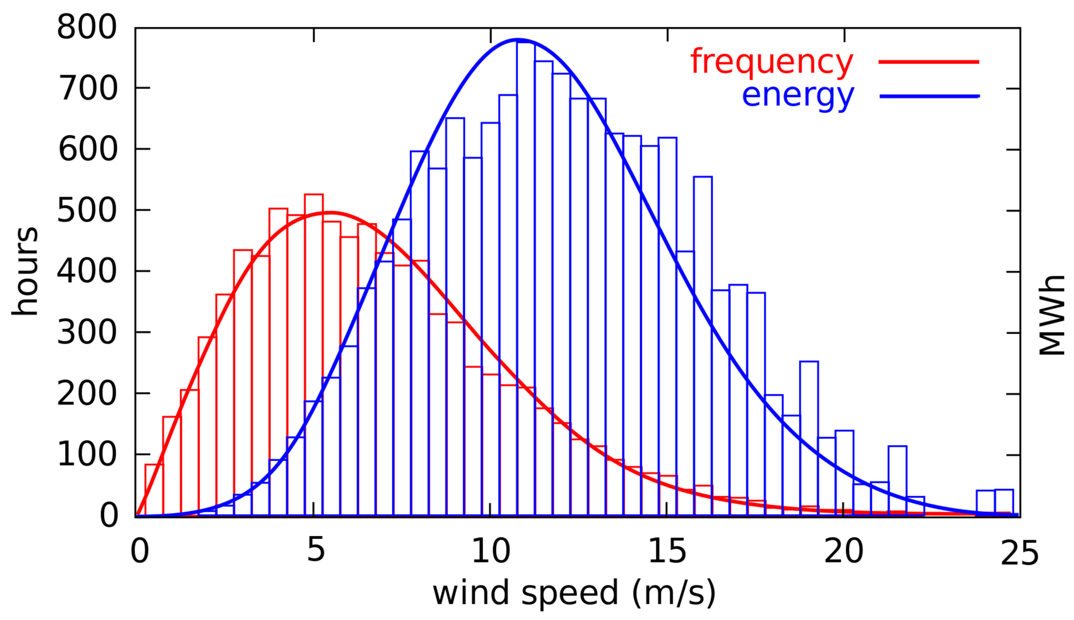
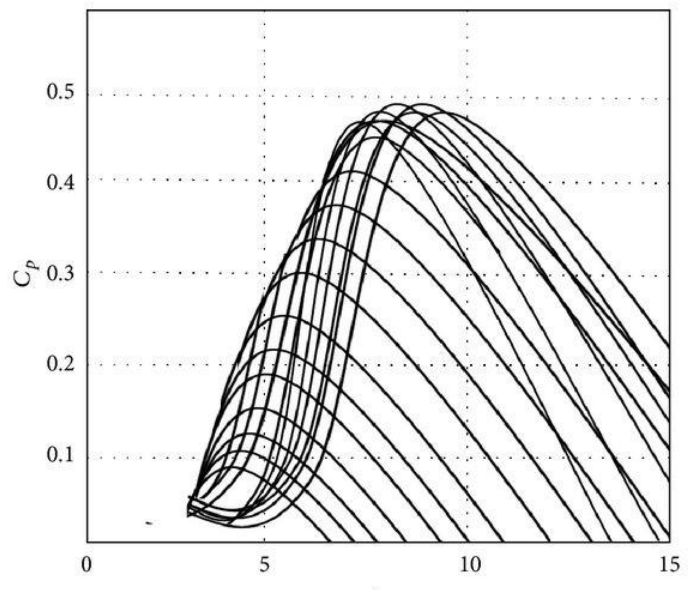
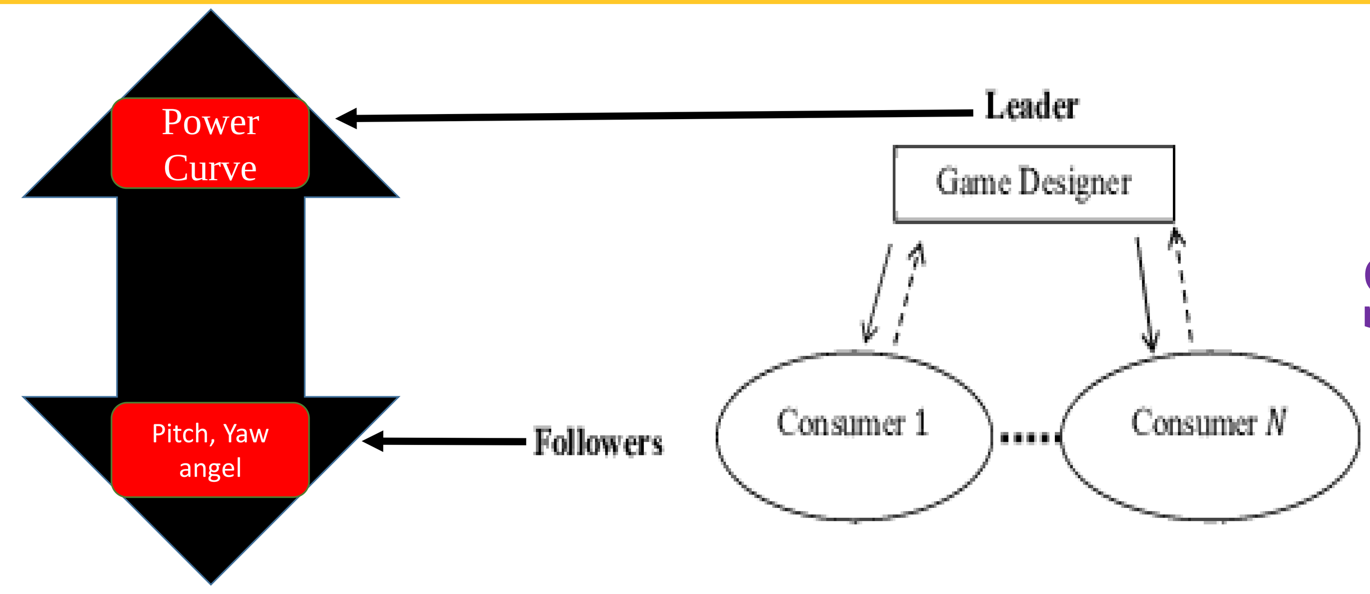
Abstract

This study proposes the optimal layout of an offshore wind farm (WF) micrositing for a fixed/imported number (N) of wind turbines (WTs) in a 2 km 2 km finite fixed area similar to previous studies with respect to the maximum power outage from the wind and inimum levelized cost of energy (LCOE) and maximum efficiency concerning highly desire from technical and commercial perspective. Thus, by applying an Stackelberg algorithm and game theory to the leaders and followers (objective functions), ensure that the optimal solution for the number of WTs used are placed at most optimum location in the WF to harness maximum power available in the wind with a more efficient and economical layout. Case studies with actual manufacturer data for same WTs with various hub heights and with realistic wind profile data are performed under the scope of research.





The power coefficient c_p versus the tip speed ratio [34].



Wind Turbine Power

The power curve of a wind turbine is a graph which indicates how large the electrical power output will be for the turbine at different wind speeds. Power curves are found by the field measurement where an anemometer is placed at a mast reasonably close to the wind turbine (not on it) . If the wind speed doesn't fluctuate rapidly then one may use the wind speed measurement from the anemometer and read the electrical power output form the wind turbine and plot two values together in a graph like the one above. There is a theoretical limit to the power which can be extracted from the turbine. This is known as the Betz limit. This limit was derived by Betz to correspond to 59% of the maximum available power which can be extracted by the turbine. The efficiency of a wind turbine is called the power coefficient and is defined by the following:

$$C_P = \frac{P}{\frac{1}{2}\rho U_\infty^3 A}$$

$$P_W = \frac{1}{2}\rho_{air}.A_r.C_p.(\lambda,\beta).v_w^3$$

Tip Speed Ratio

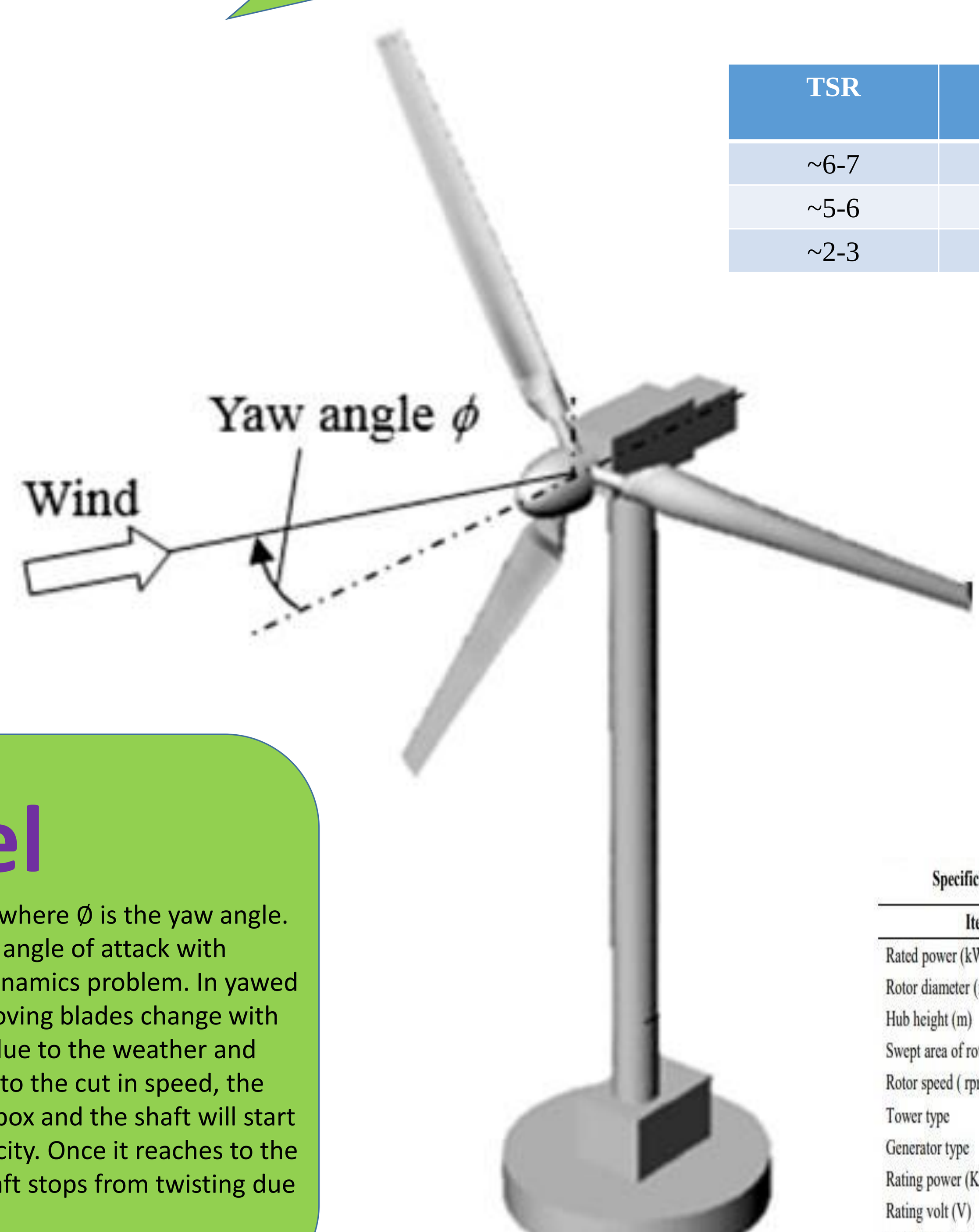
The tip speed ratio or briefly TSR, is the ratio between the tangential speed of the tip of a blade and the actual speed of the wind. The power coefficient depends upon the pitch angel and the tip speed ratio. The tip speed ratio can be formulated as follows:

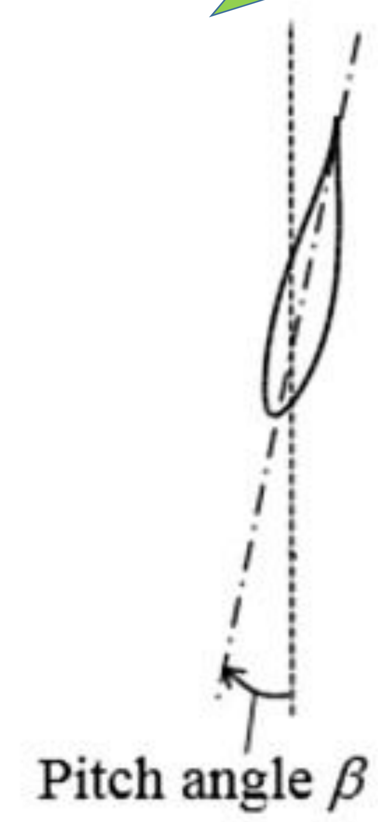
$$\lambda = \frac{\omega_{rot}.}{v_w}$$

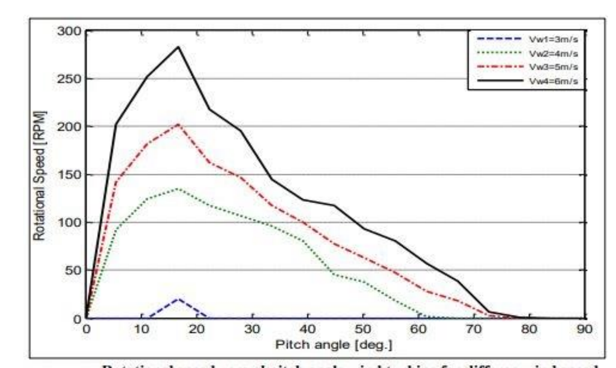
TSR	Number of Blades
~6-7	2
~5-6	3
~2-3	5

Pitch Angel

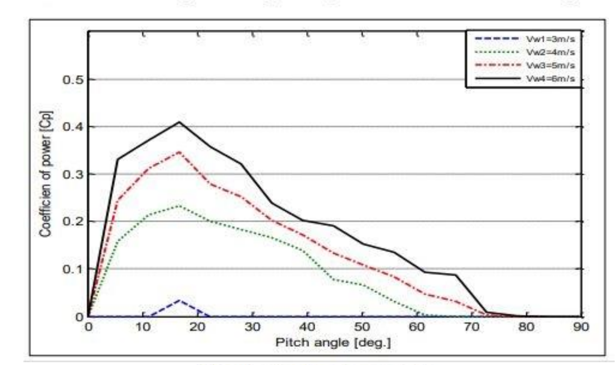
By knowing the ratio of the pitch angel β to the power outcome and their relation, we may use a linear regression to find the formula. From there we have a good combination of the formulas which they can work together as a game theory to find the optimized result of the allocation of the wind turbines in the wind farm. A pitch angel is automatically being set by the wind angel. By having this data we can determine the yaw angel to harness the most power output of the wind turbine.







Rotational speed versus pitch angle wind turbine for differen wind speed



The optimal regime characteristics

Yaw Angel

This yawed flow situation is depicted in the picture where ∅ is the yaw angle. The blade will experience a varying relative velocity and angle of attack with azimuthal blade position, leading to an unsteady aerodynamics problem. In yawed conditions, the wind speed and inflow relative to the moving blades change with azimuth angle. The yaw angel can be set automatically due to the weather and wind directions and speed. Once the speed ratio comes to the cut in speed, the generator inside the turbine starts to un-break the gearbox and the shaft will start to twist. Therefore the turbine starts to generate electricity. Once it reaches to the cut out speed, the gearbox put the break on and the shaft stops from twisting due to the safety and stability of the generator.

Specification of the wind turbine prototype

Item	Value
Rated power (kW), v=5m/s	50 W
Rotor diameter (m)	1
Hub height (m)	10
Swept area of rotor (m2)	0,785
Rotor speed (rpm)	20-500
Tower type	Tubular
Generator type	ALD50.PMA.
Rating power (KW)	0,05
Rating volt (V)	14/28
Rating amp (A)	3,57/1,79
RPM	500
(N*M)	< 0,15
Power	>65 %
Weight (kg)	6

Corelation theta, Vw and Pm for 100 s

Pitch angle position (deg.)	Wind power input (watt)	Mechanical power input (watt)	Electrical power output (watt)	Uncertainty (μ)
0	5193	0	0	0
5,6	5193	1233	850,77	1,3
11,2	5193	1461	1008,09	1,5
16,8	5193	1630	1124,70	1,6
22,4	5193	1394	961,86	1,4
28,0	5193	1250	862,50	1,3
33,6	5193	994	685,86	1,1
39,2	5193	777	536,13	1,0
44,8	5193	726	500,94	0,7
50,4	5193	602	415,38	0,7
56,0	5193	512	353,28	0,6
61,6	5193	338	233,22	0,6
67,2	5193	311	214,59	0,5
72,8	5193	89	61,41	0,5
78,4	5193	0	0	0
84,0	5193	0	0	0
89,6	5193	0	0	0

Stackelberg Game Approach

Stackelberg model, developed by a German economist H. Von Stackelberg in 1934 postulates a first-mover advantage for the oligopoly firm that initiates the process of determining market output. The idea is that we need to assign a party as a leader and the other ones, followers. The leader, However, has the authority of setting the game rules and prices due to its own profit. Followed by the prices set by leader, the followers should attend to their own profits afterwards. The leader has the authority to check the rational reaction sets of the follower in order to maximize its profits. In this case, we assume the power output of the wind farm is the follower and the pitch, yaw and tip speed angels are the followers. The goal is to maximize the leaders profit. In order to do that we have to make sure that we harvest the maximum electricity (power) form the wind farm. The power curve would be maximized and the leader will achieve its profit only by the best location of the wind turbines in the farm. As a result, one should set the location of the wind turbines due to the minimum wake effects. The wake effect, plays the most important roll of this micrositting. In another word, we need to find the spots in the wind farm which has the minimum affect of the ake effects on wind turbines. Plus, the turbines has a huge wake effect on each other due to the velocity decay. In order to minimize this, we need to locate the wind turbines in the spots also that they have the least affect on each others velocity too. One should understand that in this study, we assume the other parameters such as elevation of the ground, weather, wind conditions and, etc constant. Therefore the main focus is to harvest the most power in the least cost and the least investment. One other thing to mention is that, by finding the maximum efficient spot for the wind turbines, we might be able to minimize the cost of the investment too. There is a term called "LCOE" levelized cost of energy which determines the investment value in terms of material, installation, transmission, ground price, etc. As an investor point of view, the minimum investment value and maximum profit is efficient and optimized. By the optimized allocation, we provide enough data to obtain the minimum investment on the ground value. In another word, we can harvest the most amount of the electricity power in the smallest amount of the ground available.

Result

As a result of this poster, we provided the least amount of ground investment, in order to maximize the power output of the wind farm. By having enough data of the wind speed and angel, we can use these data to determine the best pitch and yaw angel of the turbine. Putting all together, we may determine the best allocation of the wind turbines by the least wake effect on each other that provides the maximum power output.

References

- Support from AU leadership center.
- Li, Qing'an, et al. "Effect of turbulence on power performance of a Horizontal Axis Wind Turbine in yawed and no-yawed flow conditions." *Energy* 109 (2016): 703-711.
- https://www.um.edu.mt/library/oar/bitstream/handle/123456789/18796/OA%20Chapter%20-%20%20A%20Review%20of%20Wind%20Turbine%20Yaw%20Aerodynamics.pdf?sequence=1&isAllowed=y
- http://www.savap.org.pk/journals/ARInt./Vol.3(1)/2012(3.1-61).pdf
- https://www.hindawi.com/journals/mpe/2013/982597/
- Azimian, Behrouz et al. "Stackelberg Game Approach on Modeling of Supply Demand Behavior Considering BEV Uncertainty." *2018 IEEE International Conference on Probabilistic Methods Applied to Power Systems (PMAPS)* (2018): 1-6.

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