Estimating the Available Solar and Eolian Energy to Size an Autonomous Mobile Energy Unit.

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Abstract

Several sources of environmental data are readily available. It is possible, through statistical analysis and simulation, to use to use these sources of data to ensure sufficient energy is available to power telecommunication systems using solar and wind powered energy units in a specific location. A good characterization of the wind turbine, solar panel arrays and battery banks are required to accurately model the charging/discharging cycles. A good model then allows for accurately sizing the energy units to provide a statistically acceptable availability.

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1 Available Sources of Environmental Data

A good example of the available sources of environmental data are the CWEEDS - provided by the Canadian government.

The CWEEDS files are computer data sets of hourly weather conditions occurring at 145 Canadian locations for up to 48 years of record, starting as early as 1953, and ending for most locations in 2001. The primary purpose of these files is to provide long term weather records for use in urban planning, siting and design of wind and solar renewable energy systems, and design of energy efficient buildings.

A second set of files, called CWEC (Canadian Weather year for Energy Calculation), has been provided for a limited number of the locations and includes data more specific to energy calculations.

The Canadian Weather for Energy Calculations (CWEC) files have been developed under the auspices of the National Research Council of Canada. They are derived using statistical criteria from long-term series of CWEEDS files.

The CWEC files are created by concatenating twelve Typical Meteorological Months selected from a database of, in most cases, 30 years of CWEEDS data. The method is similar to TMY procedure developed in the eighties by Sandia Laboratories. The months are chosen by statistically comparing individual monthly with long-term monthly means for daily total global radiation, mean, minimum and maximum dry bulb temperature, mean, minimum and maximum dew point temperature, and mean and maximum wind speed. The composite index used to select the most 'typical' months uses the following weights (in %).[2]

In this document, we explain how LYKO uses these sources of data to size appropriately it's mobile power units and to simulate their usage in a specific location - thus ensuring reliable operation with minimal human intervention.

2 Algorithmes

What LYKO's software does is relatively intuitive; it simulates, using an hourly sample time of archived environmental data, a full year of climate in a specified location; For each hour, it calculates the amount of energy that would have been produced by a solar array and a wind turbine. It then subtracts the load required (for example the radio system to be powered) and outputs the difference in a *battery capacity* variable. By looking at the variation of charge status of the battery bank through the whole year, it is possible to determine the lowest voltage that would have been reached by the battery bank, and even detect how many time, during that sample year, the batteries would have ended up empty.

The results can then be graphed, and - if required - the input parameters can be modified in order to achieve an acceptable performance - by adding battery capacity, solar panels or wind turbine for instance.

2.1 Required Information

The following parameters will influence the efficiency of the unit, and are therefore required to simulate a full year of autonomy. These are the input variables of LYKO's simulator:

Latitude and Longitude: Location where the unit will be deployed

Solar Panel's Surface Area: Surface of the solar panel array, in m^2

Nominal Power of Solar Panels: Nominal power of the solar array - based on the manufacturer's data-sheet

STC: Module performance is generally rated under standard test conditions (STC): irradiance of $1000 W/m^2$, solar spectrum of AM 1.5 and module temperature at $25°C$.

Solar Panel's Angle: Set angle of the solar array in reference to the horizontal plane (in deg.)

Azimuth: Set angle of the solar array in reference to geographic North (in deg.)

Load: Power (in Watts) that the unit will have to steadily output

Battery Bank Capacity: Capacity of the battery bank (in Ah)

Wind Turbine Type: This refers to a lookup table providing the power output of the wind turbine in function on the wind speed. This curve is different for every wind turbine make and model. See figure 5.

2.2 Theoretical Calculation of the Available Solar Energy

Calculating how much energy is generated by the solar panels is done in three steps.

First, we need to extract the total amount of available sun energy from the environmental database. The solar energy available is represented by two numbers; one for the direct irradiance, and one for the indirect irradiance - or ambient light.

Then, we need to calculate the This is called the /emphexposure ratio. This ratio is based on the effective angle between the sun and the normal to the solar panels. (i.e. a perpendicular to the panel's surface.)

Finally, the available energy is multiplied by a ratio, based on the efficiency of the panels and the angle of the sun. The result is a very good estimation of the amount of electrical energy that is then available for charging the batteries.

Calculating the position of the sun at a certain day and time is based on the algorithm presented by Reda et Andreas [1] From the date and time, their algorithm outputs the sun's azimuth (the vertical angle between the sun position and the North-South plane) and the sun elevation, in reference to the horizon.

The exposure ratio is determined as follow:

$$\Phi = \cos(A - \alpha) \cdot \cos(B - \beta)$$

Where:
Φ = Panels' exposure ratio

α_{sun} = Sun's azimuth - the vertical angle between the sun position and the North-South plane $\perp$ to the horizon
α_p = Solar panel's azimuth - the vertical angle between the panels and the North-South plane $\perp$ to the horizon
β_{sun} = The elevation of the sun in ref. to the horizon
β_p = Solar panels' elevation - the angle of the array in ref. to the horizon

This is still an estimation however, sufficiently accurate for our purposes, but several other factors influences the efficiency of a solar panels.

One of the main factors currently neglected in our calculations is the impact of temperature on solar panels. Most solar panels' performance charts are given using a reference temperature of 25 degree Celsius. Solar panel's efficiency increases in cold temperature. Therefore, for application in hot weather (regularly above 25C), this should be taken into account as it could lead to calculate an undersized solar array.

The following formulæ are then used to calculate the output (in Watts) generated by the solar panels during one hour:

$$W_{Out} = \frac{P_{nom}}{(STC * A) * (P_{direct} + P_{indirect})}$$

Where:
P_{nom} = Nominal Solar Panel Array Power (W)
$P_{direct} = \Phi * E_{Direct} * \frac{1000}{3600} * A\ (W)$
$P_{indirect} = E_{Diff} * \frac{1000}{3600} * A\ (W)$
Φ = Exposure ratio - as above.
E_{direct} = Direct Energy (J/m^2)
E_{diff} = Diffused Energy (J/m^2)
A = Solar Panel Surface Area (m^2)

2.3 Theoretical Calculation of the Available Wind Energy

The first step to estimating the wind available energy is to lookup the wind speed in the environment database - for each hour of the simulation.

The wind turbine manufacturers provide a table that expresses the amount of generated electrical energy produced in function of windspeed (see figure 5 on 11. This table is used to convert the wind speed (often given in m/s) into generated power in Watts.

2.4 Simulating the Battery Bank Charging Cycle

Another important factor in the simulation is the ability of the battery bank to absorb the energy produced. If the cumulative power generated by the wind turbine and the solar array is too high, the battery bank will not be able to store it, and it will be dissipated as heat. The type of batteries and size of battery bank arrays used by LYKO minimize the impact of this factor and is therefore not taken into account in the simulation software. It is however important to be aware of this when designing systems with smaller battery banks.

Cold temperature also has an effect on the maximum energy a battery can store. Even the best batteries' capacity is reduced in very cold climate. The simulation software calculates this limitation based on manufacturer's informations and environmental data. The effect of this limitation can be noticed on figures 2, 3,4 and 1. The *red* line shows the cumulative energy (in Wh) stored in the battery, while the pinkline shows the maximum theoretical battery capacity at the current temperature.

3 Validating the Model

Because the simulation software is based on some assumptions and estimations, it is critical to test the model before using it. The charge controllers used on LYKO's product allow data-logging over long periods of time. The simulation can therefore be compared to an actual period of logged data. This is the method we used to validate the theoretical model.

4 Sizing the Unit - an Application Example

In this example, we would like to calculate whether or not the AMU-900 unit would be sufficient to power a small radio load (around 35Watts) full time - 24 hours per day, 365 days per year. The challenge is that the system would be located on Baffin Island, by $71°19'24''N$ $079°12'38''W$.

By entering the coordinates in LYKO's software, we can notice that the closest dataset available is from Resolute, Nunavut. Although the two locations are not very close, the climate they experience is similar. Moreover, since Resolute is further up North, the simulation will tend to err on the safe side for our purpose.

This location may prove challenging since this area is above the arctic circle and the sun does not actually raises above the horizon for about four months per year. During that period, the solar array will receive no direct solar irradiance , so the AMU will have to rely solely on wind and ambient irradiance to generate power. Moreover, the area presents very little wind during the spring season.

The first simulation - shown on figure 2, (on page 8)- illustrates what would happen to a unit configured with an array of four solar panels, one wind turbine and six batteries over a year. Because the solar energy production (yellow line) falls to zero during the four winter months, it is not possible for the unit - relying on the wind turbine alone - to maintain the battery charge. During the month of February, the available energy in the batteries (red line) gets lower than the energy consumption (green line).

In the second simulation, show on figure 3 (on page 9) we added a second wind turbine, to see if this extra generated wind energy would be sufficient. The figure clearly show that the energy stored in the battery is always much higher than requirement of the load.

Because sun is absent for over three months in that area, one could question the relevance of having a solar array installed on this unit at all. In figure 4(on page 10), we simulated the effect of having two wind turbines installed, but no solar array. (Thus the yellow line remaining flat at the bottom of the graph.)

While this configuration allows the unit to energize the radio all winter long - without failing during the three month night from November to February, three obvious drops in battery power can be observed during March and April, because of the low wind conditions.

While solar energy is very steady almost everywhere, and provide a relatively steady supply of energy, winds tend to fluctuate a lot. This can be easily noticed by comparing the yellow and the blue lines on the graphs. The battery bank allows to take advantage of the high wind days. For a location where wind energy is predominant, it makes sense to increase the battery bank - thus allowing the unit to *flatten* or *smoothen* the energy stored curve - effectively allowing the unit to withstand a fluctuating charging source.

On the fourth simulation, we tested the effect of increasing the battery bank instead of increasing the wind turbine charging capacity. Figure 1(on page 7) illustrates a simulation for an AMU-900 configured with four 140W Solar Panels and one 340W Wind Turbine but using six batteries instead of four. The larger battery bank allows the unit to get through the windless periods without causing an outage on the radio system.

References

[1] Reda, I., Andreas, A. (2003) *Solar Position Algorithm for Solar Radiation Application. National Renewable Energy Laboratory (NREL) Technical Report NREL/TP-560-34302.*

[2] Environment Canada - Atmospheric Environment Service (AES) *CWEC Canadian Weather Energy and Engineering Data Sets - CWEEDS Files- and Canadian Weather for Energy Calculations-CWEC Files*

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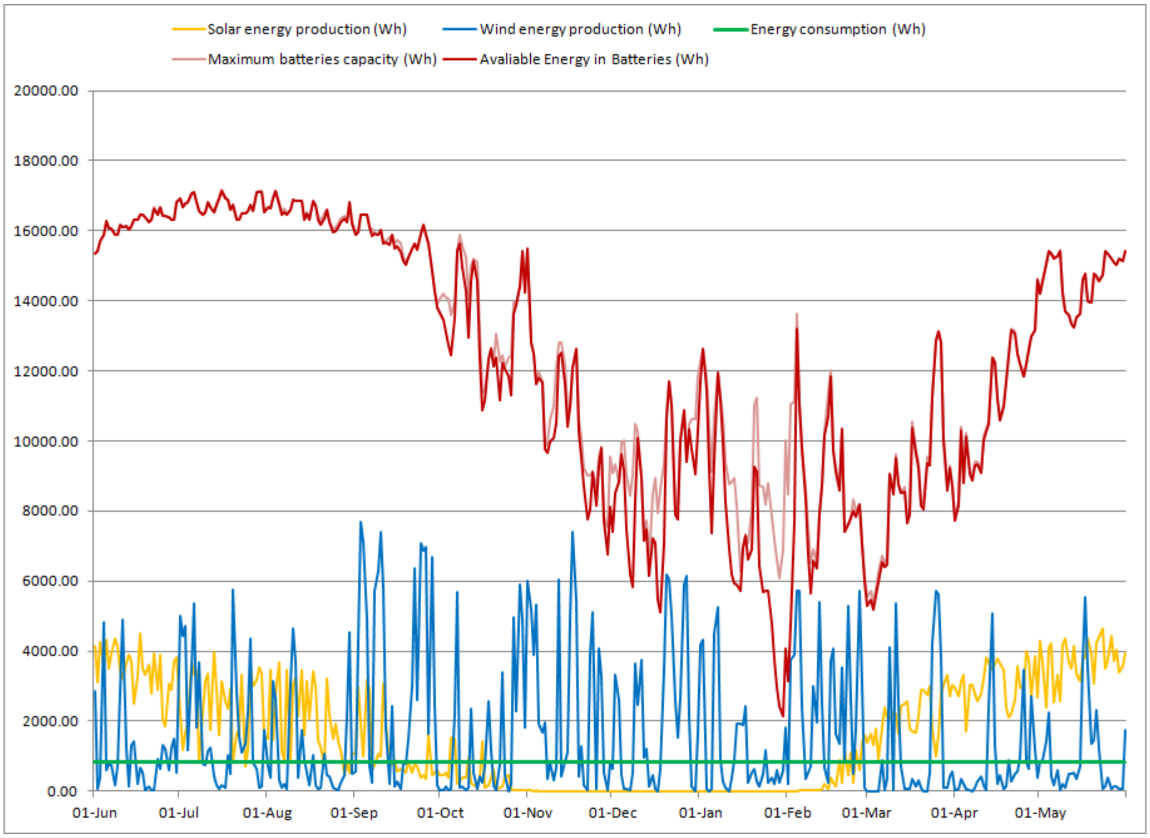

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configured with six batteries, four 140W Solar Panels and one 340W Wind Turbine.

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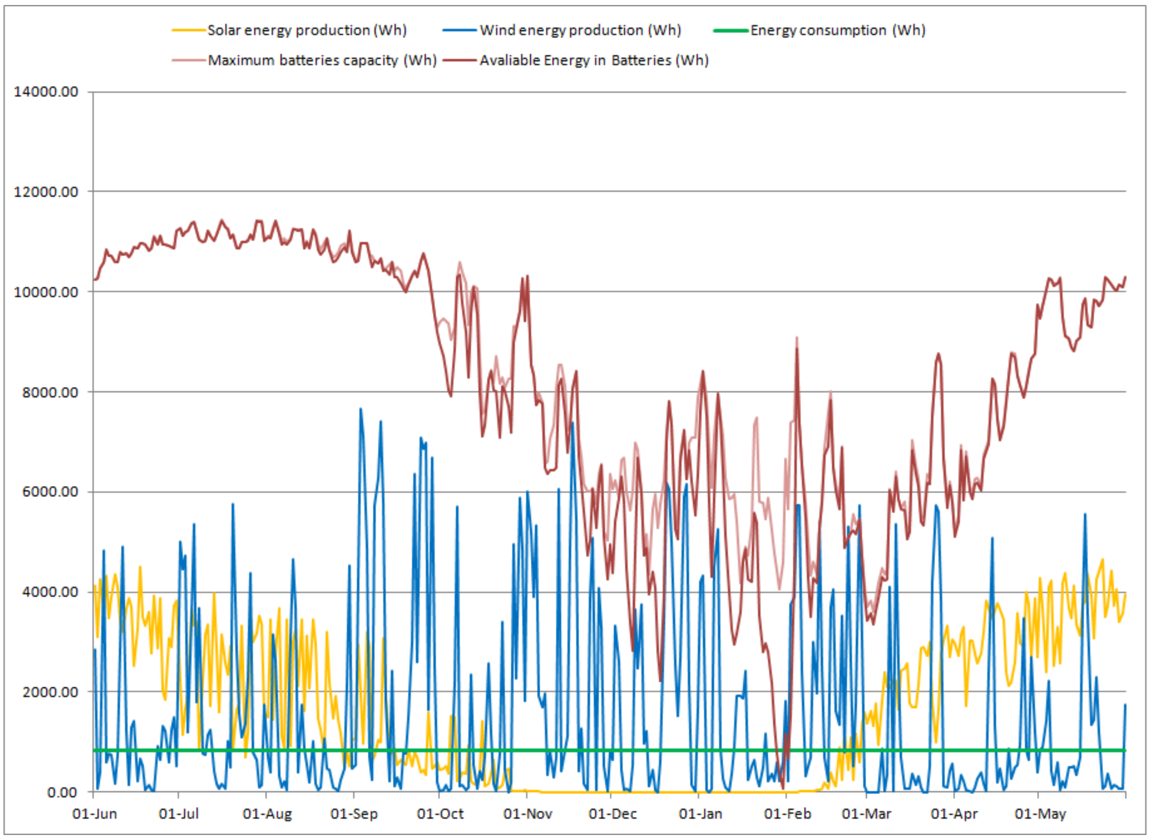

Figure 2: Simulation for an AMU-900 at $71°19'24''N$ $079°12'38''W$
configured with four batteries, four 140W Solar Panels and one 340W Wind Turbine.

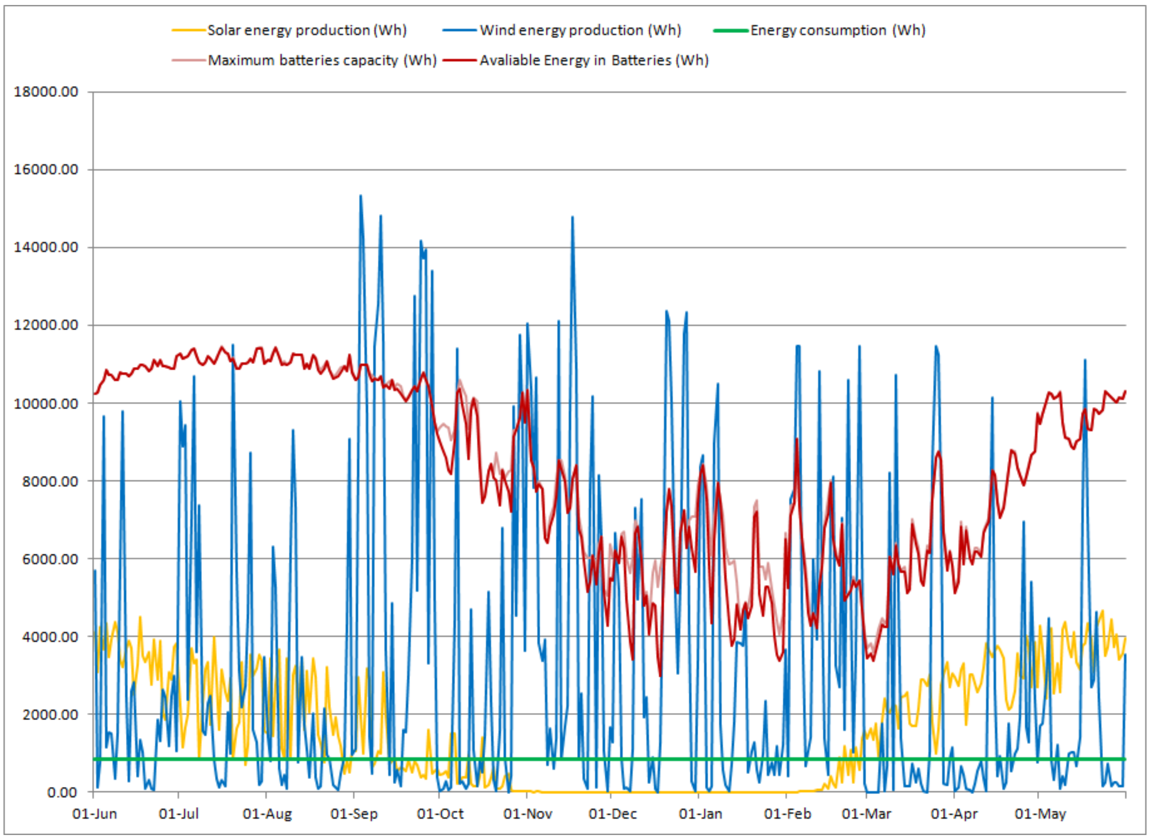

Figure 3: Simulation for an AMU-900 at $71°19'24''N\ 079°12'38''W$
configured with four batteries, four 140W Solar Panels and two 340W Wind Turbine.

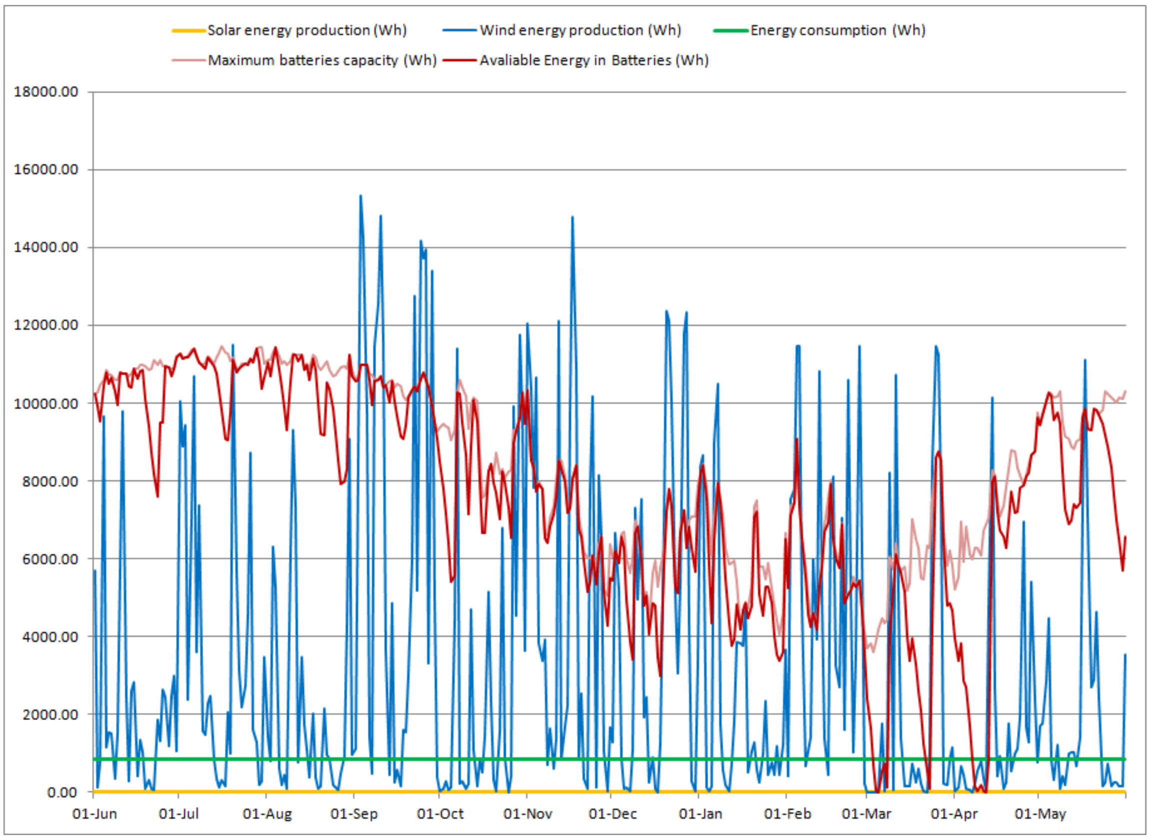

Figure 4: Simulation for an AMU-900 at $71°19'24''N$ $079°12'38''W$
configured with four batteries, no Solar Panels and two 340W Wind Turbine.

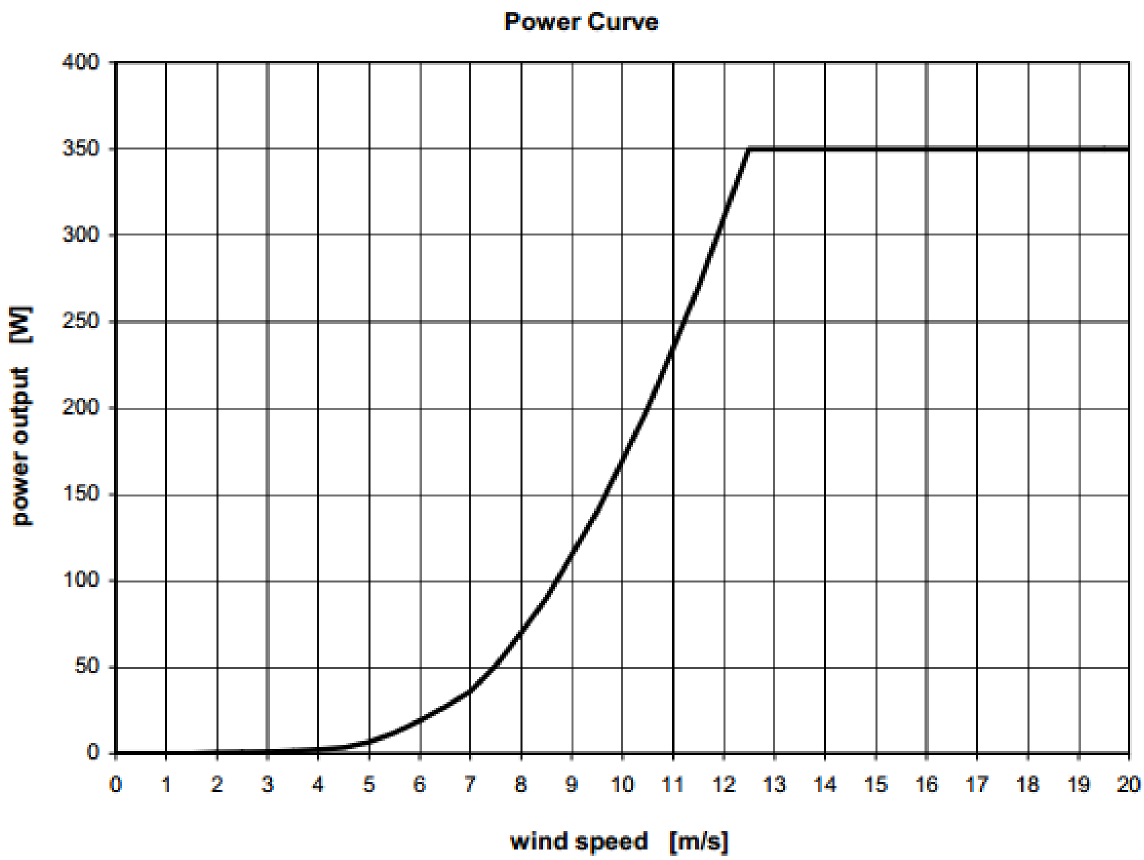

Figure 5: Power Output of the AMU-900's WindTurbine in Function of Wind Speed