Axial Flux Permanent Magnet Generator (AFPMG) Designer Documentation

2015-09-28

1 Introduction

This document describes the AFPMG Designer and the used calculations. The Designer is based on the following article: Axial Flux Permanent Magnet Generator Design for Low Cost Manufacturing of Small Wind Turbines (K.C. Latoufis) with modifications and additions.

The designer can be used to design an Axial Flux Permanent Magnet Generator (AFPMG) system. This includes the generator and the front end and back end. With front end the way the generator is driven is described. With the back end the of the generator the conversion from ac to dc, transportation and storage of energy is described.

In general an AFPMG including the front and back end can be described as follows:

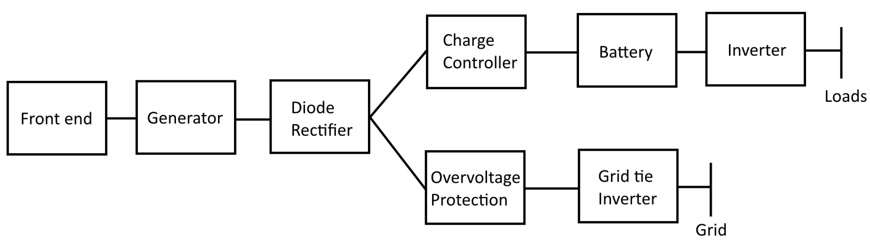

Figure 1: Schematic overview of an AFPMG system.

- **Front end and energy storage**
  The generator shaft has to be rotated with a certain force in order to produce power. This can be done using a variety of devices (e.g. wind turbine, water wheel or another generic device).
- **Generator**
  The generator generates power by moving magnets through a series of coils. The amount of coils, turns per coil and magnet size determine the performance of the generator.
- **Rectifier**
  The rectifier converts the Alternating Current (AC) to Direct Current (DC). This process is known as rectification.
- **Energy storage**
  The produced power has to be stored into a battery or returned to the grid.

2 Front end and energy storage

2.1 Horizontal wind turbine

When designing a AFPMG with a wind turbine as front end it is important to know the following things:

1. The amount of power (W) that has to be delivered by the wind turbine.
2. The minimal wind speed ($v_{minimum}$) **and** speed tip ratio (Λ) from where the generator starts generating its power.
3. The maximal wind speed ($v_{maximum}$) **and** speed tip ratio (Λ) from where the generator stops generating its power because the furling tail aerodynamic braking system starts to function.

The following values will be used:

1. 3000 Watt of rotational power is required.
2. Minimal wind speed is 3 m/s (depends on the used energy storage/return).
3. Minimal speed tip ratio is 8.75.
4. Maximal wind speed is 10 m/s.
5. Maximal speed tip ratio is 7.

Using this data the dimensions for the rotor radius as well as the RPM of the wind turbine rotor during minimal and maximal wind can be determined. The general equation for the rotational power from wind is as follows:

$$P_{\text{rotational max.}} = \frac{1}{2} \times \rho \times \pi \times R_{turbine}^2 \times v_{maximum}^3 \times C_p \times \eta \tag{1}$$

$P_{\text{rotational max.}}$ is the maximum required rotational power (W).
ρ is the air density (kg/m^3).
$R_{turbine}$ is the turbine radius (m).
$v_{maximum}$ is the maximum wind speed (m/s).
C_p is the power coefficient. Good turbines generally have C_p in the 35-45% range.
η is the generator efficiency. Generally AFPMG have a efficiency of 90% during normal operation.
Using this equation the rotor radius can be calculated:

$$R_{turbine} = \sqrt{\frac{2 \times P_{\text{rotational max.}}}{\pi \times \rho \times C_p \times v_{maximum}^3 \times \eta}} \tag{2}$$

$$R_{turbine} = \sqrt{\frac{2 \times 3000}{\pi \times 1.2 \times 0.35 \times 10^3 \times 0.90}} \tag{3}$$

$$R_{turbine} = 2.25 \text{ (m)} \tag{4}$$

After we have calculated the turbine radius it is important to know the minimun and maximun RPM (n) the rotor will rotate. This can be calculated using the speed tip ratio (Λ).

The tip speed ratio is the ratio between the tangential speed of the tip of a blade and the actual velocity of the wind. The tip speed ratio is related to efficiency, with the optimum varying with blade design. Higher tip speeds result in higher noise levels and require stronger blades due to large centrifugal forces.

$$\Lambda = \frac{\text{Tip speed of the blade}}{\text{Wind speed}} = \frac{\omega \times R_{turbine}}{v} = \frac{2 \times \pi \times n \times R_{turbine}}{60 \times v} \tag{5}$$

Λ is the tip speed ratio.
n is the rotational speed of the rotor in revolutions per minute (RPM).
$R_{turbine}$ is the turbine radius (m).
v is the wind speed (m/s).

Using this formula the minimum and maximum rotor RPM (n) can be calculated.

$$n = \frac{60 \times v \times \Lambda}{2 \times \pi \times R_{turbine}} \tag{6}$$

$$n_{minimum} = \frac{60 \times 3 \times 8.75}{2 \times \pi \times 2.25} = 111 \tag{7}$$

$$n_{maximum} = \frac{60 \times 10 \times 7}{2 \times \pi \times 2.25} = 297 \tag{8}$$

2.1.1 Horizontal wind turbine with battery storage

2.1.2 Horizontal wind turbine with grid return

2.2 Generic device

2.2.1 Generic device with battery storage

2.2.2 Generic device with grid return

Glossary

C_p	The Power coefficient
$P_{\text{rotational max.}}$	The maximum rotational power of a wind turbine (W)
$R_{turbine}$	The wind turbine radius (m)
η	The generator efficiency (%)
ρ	The air density (kg/m^3)
$v_{maximum}$	The maximum wind speed (m/s)
$v_{minimum}$	The minimum wind speed (m/s)

Value's with the unit percentage (%) should be converted to its decimal when used in calculations (e.g. 35%/100 = 0.35).