

# Axial Flux Permanent Magnet Generator (AFPMG) Designer Documentation

JR

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# 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:

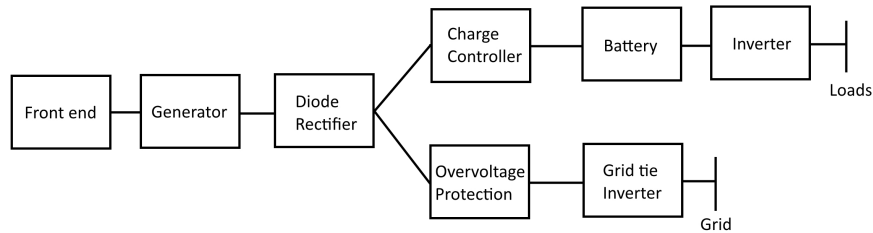


Figure 1: Schematic overview of an AFPMG system.

- **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

### 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 ( $\Lambda$ ) from where the generator starts generating its power.
3. The maximal wind speed ( $v_{maximum}$ ) **and** speed tip ratio ( $\Lambda$ ) 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:

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

$P_{\text{rotational max.}}$  is the maximum required rotational power (W).

$\rho$  is the air density ( $kg/m^3$ ).

$R_{\text{turbine}}$  is the turbine radius (m).

$v_{\text{maximum}}$  is the maximum wind speed (m/s).

$C_p$  is the power coefficient. Good turbines generally have  $C_p$  in the 35-45% range.

$\eta$  is the generator efficiency. Generally AFPMG have a efficiency of 90% during normal operation.

Using this equation the rotor radius can be calculated:

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

$$R_{\text{turbine}} = \sqrt{\frac{2 \times 3000}{\pi \times 1.2 \times 0.35 \times 10^3 \times 0.90}} \quad (3)$$

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

After we have calculated the turbine radius it is important to know the minimum and maximum RPM (n) the rotor will rotate. This can be calculated using the speed tip ratio ( $\Lambda$ ).

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.

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

$\Lambda$  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.

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

$$n_{minimum} = \frac{60 \times 3 \times 8.75}{2 \times \pi \times 2.25} = 111RPM \quad (7)$$

$$n_{maximum} = \frac{60 \times 10 \times 7}{2 \times \pi \times 2.25} = 297RPM \quad (8)$$

## 2.2 Generic device

When designing a AFPMG with a generic device it is important to know the power it outputs and at what RPM.

### 3 Energy storage

Before the design of the generator itself can begin we first look at a common problem that occurs: Voltage drop. During transport of the generated power to the storage facility (battery or grid) voltage drop occurs. The supplied energy of a voltage source is reduced as electric current moves through the passive elements of an electrical circuit.

The AFPMG system contains three sources that are subject to voltage drop.

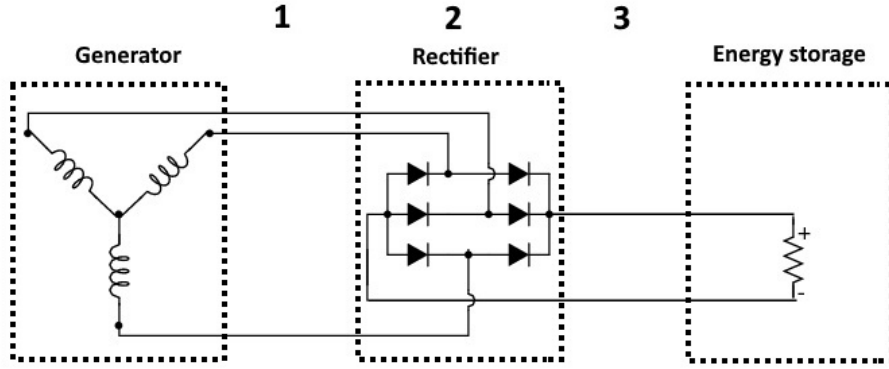


Figure 2: Schematic overview of voltage drop sources.

In the phase lines that go to the rectifier voltage drop occurs. The amount of voltage drop depends on the length, diameter and current of the wires.

Voltage drop in a phase line can be calculated as follows:

$$V_{\text{drop 3 phase}} = I_{\text{drop 3 phase}} \times (2 \times R_{\text{drop 3 phase}}) \quad (9)$$

$V_{\text{drop 3 phase}}$  is the voltage drop (V).

$I_{\text{drop 3 phase}}$  is the current flowing through the wire (A)

$R_{\text{drop 3 phase}}$  is the resistance of the phase wire (Ohm).

The resistance of the a phase line is calculated as follows:

$$R_{\text{drop 3 phase}} = \frac{(0.0000000168 \times L_{\text{drop 3 phase}})}{\pi \times \text{Radius}_{\text{drop 3 phase}}^2} \quad (10)$$

$R_{\text{drop 3 phase}}$  is the resistance of the phase wire (Ohm).

$L_{\text{drop 3 phase}}$  is the length of the phase wire (m).

$\text{Radius}_{\text{drop 3 phase}}$  is the radius of the phase wire (m).

#### 3.0.1 Battery storage

#### 3.0.2 Grid return

## Glossary

$C_p$	The Power coefficient
$I_{\text{drop 3 phase}}$	The current flowing through the lines from the coil phases to the rectifier(V).
$L_{\text{drop 3 phase}}$	The length of a phase wire from the coil phases to the rectifier(m).
$P_{\text{rotational max.}}$	The maximum rotational power of a wind turbine (W)
$R_{\text{drop 3 phase}}$	The resistance of the lines from the coil phases to the rectifier(Ohm).
$R_{\text{turbine}}$	The wind turbine radius (m)
$\text{Radius}_{\text{drop 3 phase}}$	The radius of a phase wire from the coil phases to the rectifier(m).
$V_{\text{drop 3 phase}}$	The voltage drop in the lines from the coil phases to the rectifier(V).
$V_{\text{drop rectifier}}$	The voltage drop that occurs in the rectifier components (V)
$V_{\text{drop rectifier}}$	The voltage drop in the lines from the rectifier to the energy storage/return facility. (V)
$\Lambda$	The tip speed ratio.
$\eta$	The generator efficiency (%)
$\rho$	The air density ( $kg/m^3$ )
$v_{\text{maximum}}$	The maximum wind speed (m/s)
$v_{\text{minimum}}$	The minimum wind speed (m/s)
$v$	The wind speed (m/s)
	The rotor rotational speed (radians/second)
n	The rotor revolutions per minute (RPM)

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