DESIGN ASPECTS OF A RESIDENTIAL WIND GENERATOR

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Abstract - In this paper we present some aspects about the design of a small permanent magnet wind generator with axial magnetic flux often used in residential wind turbine. There are summarised the main steps of the magnetic and electric calculations with applications to a particular case: 0.6 kVA wind generator. The axial flux wind generator design starts with the characteristics of the rare earths permanent magnet existing on the market.

Keywords: renewable energy, axial wind generator, permanent magnets electrical machines.

1. INTRODUCTION

Small wind power generators are usually made in the form of permanent magnets synchronous generators. Since the wind turbine usually has a low speed, below 400 rpm it is recommended to realize permanent magnet synchronous generators with a high number of pairs of poles, in order to assure a frequency close to 50 Hz for the generated voltage. There is no question that the frequency is going to be kept constant at 50 Hz as a speed regulator is uneconomically in terms of price for low power wind turbine.

In the Fig. 1 is presented the structure of an off grid horizontal wind turbine. The horizontal wind turbine will be of variable speed, but the variable frequency generated voltage, will not have importance because the generated three phase voltage system will be rectified in a battery charger and the obtained d.c. voltage will be sent to a battery bank, from where by means of an inverter the electric energy will be sent to an a.c. electric energy consumer.

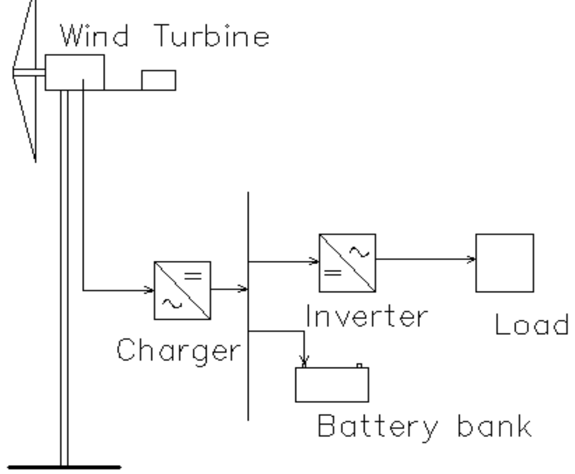


Fig. 1: The structure of an off grid wind turbine.

The structure presented in the figure 1 is suitable for residential wind turbine because they are of small rated power. The wind turbine has three main components: the horizontal wind turbine with 3 pales, the wind generator and the orientation vane.

Most of the small wind power generators [1-2] are made in the form of permanent magnet synchronous generators with radial magnetic flux.

In this paper we will design a permanent magnet synchronous wind generator with axial magnetic flux because its construction is more accessible by amateurs who do not have access to advanced machine tools [3].

Synchronous generator with permanent magnets and axial flow was first proposed by Honorati in 1991 and in 1992 by Carrichi [1] in a constructive solution with toroidal winding type.

The solution adopted for the wind turbine for residential application to be used with axial flux permanent magnet synchronous generator which will be analyzed and designed in this paper is shown in Fig. 2.

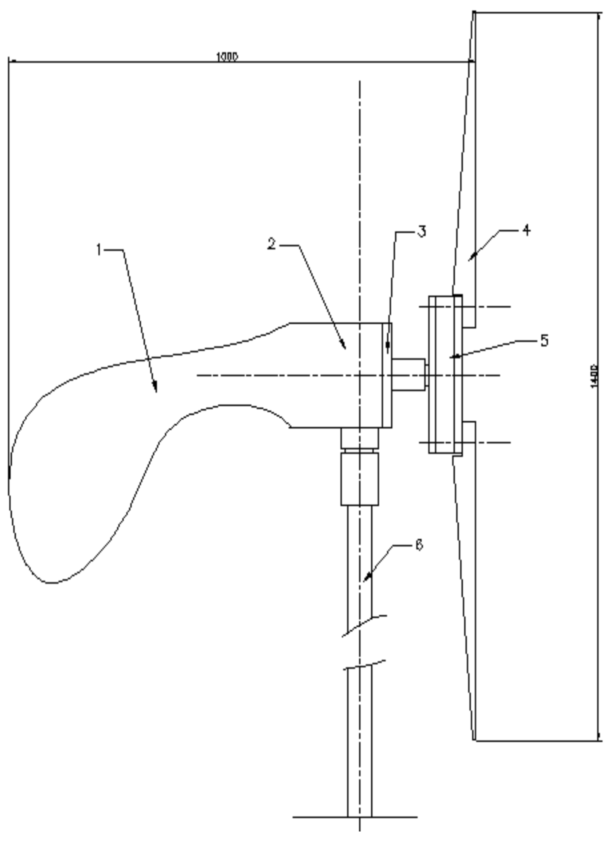


Fig. 2: The wind turbine for residential application: 1 – orientation vane; 2 – nacelle; 3 – support; 4 – blade; 5 – wind generator; 6 – mast.

This type of three blade wind turbine is a variable speed wind turbine which is stall regulated. This means that the attack angle of the blade is chosen in such a way, so that at wind speed higher than rated wind speed, the turbulence appears and the output power goes down like in figure 3. In this way, the wind turbine is protected at higher wind speeds.

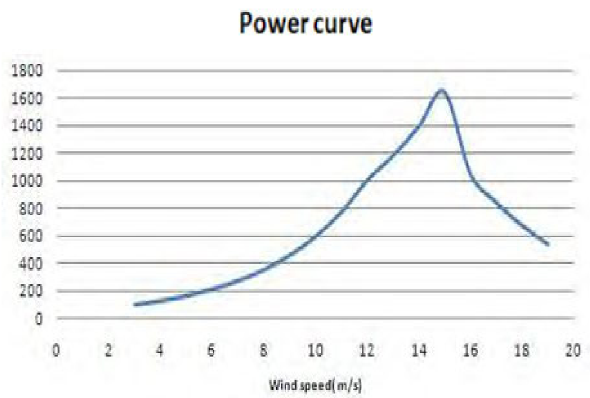


Fig. 3 The wind power curve for small power wind turbine.

For this kind of wind generator, in the following will be established a design methodology and this methodology will be applied in a case study for an axial flux permanent magnet wind generator of a small power (S_n=0.6 kVA).

2. THE MAGNETIC CIRCUIT DESIGN OF THE AXIAL WIND GENERATOR

In the book [1] there are presented a lot of constructive solution for axial flux permanent magnet generators. We have chosen an axial flux permanent magnets generator with an iron free stator, a cross-section through it being presented in the Fig.4.

The main components are: the rotors 1 and 5, made from soft magnetic iron, on which are place a big number of parallelepiped shape permanent magnets 2 like in Fig. 4a; the stator 3 with a coils 4 cast in epoxy resin and an ax 7.

The stator 3 and the ax 7 wil be fixed in the nacelle 2 by support 3 from figure 2.

The rotors 1 and 5 with permanent magnets fixed on them like in figure 5 a) are rotating by means of two bearings. On the rotor 1 will be fixed the three wind turbine blades like in figure 2.

The coils are cast in the epoxy resin stator like in figure 5 b). The interior windows of coils have the same dimensions as the permanent magnets.

In the Fig. 4b is presented the placement of the coils in the stator. It is recommended 1 and 1/3 magnets for 1 coil [3].

According with this recommendation we can build the following alternator forms: Table 1 [5].

From this table we have choosen a structure of p=12 magnets and 9 coils with q=3 coils on a phase. The structures of the rotor looks like in figure 5a.

Table 1 The number of magnets and coils.

Coils	Magnets	Coils/Phase
6	8	2
9	12	3
12	16	4
15	20	5
18	24	6

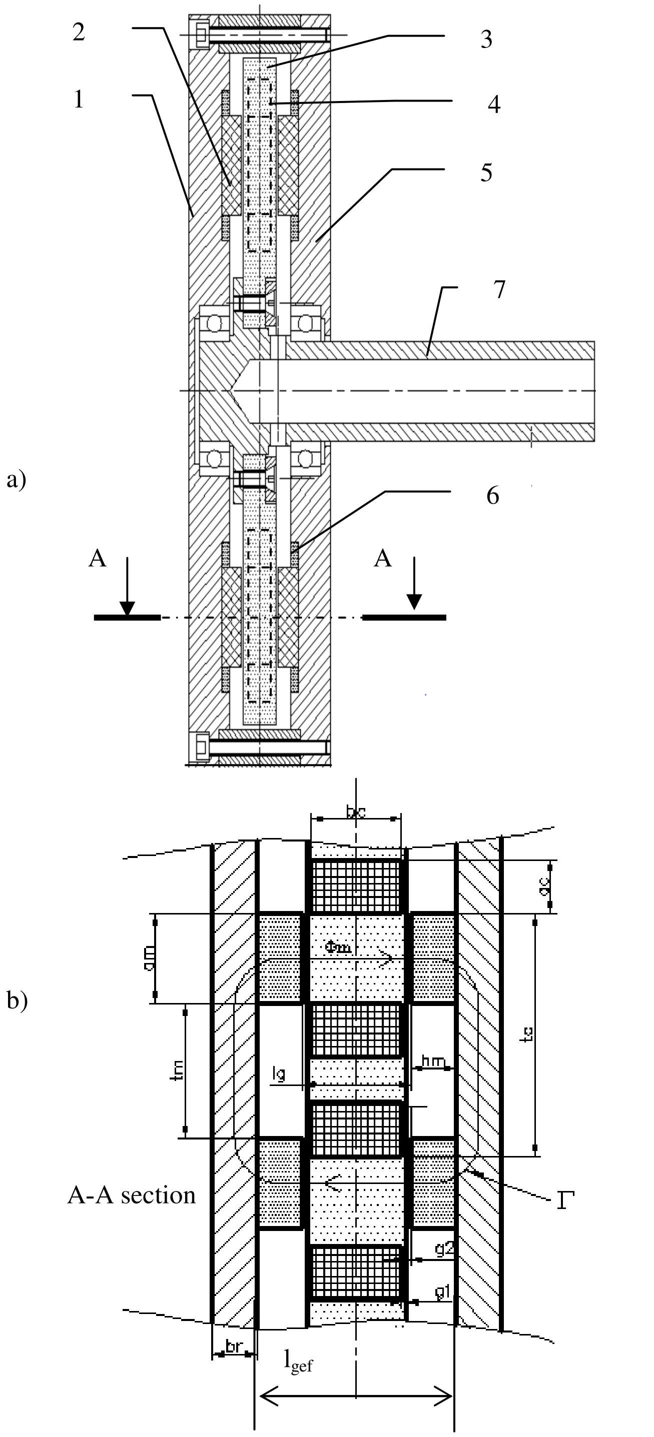
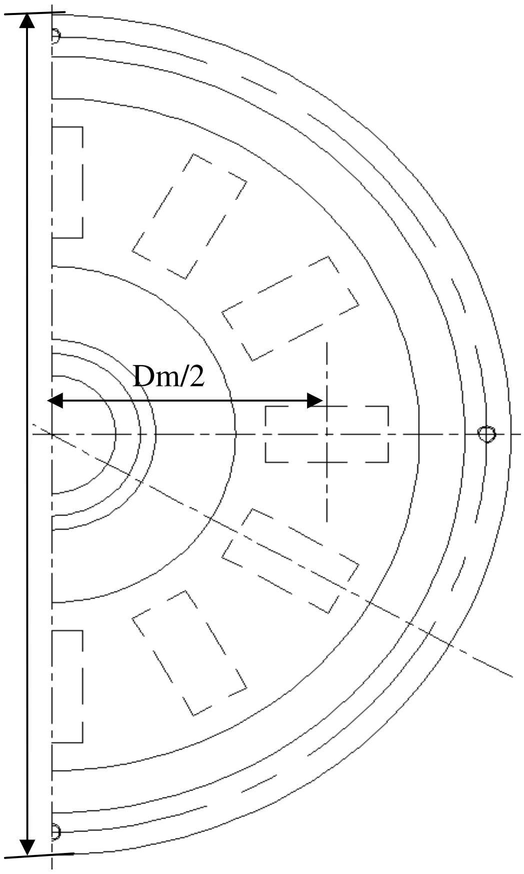


Fig. 4: a) The axial flux permanent magnets wind generator with iron free stator: 1 - rotor 1; 2 – permanent magnets, 3 – stator; 4 – coils; 5 – rotor 2; 6 – epoxy resin; 7 – ax; b) the cross-section through the rotor.



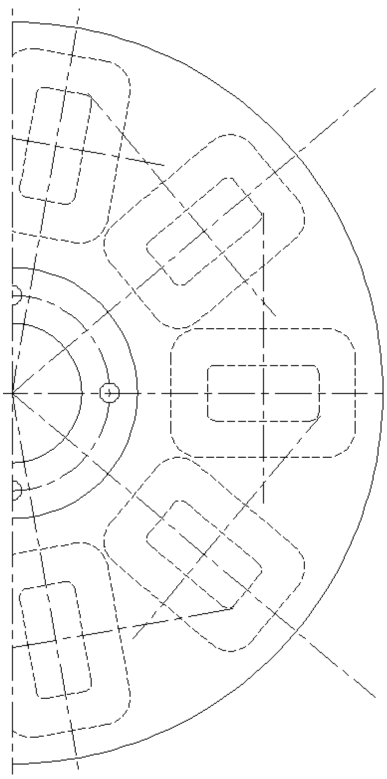


Fig.5 a) The placement of permanent magnets on the rotor; b) the placement of coils on the stator, D_e is the outer diameter of the rotor, and D_m is the average diameter for placing the permanent magnets and the stator coils.

For all kind of electric machines the design procedure starts from the imposed rated apparent power, in our case for a multi-pole 3 phase generator we have:

$$S_n = mqUI[VA] \tag{1}$$

where m=3 is the phase number and q=3 is the total number of coils per phase, U is the induced voltage in a coil and I is the coil current.

The magnetic flux through a coil is:

$$\varphi = \Phi_m \cdot \cos(\omega t), \tag{2}$$

and the induced voltage in a coil, according with the induction law, has the expression:

$$e = -N\frac{d\varphi}{dt} = -N\omega\Phi_m \cdot \sin(\omega t) = \\ = -E_m \cdot \sin(\omega t) \tag{3}$$

with the amplitude:

$$E_m = N\omega\Phi_m = \sqrt{2}E, \tag{4}$$

where „N" is the number of turns for one coil and E is the rms value of coil induced voltage.

$$E = \frac{N\omega\Phi_m}{\sqrt{2}} = 4.44 fN\Phi_m \tag{5}$$

The maximum value of the excitation magnetic flux is:

$$\Phi_m = B_g A_c = k_\sigma B_m A_m \tag{6}$$

where:

$$k_\sigma = B_g / B_m \approx 0.6 < 1, \tag{7}$$

is the stray coefficient as a rapport between air-gap magnetic flux density B_g and permanent magnet magnetic flux density B_m, supposing that the inner area of coil is exactly like the transversal area of permanent magnet (Fig. 4 b)

$$A_c \approx A_m = a_m l_m. \tag{8}$$

The rms value of a coil voltage is:

$$E = 4.44 \cdot k_\sigma \cdot f \cdot N \cdot B_m \cdot A_m. \tag{9}$$

Then the total apparent power is:

$$S_n = m \cdot q \cdot E \cdot I = \\ 4.44 \cdot m \cdot q \cdot f \cdot N \cdot k_\sigma \cdot B_m \cdot A_m \cdot I. \tag{10}$$

If the wind turbine has a rated speed of *n=250 rpm*, then for having frequency at 50 Hz we must have a number of pairs of poles (one north pole on a rotor and a south pole on another rotor):

$$p = \frac{3000rpm}{250rpm} = 12, \qquad (11)$$

which is exactly like the number of poles we have already chosen.

The coil transversal area will be related to the total current:

$$A_c = a_c \cdot b_c = \frac{NI}{J_a \cdot k_f}, \qquad (12)$$

where, J_a=10A/mm^2 is the admissible current density in the coil, k_f = 0.5 is an acceptable filling factor at coil winding, and a_c and b_c are the dimensions of the . transversal crossection of the coil (Fig. 6)

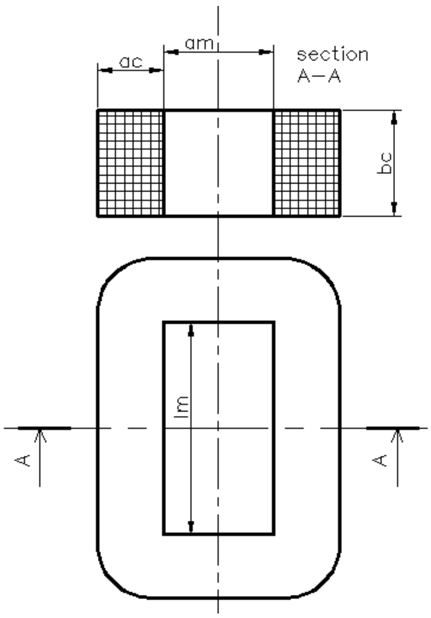


Fig. 6: The coil shape.

Now the total apparent power looks like:

$$S_n = m \cdot q \cdot E \cdot I = 4.44mqk_\sigma k_f fJ_a B_m A_m a_c b_c, \qquad (13)$$

From this equation can be seen that the same power can be obtain with a big magnet area A_m and a small cross-section area of the coil A_c or vice-versa.

From a permanent magnet supplying company [5] we have chosen the magnet type NdFeB 40x20x10 N52 (Fig. 7) with the characteristics given in Table 2.

Fig. 7: The permanent magnet.

Table 2. Permanent magnet characteristics.

	Gauss (G)	Tesla (T)	kOe	kA/m	kOe	kA/m	MGOe	kJ/m³	°C
N42	12900-13200	1.29-1.32	10.8-12.0	860-955	≥12	≥955	40-42	318-334	≤80
N45	13200-13700	1.32-1.37	10.8-12.5	860-995	≥12	≥955	43-45	342-358	≤80
N48	13700-14200	1.37-1.42	10.8-12.5	860-995	≥12	≥955	45-48	358-382	≤80
N50	14000-14600	1.40-1.46	10.8-12.5	860-995	≥12	≥955	47-51	374-406	≤80
N52	14200-14700	1.42-1.47	10.8-12.5	860-995	≥12	≥955	48-53	380-422	≤65

After the placing of the 12 magnets in a polar array we obtain a rotor diameter of D_e=300mm, and the average diameter of magnets and coils circle of D_m=190mm (Figure 5a).

The coils must be placed in a fixed stator in a polar array with 9 objects and the same medium diameter like magnets array (Figure 5b).

From constructively point of view, from these two figures we can appreciate the coil width a_c≅15mm from geometrical rations, knowing the permanent magnet dimensions, respectively the coils interior dimensions.

The coils thickness b_c will be calculated from rated power formula (13), and is is a main component of the total air gap l_{gef} (Fig. 4 b) aside the permanent magnets thickness h_m and the mechanical air-gap g_2.

From the Table 2, for the chosen magnets type we will appreciate the remanence B_r=1.44T, the coercivity H_c=900kA/m and the maximum magnetic energy $(BH)_{max}$=400 kJ/m^3.

3. THE COILS DESIGN

As we stated before we have chosen 12 magnets on the rotor with 9 coils on the stator, that means that a three phase winding will have 3 coils on a phase.

The inner area of coils will be identically with permanent magnet area like in figure 5.

The coil width $a_c \cong 15mm$ has been chosen from the constructively point of view (Fig. 5), the second cross-section dimension, the thickness b_c will be calculated from the relation (13):

$$b_c = \frac{S_n}{4.44 m q k_\sigma k_f f J_a B_m A_m a_c} = \frac{600}{4.44 \cdot 3 \cdot 3 \cdot 0.6 \cdot 0.5 \cdot 50 \cdot 10 \cdot 0.7 \cdot 8 \cdot 10^{-4} \cdot 15} =, \quad (14)$$
$$13mm$$

where S_n=600VA is the apparent rated power taken in consideration for the case study, and the permanent magnet flux density $B_m = B_r/2 = 0.72T$.

The equivalent air-gap has the length (Figure 3b):

$$l_{gef} = 2h_m + b_c + 2g_1 + 2g_2 = 2 \cdot 10 + 13 + 2 \cdot 1 + 2 \cdot 1 = 37mm \quad (15)$$

From the Ampere law [6], neglecting the magnetic potential drop in the rotor iron, we can write for a Γ contour (figure 3b):

$$\oint_\Gamma \overrightarrow{H} \cdot \overrightarrow{dl} = 4H_m \cdot h_m + 2H_g \cdot l_{gef} = 4 \cdot \frac{B_m}{\mu_{rm} \cdot \mu_0} \cdot h_m + 2 \cdot \frac{B_g}{\mu_0} \cdot l_{gef} = 0 \quad (16)$$

From here results the magnetic flux density in the air-gap:

$$B_g = 2 \cdot \frac{B_m}{\mu_{rm}} \cdot \frac{h_m}{l_{gef}} = 2 \cdot \frac{0.72}{1} \cdot \frac{10}{37} \approx 0.4T \quad (17)$$

Knowing that $U_f = 36\,Vca$, we can find the coil voltage:

$$U_c = \frac{U_f}{3} = \frac{36}{3} = 12\,V \quad (18)$$

But the expression of induced voltage in a single coil is:

$$U_c = 4.44 \cdot f \cdot N_c \cdot \Phi_c = 4.44 \cdot f \cdot N_c \cdot B_g \cdot A_m \quad (19)$$

From equation (19) we can find,

$$N_c = \frac{U_c}{4.44 \cdot f \cdot B_g \cdot A_m} = \frac{12}{4.44 \cdot 50 \cdot 0.4 \cdot 8 \cdot 10^{-4}} = 169\ turns \quad (20)$$

The coil conductor cross-section area will be:

$$s_c = \frac{a_c \cdot b_c \cdot k_f}{N_c} = \frac{0.015 \cdot 0.013 \cdot 0.5}{169} = 576 \cdot 10^{-9}\ m^2 \quad (21)$$

The coil conductor diameter will be:

$$d_c = \sqrt{\frac{4s_c}{\pi}} = \sqrt{\frac{4 \cdot 576 \cdot 10^{-9}}{\pi}} = 0.86 \cdot 10^{-3} m \approx 0.9 mm \quad (22)$$

In the figure 8 is presented the final dimensions of the designed prototype of permanent magnet axial wind generator.

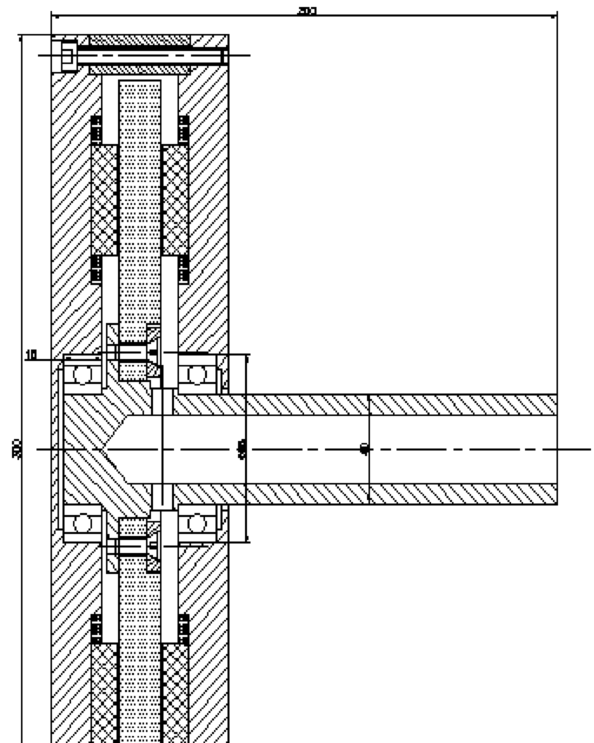


Fig. 8 The final dimensions of the designed prototype of permanent magnet axial wind generator.

4. CONCLUSIONS

The permanent magnet axial magnetic flux generator is a good option in the case of small power wind systems, because the simplicity of the manufacturing technology makes it available for a big number of small wind systems fans. There are some similar projects with the construction data for a fixed power system that can be bought from the market. This paper presents the design methodology that allows the design of a large domain of small power wind systems.

The proposed permanent magnet wind generator from this article operates at low speeds and it is ideal to convert wind energy into electrical energy especially for remote and isolated area.

The using of rare earth permanent magnets in designing of wind generators is very actually because of their big rate of decreasing price.

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