Operation of the synchronous generators with permanent magnets in parallel to the power grid

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Abstract — **The article is devoted to the axial permanent magnet generator. The construction of the active part, magnetic and winding systems are described. It is analyzed the oscillation of the generator excited by permanent axially magnets which operates in parallel with power grid. The obtained results show, that this type of generators has a higher moment of inertia and can stably operate in parallel to the power grid.**

Keywords—generator; permanent magnets; rotor.

I. Introduction

Many consumers such as individual small farms, for the purpose to have the electrical energy at the lower prices, are interested to use unconventional energy sources, particularly the individual wind mills generators (3-15) kW excited by permanent magnets (PM).

For improve the efficiency, often these generators should operate in full power, but the consumers are not need always to consume all the produced energy. In this case, the overfull energy can be used for supply others consumers, if the generator is connected to power grids. In other cases, if the generator does not cover the need for energy, the drawback could be consumed directly from the network.

Based on suggestions exposed, some problems should be solved such as connecting the generator with PM to the network and their operation in parallel with the network.

It seemed that these phenomena are known and are similar to those that occur in the excited electromagnetic generators. But things become more complicated for permanent magnet generators.

At the first, parallel connection to the network of the generator with PM is performed at the full excitation. At the second, variation speed of drive motor, for example wind driver, can lead to oscillation of the rotor and its output from synchronism.

In figure 1 is shown the synchronous axial generator with permanents magnets.

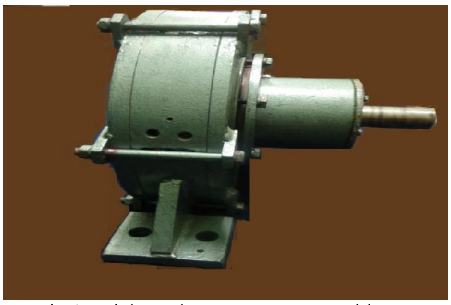


Fig.1 Axial synchronous generator with PM

The stator winding is hybrid winding. The front side shown on the outside of the package of the stator is similar to the toroidal coil, but the front side inside of the stator's package are cylindrical as stator windings of the machine.

Below are shown two axial machines, one with toroidal winding, other with plate winding. From figure 3.a, is observed that the toroidal winding has frontal parts essentially reduced, but the mounted technology is complicated. Plate winding with usual sections, fig.3.b is easier in manufacturing, but the frontal parts are essentially bigger compared with the toroidal.

a)

b)

Fig.3 . Axial winding machine with toroidal winding (and with plate winding (b).

Winding of the study generator is a hybrid winding combined in better manner the advantages of toroidal and plate windings.

The new technologies used in the manufacture of permanent magnets improved thermal, mechanical and magnetic characteristics of the permanent magnets . Such permanent magnets are used successfully in the construction of direct current and synchronous machines. The values of the remaining magnetic inductance more above one unit allow to use stator's packages without stator slots (figure 4) with smooth air gap.

In this context, let to analyze the parallel operation of this type of synchronous generator with power grid.

In synchronous generators as known, shocks of the drive torque or load variation can cause electrical oscillations of the generator rotor or turn out the generator of synchronism. These problems are described and solved rigorously for synchronous machines with electromagnetic excitation [3, 4, 5].

Fig.4.Axial synchronous generator with hybrid winding and smooth air gap

The axial generator with permanent magnets has essential features compared to the classic:

- high radial dimensions;
- bigger inertial moment;
- constant excitation flow;
- unilateral interaction forces;
- smooth air gap.

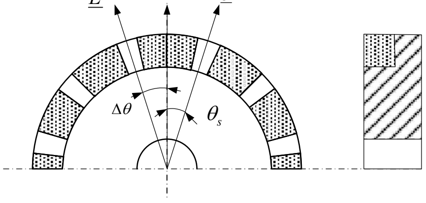
Based on the above study further proposes let to analyze the operation of the axial generator with permanent magnets in parallel with network.

The equation of the applied couples of the machine:

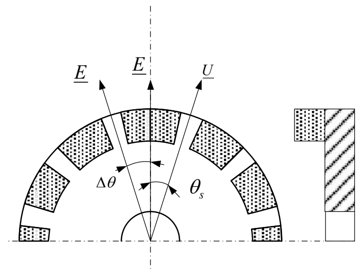
$$M=M_{em}+M_j+M_a+M_s \quad (1)$$

where the electromagnetic torque of the generator with PM and exit magnets (fig.5,a)

$$M_{em}=\frac{m_1\cdot E_0\cdot U_1}{x_d}\sin\theta+\frac{m_1\cdot U_1^2}{2}\left(\frac{1}{x_q}-\frac{1}{x_d}\right)\sin 2\theta \quad (2)$$



a)



b)

Fig.5. Rotors with) embedded magnets (a) and with exit magnets (b)

In the case when permanent magnets are not embedded in the rotor body, the reactance $x_d = x_q= x_s$ figure 5, b.

Following equation (2) is amended as follows

$$M_{em}=\frac{m_1\cdot E_0\cdot U_1}{x_s}\sin\theta \quad (3)$$

when synchronous reactance can be written as $x_d = x_a= x_\varepsilon$

Stator's dispersion reactance has high value due air gap and obviously due dispersion fluxes closed through space between ferromagnetic rotor and stator package.

Magnetic torque produced by rotating inert masses

$$M_J=\frac{J\cdot d\omega}{p\cdot dt}=\frac{J}{p}\cdot\frac{d^2\left(\theta_s+\Delta\theta\right)}{dt^2}=\frac{J}{p}\cdot\frac{d^2\Delta\theta}{dt^2} \quad (4)$$

Asynchronous torque produced by rotor's eddy currents is given by expression

$$M_a=\frac{m_1\cdot U_1^2\cdot R_2}{S\cdot\Omega\left[R_1^2+\left(\frac{R_2}{S}\right)^2+X_{sc}{}^2\right]} \quad (5)$$

If the oscillation of the generator's rotor begin, slip S has extremely low values and for generators with power (30-50) kW, R_2/S<X1 is greater than for generators with electromagnetic excitation and can be neglected. On the other hand, the maximum asynchronous torque

corresponding the critical slip $S_m=\pm\frac{R_2}{\sqrt{R_1^2\cdot X_{sc}^2}}$ whence $R_2=\pm X_{sc}\cdot S_m$ because $R_1=0$.

Substituting $X_{sc}=\frac{R_2}{S_m}$ in (5), taking into account that $S=S_m$ and $M_a=M_{a\max}$ we have:

$$M_{a\max}=\frac{m_1\cdot U_1^2\cdot R_2}{S_m\cdot\Omega\left[\left(\frac{R_2}{S}\right)^2+\left(\frac{R_2}{S}\right)^2\right]}=\frac{m_1\cdot U_1^2\cdot S_m}{2\cdot\Omega\cdot R_2} \quad (6)$$

When S changes, the torque will change proportional S:

$$M_a=\frac{m_1\cdot U_1^2}{\Omega\cdot R_2^{`}}S$$

Where R_2 is the equivalent resistance of the eddy current circuit given to the stator.Synchronous torque.

$$M_s = \frac{dM_{em}}{d\theta} = \frac{m \cdot E \cdot U}{\Omega_1 \cdot x_s} \cos\theta; \quad (7)$$

depends on the change of angle Θ.

Stable operation of synchronous generator with permanent magnets is ensured at the windmill speed variation within certain limits.

Usually classical generators have the damping windings, but in our case, the generator with PM has not a special damping winding.

Dampers function plays massive ferromagnetic rotor through which closed the eddy currents and partially damp the rotor's oscillation.

Let supposed, that torque M on the shaft sharply increased, as a result will increase also the electromagnetic torque because increases the angle Θ.

These couples will balance after a few oscillations of the rotor.

The couples equation (1) in this case can be rewritten as:

$$M - M_{med} = M_J + M_a + M_s \quad (8)$$

On oscillatory process will work the couples at the right side of equation (8) as the difference $M\text{-}M_{med}$ be neglected for small values $\Delta\Theta$ of the angle. Simultaneously can be neglected and damping torque of eddy currents in the rotor, because they are not able to produce significant effect. As a result, equation (8) can be rewritten as follows:

$$M_J + M_s = \frac{J}{p} \cdot \frac{d^2\Delta\theta}{dt^2} + M_s \Delta\theta = 0 \quad (9)$$

or

$$\frac{d^2\Delta\theta}{dt^2} + \frac{pM_s}{J}\Delta\theta = 0 \quad (10)$$

The general solution of the equation (10) is:

$\Delta\theta = A_1 \cdot e^{r_1 t} + A_2 \cdot e^{r_2 t}$, where A_1 and A_2 - integration constants. The characteristic equation

$$r^2 + \frac{p}{J} M_s = 0 \quad (11)$$

has two roots as imaginary numbers:

$$r_{12} = \pm\sqrt{\frac{p}{J} M_s} \quad (12)$$

Therefore, the cyclic oscillation frequency:

$\omega_0 = \sqrt{\frac{pM_s}{J}}$ $\quad f_0 = \frac{\omega_0}{2\pi}$ $\quad$ and $\quad r_1 = +j\omega_0$; $r_2 = -j\omega_0$.

Expressions (11) and (12) shows, that the construction of permanent magnet generators in particular with axial magnetic flux have much higher moment of inertia compared to the conventional generators and operates more stable when the load changes.

In the table. 1 are represented the results of calculations the basic parameters of the synchronous axial generator with permanent magnets and with one and two rotors.

TABLE I.
THE BASIC PARAMETERS OF THE SYNCHRONOUS AXIAL GENERATOR WITH PERMANENT MAGNETS AND WITH ONE AND TWO ROTORS

Nr	J Nm2	Number of the rotors	Pn kW	Un V	2p	m1	t1 Hz	Ω0 $\frac{1}{s}$	f0 Hz
1	3	1	3,0	220	18	3	50	23	3,7
2	6	2	3,0	220	18	3	50	16,4	2,6

Conclusions: In the paper was demonstrated the shortcomings and priorities of various construction of the axial synchronous generators with permanent magnets. As a results was selected the generator with smooth air gap which helps improve the quality of produced energy and more efficiently using the electro technical steel and copper.

The calculations made according of the above obtained expressions showed that axial synchronous generators with permanents magnets can operate more stable as others generators in parallel with the network. Oscillation frequency is within the recommended limits even for small power generators.

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