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VOLTAGE REGULATION OF THE ASYNCHRONOUS GENERATOR IN AN INDEPENDENT MODE OF OPERATION

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***Abstract* – In this paper, smoothly regulation of the output voltage on the terminals *of* asynchronous gene-rators is presented. It is based on use the additional winding of pre-magnetization mounted on stator's yoke and condensers, which are connected in a delta to the working winding with the rectifier.**

Keywords – *self-excitation asynchronous generator, yoke of pre magnetization, controlled rectifier, output voltage regulation*

1. INTRODUCTION

The asynchronous machines are widely used in electromechanics as a basic element of the electric drive. The design of the asynchronous machines is rather simple and reliable, they are convenient and unpretentious in operation, easily pass from one mode of operations to another, due to what they make 70 % from general used electrical machines. More often, asynchronous machines are used independently as electric motors for a drive of various machines and mechanisms or connected in pair with synchronous machines for realization more complex electric drives or special characteristics. Seldom as synchronous generators are used asynchronous machines, as they have a number of characteristic lacks, including most important of them as frequency and voltage change with change of the load. For maintenance of last is necessary to adjust speed of a rotor and current of magnetization. Besides, as known, the efficiency of the asynchronous generator is less then unit.

2. ASINCHRONOUS GENERATORS WITH VOLTAGE REGILATION

Despite of it, at independent use of asynchronous machines as asynchronous generator, have a number of essential advantages in comparison with the synchronous generator. Especially for asynchronous generators with short-circuit rotor, which design is extreme simple and reliable.

2.1. Self-excited asynchronous generator

If to a stator winding of the asynchronous generator W_s is connected the condenser battery C, and the speed appropriate to number of poles pairs is given, it is self-excited (fig. 1).

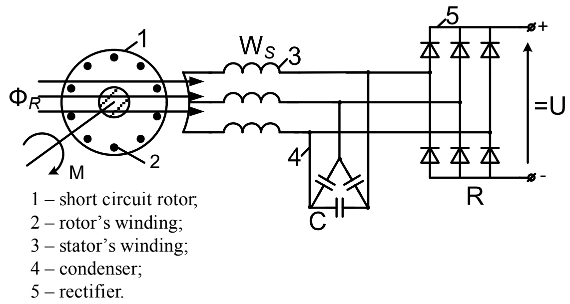

Fig.1 The scheme of the asynchronous generator operating in an independent mode

Such generator can be used as a source of a direct current, if the controlled or not controlled rectifier R is connected to its terminals (fig.1). There is no necessity in this case to support frequency, and the controlled rectifier provides voltage regulation. The process of excitation takes place due to a residual magnetic flux Φ_R, which rotates together with a rotor and induces in a stator winding Ws electromotive force E_R (fig. 2). Stator winding with the inductance L and condenser battery with capacitance C form an oscillatory contour LC. The current pulsation can be determined in it from the formula:

$\omega = \dfrac{1}{\sqrt{LC}}$, and accordingly frequency from: $f = \dfrac{1}{2\pi\sqrt{LC}}$, using dependence of the electromotive force E of the generator from magnetization current $I_{\mu o}$ and volt-amperes characteristic $I/\omega C$, which being combined have a common point of crossing with coordinates $I_{\mu o}$ and E_o (fig. 1.3). Graphically on the fig. 1.3, self-excitation process is illustrated.

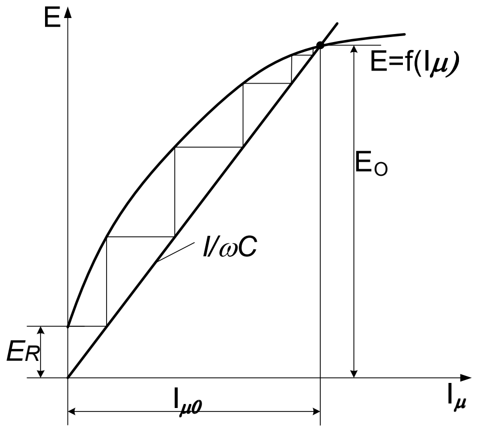

Fig.2. Self-excitation process

By using the control-led rectifier, or machine design for such generator, regulation of the output voltage can be carried out. Most simply and reliably it can be carried out by use in a design of the given generator the magnetization yoke.

2.2. The asynchronous generator with self--excitation and magnetization yoke

The asynchronous generator with short-circuit rotor and self-excitation due the condenser battery and magnetization yoke represents the usual asynchronous machine with two windings W_S and W_R, located both in stator grooves (fig.3).

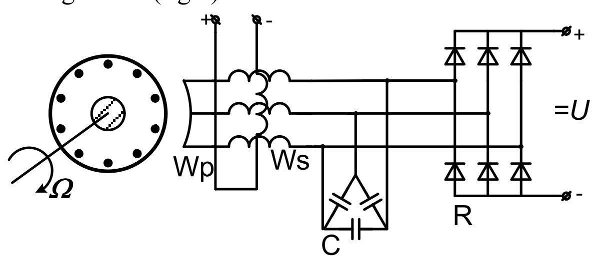

Fig.3.The basic circuit of the asynchronous generator with self-excitation and premagnetization yoke

The working winding W_R is a three-phase winding and for suppression of 3-th harmonics and multiple to three, which a magnetic flow are induced in to the machine, it is connected in a star. Induced harmonics multiple 5 and 7 are much more on amplitude and for their suppression is stipulated the reduction of a step of the winding on 1/6 τ . Other harmonics have insignificant amplitude, as their amplitude decreases proportionally to order of a harmonic and they practically do not influence machine operations mode.
In fig.4, general view of the asynchronous generator with self-excitation premagnetization yoke is given.
Working three-phase winding 1 and winding of premagnetization 4 settle down in the same slots of the stator 3, which is fixed at the frame 3.
The magnetic flux created by alternating currents of a three-phase working winding, passes through air gap and is closed in to stator yoke 2 of the machine, and the magnetic flux created by a direct current of a premagnetization winding, is closed only through stator's yoke.

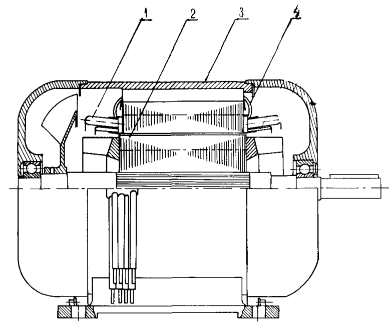

Fig.4.General view of the asynchronous generator with self-excitation premagnetization yoke

The premagnetization winding covers the stator's yoke along its average line representing circle. and can have a step equal or more, than step of stator slots.
If the premagnetization winding to terminals of the generator is connected, it is self-excitation winding. If to a separate source it is connected, the generator is the generator with independent excitation.
On fig.3 is shone the winding of premagnetization to a separate source of a direct current is connected, and to three-phase working winding are connected condensers which are in a delta connection.
Due to connection of condensers in a delta, the necessary capacity of condensers three times is less, than at their connection in a star, but in this case, condensers should maintain a linear voltage.
At connection of condensers by a star, reactive capacity power, given out by them:

$$Q_Y = U_f^2 \cdot \omega \cdot C \cdot 10^{-3} = (\frac{U_L}{\sqrt{3}})^2 \cdot \omega \cdot C \cdot 10^{-3},$$

where ω - cyclic frequency; C - capacity of condensers.
At connection of condensers in delta, capacity power, given out by them is equal:

$$Q_\Delta = U_f^2 \cdot \omega \cdot C \cdot 10^{-3} = U_L^2 \cdot \omega \cdot C \cdot 10^{-3}.$$

From the listed formulas it is visible, that at connection of condensers in a delta the capacity power, given out by them, three times is more, than connection them in a star. It is very important, when is pursued the purpose of reduction of weight and dimension of the machine.
The magnetic flux ϕ_p (fig.5):

$$\phi_p = \frac{F_p}{R_{mp}}. \qquad (1)$$

When the premagnetization winding is feed by the direct current, where the force of magnetization:

$$F_p = I_p \cdot W_p. \qquad (2)$$

The reactance:

$$R_{mp} = \frac{L_j}{\mu_{F_e} \cdot S_\tau}. \qquad (3$$

Substituting (2) and (3) in the formula (1), we receive, that the flux of premagnetization is equal:

$$\phi_p = \frac{I_p \cdot W_p \cdot \mu_{F_e} \cdot S_j}{L_j}, \quad (4)$$

where:

μ_{F_e} - magnetic permeability of steel;

L_μ - average length of a circle of the stator yoke;

S_τ - cross section of the stator yoke.

The force of magnetization created by currents in a three-phase working winding

$$F_S = \frac{m_1 \cdot W_S \cdot k_{w_1}}{\pi p} \cdot I_S. \quad (5)$$

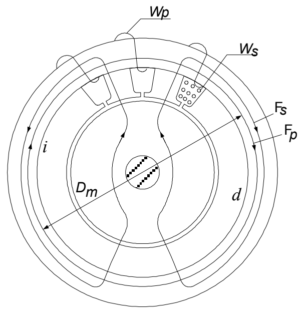

Fig.5 Cross sections of an active part of the generator

Given force of magnetisation creates a rotating mag-netic flux Φ_S, becoming isolated through air -gap and through sectors **d** and **i** which are symmetric in relation to its axis. It is easy to notice, what in sector **d** of the magnetic yoke, a direction of a magnetic flux Φ_S coin-cides with a direction of a magnetic flux Φ_P, and in the another sector **i** of the magnetic yoke, a direction of a magnetic flux Φ_S is in oposite of magnetic flux Φ_P..

Hance, the resulting magnetic force from the both **d** and **i** sectors of the mashine:

$$F_R = \frac{F_s}{p} \pm F_p, \quad (6)$$

or for the instantaneos value:

$$f_R = \frac{m_1 \cdot W_S \cdot k_{w_1}}{\pi p^2} \cdot \cos(\frac{2\pi t}{T} - \frac{2\pi x}{\tau}) \pm I_P W_p \quad (7)$$

where:

p - number of pairs poles;

T – period of the rotating wave of the magnetic flux

τ - step of the working winding.

From here follows, that magnetic force from both sectors of the stator yoke can be submitted by expression:

$$F_R = \frac{F_s}{p} \pm F_p \quad (8)$$

Considering (3) and (4), we receive:

$$\phi_{td_1} = \frac{m_1 W_S k_{w_s} \mu_{Fi} S_I}{\pi p^2 L_j} I_S \cos(\frac{2\pi t}{T} - \frac{2\pi x}{\tau}) + \frac{I_P W_p \mu_{Fi} S_I}{L_\tau} = \quad (9)$$
$$= \frac{\mu_{Fi} S_I}{L_\tau}\left(\frac{m_1 W_S k_{w_1}}{\pi p^2} I_S \cos(\frac{2\pi t}{T} - \frac{2\pi x}{\tau}) + I_P W_p\right).$$

In the second half-cycle of time the instantaneous value of a flux in sector **d** will be:

$$\phi_{td_2} = \frac{\mu_{Fe} \cdot S_j}{L_i}\left(\frac{m_1 \cdot W_S \cdot k_{w_1}}{\pi p^2} \cdot I_S \cdot \cos(\frac{2\pi t}{T} - \frac{2\pi x}{\tau}) - I_P W_p\right) \quad (10)$$

The same phenomenon takes place in sector **i**. The instantaneous value of a flux in the first period:

$$\phi_{ti_1} = \frac{\mu_{Fe} \cdot S_j}{L_i}\left(\frac{m_1 \cdot W_S \cdot k_{w_1}}{\pi p^2} \cdot I_S \cdot \cos(\frac{2\pi t}{T} - \frac{2\pi x}{\tau}) - I_P W_p\right). \quad (11)$$

In the second period of time the fluxes are summarized:

$$\phi_{ti_2} = \frac{\mu_{Fe} \cdot S_j}{L_\tau}\left(\frac{m_1 \cdot W_S \cdot k_{w_1}}{\pi p^2} \cdot I_S \cdot \cos(\frac{2\pi t}{T} - \frac{2\pi x}{\tau}) + I_P W_p\right). \quad (12)$$

The expressions (9) - (12) show that the resulting magnetic flux in yoke of the stator and air-gap depends on a degree of magnetic saturation of a stator's package and on value of the pre premagnetization current.

In the first case, resulting magnetic flux decreases owing the reduction of magnetic permeability μ_{F_e}. In the second case it decreases owing to subtraction of magnetic fluxes, making it. Thus, at change of a current of magnetization I_P, changes the electromotive force at the terminals of the asynchronous generator.

Let's consider process of output voltage regulation of the unload generator and assume that the angular speed of a rotor $\Omega = \frac{\omega}{p}$ is constant and corresponds to nominal angular speed Ω_n.

As to the three phases winding the condenser battery is connected, the process of self-excitation of the generator takes place. The process comes to the end by an establishment of electromotive force on the ends of a three-phase winding determined of the condensers capacity C and angular speed of a rotor Ω

At a feed of the winding of premagnetization by a direct current, according to expressions (10) - (12), sectors **d** becomes super magnetized and sector **i**–un sufficiently magnetized what reduce the basic magnetic flux in the air-gap.

As the characteristic of premagnetization of the magnetic system of the generator is nonlinear, total magnetic reluctance around yoke of the stator increases output voltage of the generator decrease. and consequently the magnetic flux Φ_σ in air-gap and the

The reactive capacitive power which is used by the generator from the condenser battery of excitation will decrease, as it is proportional U^2. This process will proceed so long as the reactive capacitive power which is used by the generator will be equal to reactive capacitive power given by the condenser battery.

The regulation of the voltage at the terminals of the asynchronous generator with yoke of pre-magnetization can be illustrated, using one of graphic models. In [2] is proved, that at imposing on a variable magnetic field a constant magnetic field, the characteristic of magnetization is deformed. According to expression (6), the same distortion takes place in the asynchronous generator with yoke of premagnetization.

In fig.6, the characteristics of magnetization are given for unload asynchronous generator for various values of the premagnetization current I_p.

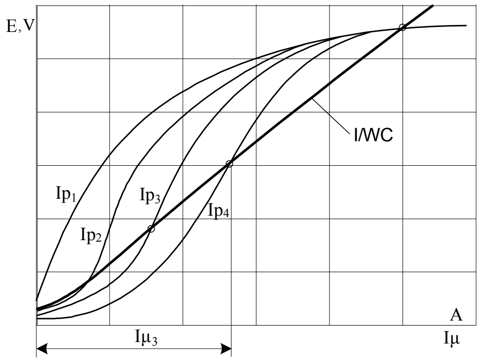

Fig.6 Regulations of the output voltage of the generator

In both cases, when the magnetic fluxes having the same direction are summarized or having the opposite direction are subtracted, resulting magnetic flux decreases. In the first case the resulting magnetic flux decreases owing the reduction of magnetic permeability μ_{F_e}, in the second case - owing to subtraction of magnetic fluxes, making it. Thus, at change of a current of magnetization I_P, changes the electromotive force at the terminals of the asynchronous generator.

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As the characteristic of premagnetization of the magnetic system of the generator is nonlinear, total magnetic reluctance around yoke of the stator increases and consequently the magnetic flux Φ_σ in air-gap and the output voltage of the generator decrease.

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The regulation of the voltage at the terminals of the asynchronous generator with yoke of premagnetization can be illustrated, using one of graphic models [2]. In this paper is proved, that at imposing on a variable magnetic field a constant magnetic field, the characteristic of magnetization is deformed. According to expression (6), the same distortion takes place in the asynchronous generator with yoke of premagnetization. In fig. 1.7 the characteristics of magnetization are given for unload asynchronous generator for various values of the premagnetization current I_p. By imposing this characteristic and volt-ampere characteristic $U_C = \dfrac{I}{\omega C}$, we will have some points of crossing (1, 2, 3, 4) of the straight line characteristic $I/\omega C$ with generator's unload characteristic $E = f(I_\mu)$ showing what voltage we have on terminals of the generator at the given current of premagnetization.

Regulations of the output voltage at the terminals of the asynchronous generator can be carried out and by steps, but it is necessary to ensure the switching of condensers and so to take into account, then the output voltage will change by steps. In our case by using the yoke with premagnetisation windings we can smoothly regulate the voltage on the terminals of the generator without necessary to ensure the switching of condensers.

For regulation the output voltage at the terminals of the asynchronous generator within the limits of 1,5 up to 1, the winding of premagnetization should occupy (5-8) % of the stator' slots.

CONCLUSION

The use an additional winding of pre-magnetization mounted on stator's yoke and condensers, which are connected in a delta to the working winding with the rectifier allows smoothly and reliably to adjust a output voltage on the terminals of the asynchronous generator at change of load, without use of additional devices, expanding possibly areas of its independent use and advantages after comparison with the synchronous generator.

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