A mathematical model of synchronous generator

In developing a mathematical model of the SG in order to avoid too cumbersome and complex descriptions applied the following assumptions::

- There are no losses in the steel;

- Air gap is uniform, the magnetic conductivity of the same and the magnetic field distribution in the air gap sinusoidally;

- No influence of reservoirs within and between the windings;

- Active resistance is not dependent on temperature;

- Stator and rotor are balanced three-phase winding.

In order to best display the processes occurring in a synchronous machine in transient and at steady speeds, the generator should be presented multicontour equivalent circuit in which the rotor is presented in the form of several parallel-connected active-inductive chains with constant parameters [].

In order to avoid periodic coefficients depending on the angular position of the rotor, differential equations of the synchronous generator is written in the axes *d*, *q*, is rigidly connected with its rotor. To account for the displacement of the rotor current array is *k* equivalent damper circuits on each of the axes *d*, *q* and the excitation winding axis *d*.

Control, describing the behavior of the SG with multiloop rotor *(i* = 1,2 ,..., *k)*, based on [72], can be represented as follows:

$$p\Psi_{Sd} = u_{Sd} - \alpha_S \Psi_{Sd} + \alpha_S \Psi_{\mu d} + \omega \ p\Psi_{Sq},,$$

$$p\Psi_{Sq} = u_{Sq} - \alpha_S \Psi_{Sq} + \alpha_S \Psi_{\mu q} - \omega \ p\Psi_{Sd},,$$

$$p\psi_{Rd}^{(i)} = -\alpha_{Rd}^{(i)}\left(\psi_{Rd}^{(i)} - \psi_{\mu d}\right),,$$

$$p\psi_{Rq}^{(i)} = -\alpha_{Rq}^{(i)}\left(\psi_{Rq}^{(i)} - \psi_{\mu q}\right),,$$

$$p\psi_{f} = u_{f} - \alpha_{f}\left(\psi_{f} - \psi_{\mu d}\right),,$$

$$p\omega = \frac{1}{J}(m_T - m_E)$$, ,

$$p\gamma = \omega$$, ,

$$m = \vec{\Psi}_S \times \vec{i}_S$$, ,

where

$p = \frac{d}{dt}$ - The operator of time derivative;

$u_{sd}, u_{sq}\ u_{Sd}, u_{Sq}$ - Voltages on the findings of the SG on axes *d* and *q;*

$\psi_{Sd}, \psi_{Rd}^{(i)}, \psi_{Sq}, \psi_{Rq}^{(i)}, \psi_f$ - Stator flux linkage, *i-th* rotor circuit SH at axes *d*, *q* and the field winding flux linkage, respectively;

$p\psi_{Sd}, p\psi_{Rd}^{(i)}, p\psi_{Sq}, p\psi_{Rq}^{(i)}, p\psi_f$ - Derivatives of the stator flux linkages, *i-th* rotor circuit SH at axes *d*, *q* and the derivative of the field winding flux linkage, respectively;

u_f - Voltage of the field winding;

ω - Rotor speed SG;

J - The total moment of inertia;

m_T, m_E - Torque of the turbine and generator electromagnetic torque;

$\vec{i}_S, \vec{\Psi}_S$ - The resulting stator current vector and flux linkage;

γ - Rotation angle of the rotor, the angle between the *d-axis* and electric winding phase *a;*

$\alpha_S, \alpha_{Rd}^{(i)}, \alpha_f, \alpha_{Rq}^{(i)}$ - The damping coefficients of the contour of stator, *i-th* rotor circuit, the field winding on *d-axis* and *the i-th* rotor loop along the axis *q:*

$$\alpha_S = \frac{R_S}{L_{\sigma S}},\ \alpha_{Rd}^{(i)} = \frac{R_{Rd}^{(i)}}{L_{\sigma Rd}^{(i)}},\ \alpha_f = \frac{R_f}{L_{\sigma f}},\ \alpha_{Rq}^{(i)} = \frac{R_{Rq}^{(i)}}{L_{\sigma Rq}^{(i)}},$$

where

$R_S, R_{Rd}^{(i)}, R_f, R_{Rq}^{(i)}$ - Active resistance of stator windings, *i-th* rotor circuit winding of the longitudinal axis of the SG and *the i-th* rotor circuit along the transverse axis of the SG;

$L_{\sigma S}, L_{\sigma Rd}^{(i)}, L_{\sigma f}, L_{\sigma Rq}^{(i)}$ - Russenia inductance of the stator winding, *i-th* rotor circuit excitation winding along the longitudinal axis of the SG and *the i-th* rotor circuit along the transverse axis of the SG.

Linkage branch of the magnetization:

$$\psi_{\mu d} = a_{Sd}\,\psi_{Sd} + a_f\,\psi_f + \sum_{i=1}^{k} a_{Rd}^{(i)}\,\psi_{Rd}^{(i)},,$$

$$\psi_{\mu q} = a_{Sq}\,\psi_{Sq} + \sum_{i=1}^{k} a_{Rq}^{(i)}\,\psi_{Rq}^{(i)},,$$

where

$a_{Sd}, a_{Rd}^{(i)}, a_{Sq}, a_{Rq}^{(i)}, a_f$ - The distribution coefficients of stator flux linkages, *i-th* rotor circuit by axes *d*, *q*, and the field winding, respectively, which is defined as:

$$a_{Sd} = \frac{L_{SRd}}{L_{\sigma S}},,\quad a_f = \frac{L_{SRd}}{L_{\sigma f}},,\quad a_{Rd}^{(i)} = \frac{L_{SRd}}{L_{\sigma Rd}^{(i)}},,$$

$$a_{Sq} = \frac{L_{SRq}}{L_{\sigma S}},,\quad a_{Rq}^{(i)} = \frac{L_{SRq}}{L_{\sigma Rq}^{(i)}},,$$

where

$$L_{SRq} = \left[\frac{1}{L_{\sigma S}} + \frac{1}{L_{\mu q}} + \sum_{i=1}^{k}\frac{1}{L_{\sigma Rq}^{(i)}}\right]^{-1},,$$

$$L_{SRd} = \left[\frac{1}{L_{\sigma S}} + \frac{1}{L_{\mu d}} + \frac{1}{L_{\sigma f}} + \sum_{i=1}^{k} \frac{1}{L_{\sigma Rd}^{(i)}} \right]^{-1},,$$

where

$L_{\mu d}, L_{\mu q}$ - Magnetizing inductance branch of axes *d* and *q*.

Stator currents, the excitation winding and *the i-th* rotor circuit:

$$i_{Sd} = \frac{\psi_{Sd} - \psi_{\mu d}}{L_{\sigma S}},, \quad i_{Sq} = \frac{\psi_{Sq} - \psi_{\mu q}}{L_{\sigma S}},, \quad i_f = \frac{\psi_f - \psi_{\mu d}}{L_{\sigma f}},,$$

$$i_{Rd}^{(i)} = \frac{\psi_{Rd}^{(i)} - \psi_{\mu d}}{L_{\sigma Rd}^{(i)}},, \quad i_{Rq}^{(i)} = \frac{\psi_{Rq}^{(i)} - \psi_{\mu q}}{L_{\sigma Rq}^{(i)}}..$$

Equations for determining the excitation voltage, taking into account the type of pathogen and automatic regulation of arousal (ARVs) are part of a mathematical model of the SG. In view of the field forcing the equation to determine the voltage of the generator with a system of self-excitation is represented as:

$$u_f = k_f \cdot \frac{u_{f\text{ном}} \cdot u_S}{u_{S\text{ном}}},,$$

where

$u_{f\text{ном}}$ - Nominal value of the excitation voltage;

$u_{S\text{ном}}$ - Nominal voltage of the stator;

u_S - Rms voltage of the stator;

k_f - The multiplicity of field forcing.

A mathematical model of synchronous motor

Control, describing the behavior of LEDs with multiloop rotor *(i* = 1,2 ,..., *k)*, similar to the SG equation, except in the expressions for the rotor speed, which takes the form:

$$p\omega = \frac{1}{J}\left(m - m_C\right)$$, ,

where

m_C, m - Moment of resistance mechanism and engine torque.