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Testing and model validation of round rotor synchronous generator (GENROU)

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ABSTRACT

Role of round rotor synchronous generator in renewable and sustainable energy is rapidly growing due to growing demand of energy production from the renewable resources. The less wear and tear, high robustness and accessibility to power electronics deployment (for active/reactive power flows from and to the grid) has increased the scope of round rotor synchronous generators across large onshore and offshore wind farms besides in hydro power plants. In many commercial power modeling softwares, like System Simulator for Engineering (PSS/E), it is quite difficult to write, access, test, evaluate and validate the built-in models. Therefore to avoid these problems and help the researchers in evaluating, testing, modifying, expanding and enabling the power equipment models as user written, it is important that the equivalent models are designed in an accessible and comparable design and simulation environment like Simulink. The work presented in this paper therefore addresses these issues and provide researchers the equivalent PSS/e models of generator, its associated governor and exciter designed and modeled in Simulink environment.

1. Introduction

The round rotor synchronous generator is equipped with stator and rotor, where, its rotor is examined in terms of the mechanical power and speed that ultimately lead to produce voltage on its stator windings. Therefore, the working principle of this generator mainly focuses on its mechanical power, rotor speed, the voltage across its field windings (field voltage) and the voltage across its stator terminals (terminal voltage). The round rotor synchronous generator (GENROU) is an important power equipment in renewable energy, mainly hydro and wind. Its important role in hydro power plant is due to its high mechanical strength, better thermal and electrical properties and the assembling methods [1]. The implementation of round rotor synchronous generator (GENROU).

in large wind farms requires the dynamic simulation studies to be carried out on this conventional generator to analyze its capability to be used in renewable and sustainable energy applications [2]. Moreover, the benefit of using GENROU in wind power plants is to simulate the generator part of the Dual-fed Induction Generator (DFIG) for initializing the model at synchronous speed instead of user-defined slip frequency [3,4]. GENROU is widely used in many national grids for transient and small signal stability analysis as well as to run the load flow for testing and validation purposes [5].

Moreover, the built-in models of power equipments like synchronous machines in PSS/e are difficult to be diagnosed, modeled, tested and validated. Besides, it is important to know their internal architecture, associated mathematical equations, solvers and interfacing logics. To overcome this problem, this research work therefore focuses on building the equivalent models of round rotor synchronous generator (GENROU), its associated governor (Hygov) and exciter (IEEET1) in an editable testing environment like Simulink to help researchers and scientists to effectively use these models and improve their compatibility. It will further help in broadening the research area to improve and apply the modified models in specific applications besides contributing in writing and/or modifying these models across different open-source programing platforms.

The study of synchronous generator helps in providing a useful knowledge required in static and dynamic analysis of bulk power systems [6]. The usefulness of this work results in knowing the system status under controlled constraints. The dynamic model of GENROU is developed by a set of algebraic equations [7] that control voltage and current phasors during both normal and abnormal situations. Besides, in the development of generator's dynamic model, the differential equations of rotor speed and the flux linkages are included to control the instantaneous values of voltage and power.

Moreover, to fully understand the behavior of round rotor synchronous generator, it is vital to validate its mechanical power, rotor speed, field and terminal voltages under different scenarios. The validation furthermore, helps in reducing the margin of error, mainly caused when the machine starts working (initialization). During initialization,

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Nomenclature

D	Damping coefficient, pu
r_a	Armature resistance, pu
x_d	d-axis synchronous reactance, pu
x_d''	d-axis sub-transient reactance, pu
x_q'	q-axis transient reactance, pu
H	Inertia constant, s
x_l	Leakage reactance, pu
x_d'	d-axis transient reactance, pu
x_q	q-axis synchronous reactance, pu
x_q''	q-axis sub-transient reactance, pu

the generator is assumed to follow steady state operation, i.e. no transient change in active and/or reactive power flows, voltage phasors and the system frequency [8].

2. Mathematical modeling

2.1. Synchronous Generator (GENROU)

Testing of dynamic models of GENROU was performed in Simulink and PSS/e platforms. A number of algebraic equations identical to real-time model of GENROU were written in Simulink. Thereafter, the same equations were matched with built-in GENROU models in PSS/e for the precision check. Fig. 1 represents the GENROU model in Simulink based on sub-transient, transient and synchronous parameters. The complete model of the GENROU is equipped with exciter and governor. With the help of governor, mechanical power is used to control the speed of synchronous generator, whereas its exciter model helps in controlling the terminal voltage through the field voltage 'E_{field}.' In the simulated model of synchronous generator, the factor of saturation is taken into account across its direct axis and is evident from the Fig. 1.

Therefore, the mathematical models of both direct and quadrature-axes of the generator are formulated Simulink for the simulation purpose. The emf voltage across q-axis winding of GENROU (E_q') mainly depends upon the field current due to d-axis (I_{fd}), the d-axis armature reactance (X_{ad}), the field voltage across d-axis winding (E_{fd}) and the d-axis open circuit transient time constant (T'_{d0}) [10], i.e.

$$\dot{E}_q{}' = \frac{1}{T_{d0}{}'}(E_{fd} - X_{ad} I_{fd}) \tag{1}$$

Similarly, the emf voltage across d-axis winding of GENROU (E_d') mainly depends upon the field current due to q-axis (I_{fq}), the q-axis armature reactance (X_{aq}), and the q-axis open circuit transient time constant (T'_{q0}) [5], i.e.

$$\dot{E}_d{}' = \frac{1}{T_{q0}{}'}(-1)(X_{aq} I_{1q}) \tag{2}$$

Furthermore, the sub transient flux linkage in d and q-axes (ψ'') of GENROU is produced after induced voltage in both generator windings as shown in Eq. (3) [10].

$$\psi_d{}'' = \frac{E_q{}'(X_d{}'' - X_l) + \psi_{kd}(X_d{}' - X_d{}'')}{X_d{}' - X_l}$$
$$\psi_q{}'' = \frac{-E_d{}'(X_q{}'' - X_l) - \psi_{kq}(X_q{}' - X_q{}'')}{X_q{}' - X_l} \tag{3}$$

Now, as shown in Eq. (4), the resultant flux linkage in the synchronous generator will be the sum of mutual flux-linkages in

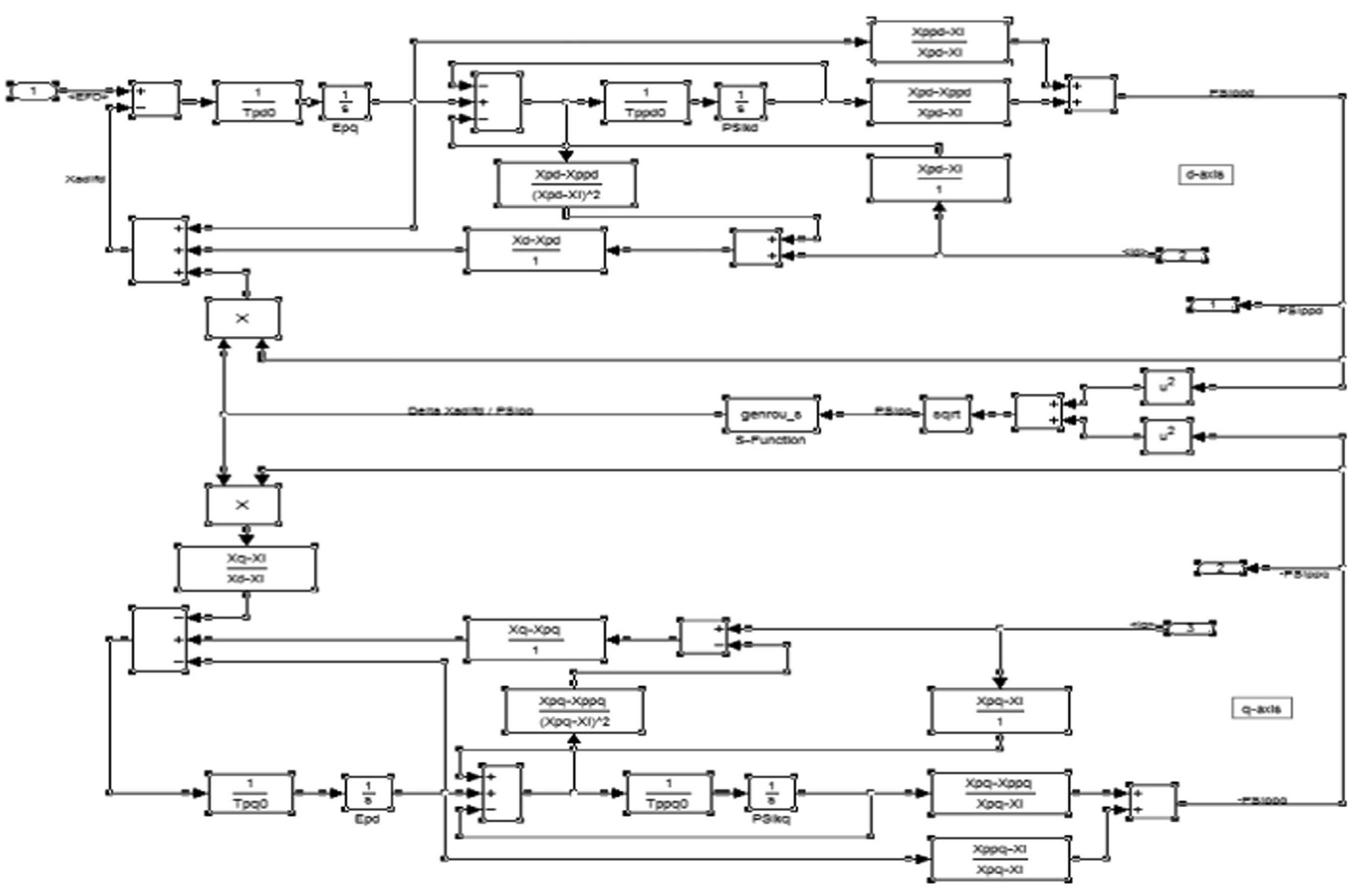

Fig. 1. Synchronous generator GENROU model in simulink.