Performance Analysis of Self-Excited Induction Generator connected to a micro hydro turbine

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***Abstract*— In this paper, the performance of self-excited induction generator driven by hydro turbine is presented. Hydro- turbine is one of distributed generation which is used in rural areas. Self-Excited Induction Generator is usually connected to a wind turbine. Performance analysis for two identical self-excited induction generators driven micro-hydro turbine is studied. The mathematical model of the system which consists of the induction generator and the micro hydro-turbine is developed. MATLAB/Simulink software is used to simulate the system under steady state and transient operations. The results of simulation had been discussed, and from the results it proved that the model of two generators gives good dynamic and steady-state performance. A micro-hydro system can be installed easily and economically in remote locations/rural areas**

***Index Terms*— Electro Hydraulic Governor, Hydraulic Turbine, Small Hydro-Power Plant.**

I. Introduction

Due to an increase in greenhouse gas emission more attention is being given now to renewable energy and moreover rapid depletion of conventional fossil fuels and environmental concern have result in extensive use for electrical power generation. The inability of the power utilities to supply isolated users has resulted in the development of stand-alone power generation system. Distributed and stand- alone power generation are receiving greater attention due to the cost and complexity of grid systems with related to transmission losses [1]. A micro-hydro turbine is one of the distribution generation. Micro-hydro system and wind energy system remain the most competitive. Since the location of these systems is in remote areas these systems must be reliable, robust, economical and manageable by the local people [2]. They can be installed easily and economically in remote locations/rural areas.

Synchronous generators are being used for power generation but induction generators are increasingly being used because of their relative advantageous features over conventional synchronous generators. Induction generators are mechanically and electrically simpler than other generator types. Induction generators are rugged in construction, low cost and low maintenance, self-protection against faults, and capability to generate power at varying speed. These features facilitate the induction generator operation in stand-alone/isolated mode to supply remote aria. Much emphasis has been placed on the induction machine as the electromechanical energy converter in such generation schemes. Low and medium power self-excited induction generators are ideally suited for non-conventional energy systems such as wind electric generators,

micro-hydro power stations, etc. The development in power electronics and control devices has also removed the drawback of induction generators regarding voltage and frequency control [3].

Usually, Induction generators require an external supply to produce a rotating magnetic flux. The external reactive supply can be supplied from the electrical grid or from the externally connected capacitor bank, once it starts producing power.

A detailed study of the performance of the induction generator during steady-state and transient condition is important for the optimum utilization. The steady-state performance is important for ensuring good quality power and assessing the suitability of the configuration for a particular application, while the transient condition performance helps in determining the insulation strength, suitability of winding, shaft strength, value of capacitor, and devising the protection strategy. [4, 5].

Two main problems arise in stand-alone systems based on micro-hydro and wind concerning frequency regulation. First the mechanical power delivered by the turbines can vary, especially in wind farms. Second, the loads supplied are variable by nature, so an active power balance should be achieved rapidly. From the efficiency point of view turbine governor seems an appropriate solution because by maintaining the produced power in range with the demanded one eliminates the produced power in range with the demanded one eliminates the need for an additional circuit in the system. But, such a configuration is expensive and inefficient for low-power applications (few tens of KW) [6]. As the mechanical constants are high, the regulating process is slow and the overall cost is significant. Also, the system's response under suddenly load switching is poor, resulting in voltage sags and frequency deviations. Using a load controller is better option, which feeds a dump load, enabling the total power supplied by the generator to match the sum between the consumer's loads and dump load. As the active power balance is achieved, the frequency is satisfactory regulated [7]. Based on a detailed review of induction generators, the aim of this paper are to present complete modelling and simulation of hydro turbine which drive self-excited squirrel-cage induction generator and to control of the system during the steady state and transient period.

In the literature, starting in the early nineteenth century, it is well known that a three-phase induction machine can be made to work as a self- excited induction generator (SEIG) [8, 9]. In an isolated application a three-phase induction generator operates in the self-excited mode by connecting three AC capacitors to the stator terminals [10], or using a converter and a single DC link capacitor [11]. The normal connection of

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a SEIG is that the three exciting capacitor are connected across the stator terminals and there is no electrical connection between rotor and stator and rotor windings. However, in the literature a SEIG with electrical connection between rotor and stator windings is also reported [12].

II. Mathematical Model

The equations of the three phase squirrel cage induction generator were developed from principles. The windings of the induction generator can be represented diagrammatically as shown in Figure 1 [12]. There are six voltage equations, and each of the six voltages depends upon all of the six currents. The impedance matrix therefore consists of 36 non-zero terms.

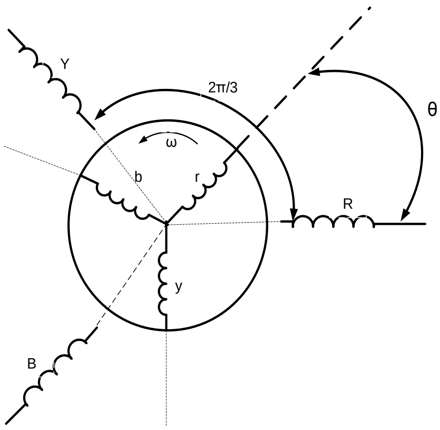


Fig. 1. Three phase winding of induction generator

From Figure 1 the stator voltage equations are:

$$V_R = R_S I_R + \frac{d\lambda_R}{dt} \quad (1)$$

$$V_Y = R_S I_Y + \frac{d\lambda_Y}{dt} \quad (2)$$

$$V_B = R_S I_B + \frac{d\lambda_B}{dt} \quad (3)$$

And the rotor voltage equations are:

$$V_r = R_r I_r + \frac{d\lambda_r}{dt} \quad (4)$$

$$V_y = R_r I_y + \frac{d\lambda_y}{dt} \quad (5)$$

$$V_b = R_r I_b + \frac{d\lambda_b}{dt} \quad (6)$$

where $\lambda's$ are flux linkages, R_s and R_r are stator and rotor phase resistances, R,Y and B represent stator winding while r, y, and b represent rotor windings.

$$[V] = \begin{bmatrix} v_R \\ v_Y \\ v_B \\ v_r \\ v_y \\ v_b \end{bmatrix} \qquad [I] = \begin{bmatrix} i_R \\ i_Y \\ i_B \\ i_r \\ i_y \\ i_b \end{bmatrix} \quad (7)$$

$$[Z] = \begin{bmatrix} R_S+\hat{L}_S P & P\widehat{M}_S & P\widehat{M}_S & \hat{M}p\cos\theta+\widehat{M}_3 p\cos 3\theta & \hat{M}p\cos\theta_2+\widehat{M}_3 p\cos 3\theta & \hat{M}p\cos\theta_3+\widehat{M}_3 p\cos 3\theta \\ P\widehat{M}_S & R_S+\hat{L}_S P & P\widehat{M}_S & \hat{M}p\cos\theta_2+\widehat{M}_3 p\cos 3\theta & \hat{M}p\cos\theta_3+\widehat{M}_3 p\cos 3\theta & \hat{M}p\cos\theta+\widehat{M}_3 p\cos 3\theta \\ P\widehat{M}_S & P\widehat{M}_S & R_S+\hat{L}_S P & \hat{M}p\cos\theta_3+\widehat{M}_3 p\cos 3\theta & \hat{M}p\cos\theta+\widehat{M}_3 p\cos 3\theta & \hat{M}p\cos\theta_2+\widehat{M}_3 p\cos 3\theta \\ \hat{M}p\cos\theta+\widehat{M}_3 p\cos 3\theta & \hat{M}p\cos\theta_2+\widehat{M}_3 p\cos 3\theta & \hat{M}p\cos\theta_3+\widehat{M}_3 p\cos 3\theta & R_r+\hat{L}_r P & P\widehat{M}_r & P\widehat{M}_r \\ \hat{M}p\cos\theta_2+\widehat{M}_3 p\cos 3\theta & \hat{M}p\cos\theta_3+\widehat{M}_3 p\cos 3\theta & \hat{M}p\cos\theta+\widehat{M}_3 p\cos 3\theta & P\widehat{M}_r & R_r+\hat{L}_r P & P\widehat{M}_r \\ \hat{M}p\cos\theta_3+\widehat{M}_3 p\cos 3\theta & \hat{M}p\cos\theta+\widehat{M}_3 p\cos 3\theta & \hat{M}p\cos\theta_2+\widehat{M}_3 p\cos 3\theta & P\widehat{M}_r & P\widehat{M}_r & R_r+\hat{L}_r P \end{bmatrix} \quad (8)$$

where:

$$\theta_2 = \theta - 2\pi/3 , \qquad \theta_3 = \theta + 2\pi/3$$

R_s= Stator resistance.

R_r= Rotor resistance.

L_s= Stator self-inductance

L_r=Rotor self-inductance

M_s= Mutual inductance between stator phases.

M_r= Mutual inductance between rotor phases.

M, M_3= Fundamental and third harmonic components of the inductance between stator and corresponding rotor phases windings at θ=0.

To simplify the equations the phase transformation C1 is used to transform the three phase windings to two phase windings, and the commutator transformation C2 is used to transform the two phase windings to commutator windings.

So the final impedance will be as shown in equation 9:

$$\begin{bmatrix} V_D \\ V_d \\ V_Q \\ V_q \end{bmatrix} = \begin{bmatrix} R_S + L_S P & MP & 0 & 0 \\ MP & R_r + L_r P & \omega_m M & \omega_m L_r \\ 0 & 0 & R_S + L_S P & MP \\ -\omega_m M & -\omega_m L_r & MP & R_r + L_r P \end{bmatrix} \begin{bmatrix} i_D \\ i_d \\ i_Q \\ i_q \end{bmatrix}. \quad (9)$$

A. *SEIG Model*

The model of SEIG is similar to an induction motor. The only difference is that the self-excited induction generator has capacitors connected across the stator terminals or excitation. The d-q representation of SEIG with capacitors connected at the terminals of the windings and without any electrical input from rotor side is shown in Figure 2.

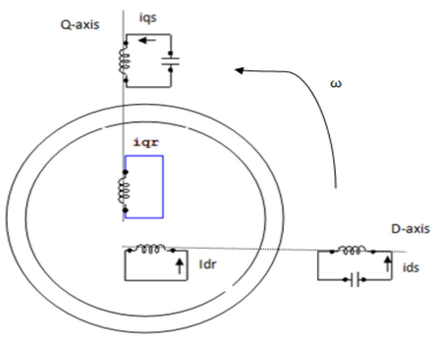


Fig. 2 d-q representation of self-excited induction generator (SEIG) with capacitor.

The matrix equation for the d-q model of self-excited induction generator in the stationary stator reference frame, using the SEIG model given in Figure 2 is given as:

$$\begin{bmatrix} V_{qs} \\ V_{ds} \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} R_S + L_S P + 1/PC & 0 & PL_m & 0 \\ 0 & R_s + L_s P + 1/PC & 0 & PL_m \\ PL_m & -\omega_r L_m & R_r + L_r P & \omega_r L_r \\ -\omega_r L_m & PL_m & \omega_r L_r & R_r + L_r P \end{bmatrix} \begin{bmatrix} i_{qs} \\ i_{ds} \\ i_{qr} \\ i_{dr} \end{bmatrix} \quad (10)$$

B. Hydraulic Turbine Model

The turbine output power is proportional to the product of head and volume flow. Figure 3 shows the control system of hydraulic plant [13].

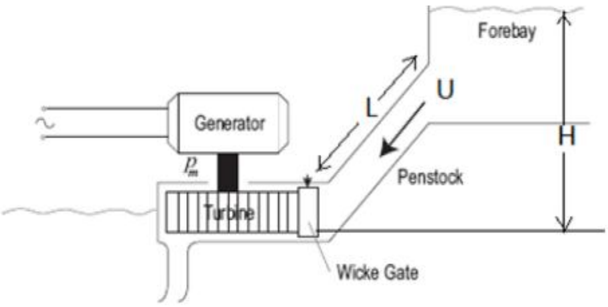


Fig. 3 Typical control system of hydraulic plant

The velocity of the water in the penstock is given by

$$u = K_U G\sqrt{H} \quad (10)$$

Where

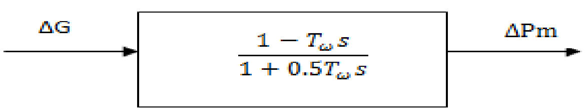
U = water velocity

G = gate position

H = hydraulic head at gate

Ku= Constant of proportional

Figure 4 shows the mathematical model of hydraulic turbine.



C. Governor Model

The basic function of a governor is to control speed and load. The primary speed/load control function involves feeding back speed error to control the gate position. This is accomplished by the provision or a rate feedback or transient gain reduction compensation as shown in the Figure 5.

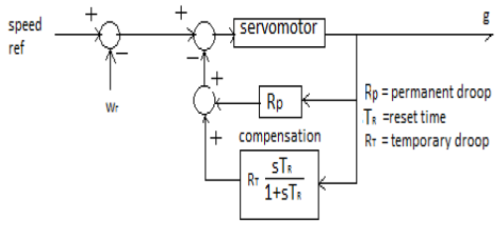


Fig. 5 Governor with transient droop compensation

The block diagram of the MHP plant with PID controller can be reduced to a simpler transfer function representation as shown in Figure 6

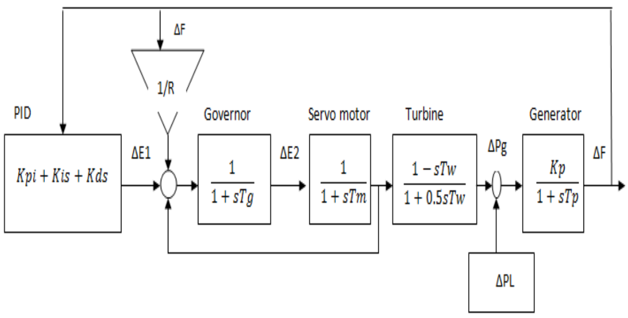


Fig. 6 Models of MHP plant using servomotor as governor with PID-Controller

III. SIMULATION OF PID CONTROLLER FORMHP PLANTS

Using the simulated model enhancement through PID controller to reduce oscillations, overshoot and peak undershoot during transient period and also to improve the steady state response.

The transfer function of PID-Controller equations is transformed using MATLAB/Simulink based on neural network as shown in Figure7.

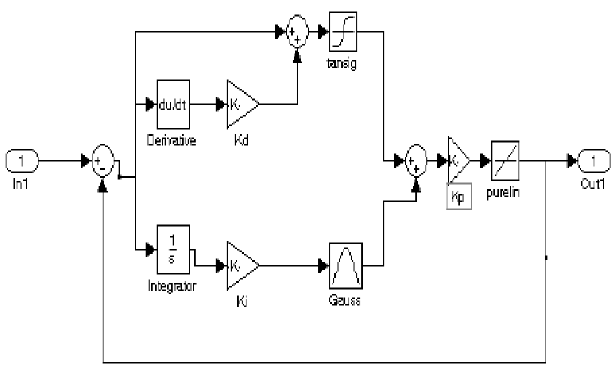


Fig.7 Simulink model of PID-Controller

PID transfer function:

$$G_1 = K_p + \frac{k_i}{s} + Kd_s \qquad (11)$$

MATLAB/Simulink software is used to simulate the behavior of the two identical self-excited induction generators connected to hydro-turbine, at steady state operation and during transient period. The behavior of the two generators model is then examined when feeding a purely resistive load connected to the stator terminals and isolated from the national network.

IV. Results and Discussions

A. Results at Steady- State Operation

The two induction machines shaft is initially rotated by hydro turbines as prime mover at a steady speed. When the three-phase, star connected self-excitation capacitor bank (*16.74KVAr*), calculated by the nodal analysis method, is applied to the stator terminals, the two machines work as induction generator.

Figures 9 and 10 show the output voltage and current of one generator. It observed from the figures that the voltage and current are equal to zero from (t=0 sec) until (t=0.2 sec), then they increasing because the voltage built up by capacitor bank, and then reached to the steady-state value (220V) and (39A), respectively at (t=1sec).

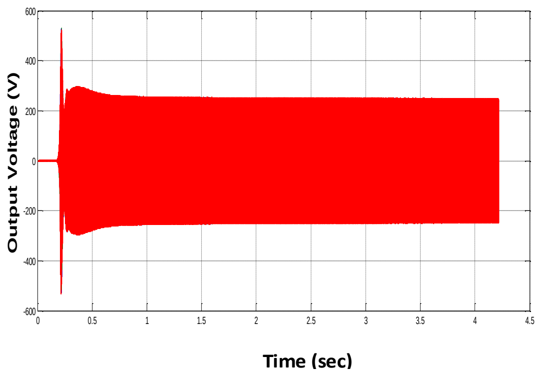


Fig. 9 Output Voltage of SEIG

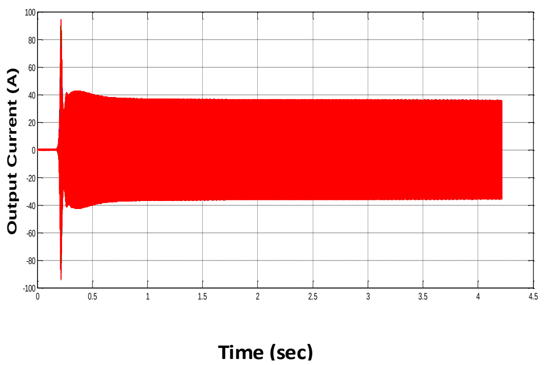


Fig.10 Output Current of SEIG

Figures 11 represent the generated power by the generator1 and, it can be noted that generated power by the generator start from zero to high value at starting, and then reached the steady state value (390Kw) at (t=1sec).

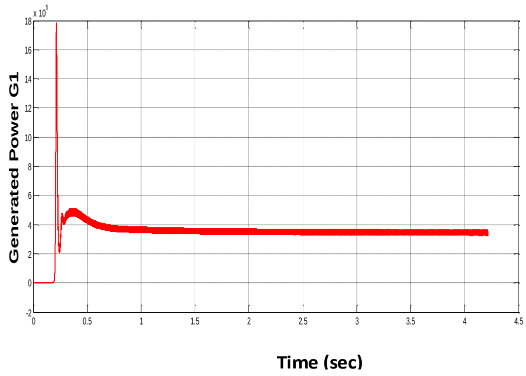


Fig.11 Generated Power by generator 1

Figure 12 shows the rotor speed of generator 1. At starting period, the speed increased as linear relation to higher value, and at (t=1 sec), it reached to full load speed (steady state speed) (6.1p.u).

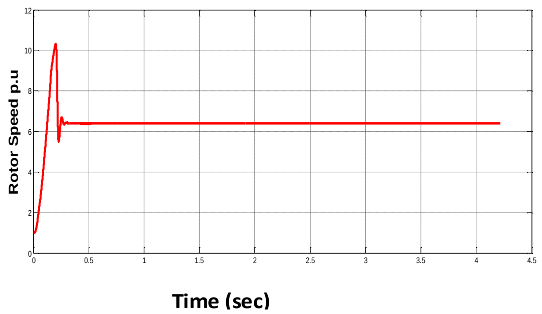


Fig.12 Rotor Speed of Generator 1

B. Results at Three-Phase Fault

Figure 13 represents the output current of generator 2 during the 3-phase fault, it note that the current increase to high value (225A) when the fault occurs at the terminal of generator 2 at (t=3.8). And when the fault was clear at (t=4sec) the current back to steady state value at (t=4.2sec).

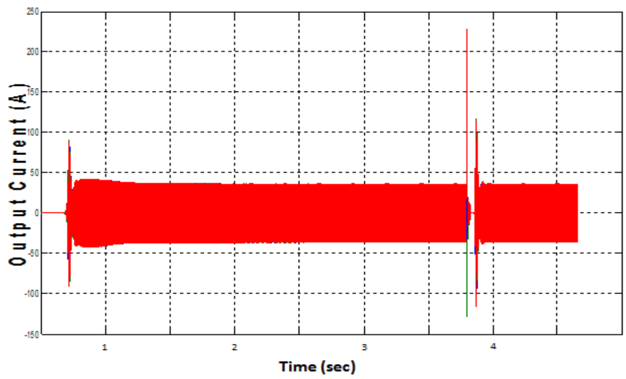


Fig.13 The Output Current of generator 2

Figure 14 shows the Output voltage of generator 2 during the 3-phase fault, it note that the voltage is decrease to zero when the fault occurs at the terminal of generator 2, at (t=3.8).

And when the fault was clear the voltage back to steady state value at (t=4.2sec).

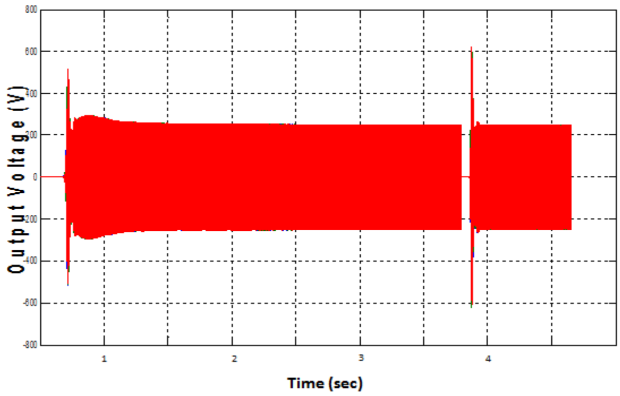


Figure 14 Output Voltage of generator 2

V. CONCLUSIONS

A micro-hydro system can be installed easily and economically in remote locations/rural areas. Many countries have enormous hydroelectric potential in isolated and remote location. This study has presented the simulation of dynamic modeling of two identical self-excited induction generators (SEIGs) driven by micro-hydro turbine. MATLAB/Simulink software was used to simulate the system. The steady state operation and transient characteristics with constant load was presented. The results of simulation had been discussed, and from the results it proved that the model of two generators gives good dynamic and steady-state performance.

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