ANALYSIS OF SELF-EXITED INDUCTION GENERATOR FOR ISOLATED SYSTEM

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Abstract

Self exited Induction generators are widely used in non conventional energy systems such as wind, micro/mini hydro, etc. The squirrel cage induction generator is simple, reliable, cheap, lightweight, ruggedness, and requires very little maintenance. This paper presents the self-excitation and modeling, steady-state, performance analysis and generating schemes of induction generators.

Keywords: self-exited induction generator; steady-state and performance analysis; generating schemes.

1. Introduction

An externally driven induction machine with an appropriate value of capacitor bank can be used as a generator [1]. This system is called self-excited induction generator (SEIG). The self-excited induction generators (SEIG) have been found suitable for energy conversion for remote locations. Such generators may be commonly used in the remote rural areas where it is not possible to draw from transmission lines. These machines can be used to meet the local demand of remote areas in the absence of a grid [2]. This system is called self-excited induction generator (SEIG). The SEIG has many advantages over the synchronous generator: brushless (squirrel cage rotor), reduced size, rugged and low cost. But the induction generator offers poor voltage regulation and its value depends on the prime mover speed, capacitor bank and load [3]. Use of an induction machine as a generator is becoming more and more popular for the renewable sources [4].

The paper is organized as follows. Section 2 presents the system Configuration. Steady-state and performance analysis is presented in Sections 3. Generating schemes of induction generators has been presented in Sections 4.

2. System Configuration

A SEIG is driven by prime mover. The generator supplies an isolated three-phase four-wire load. When an induction machine is driven at a speed greater than the synchronous speed (negative slip) by means of an external prime mover, the direction of induced torque is reversed and theoretically it starts working as an induction generator. From the circle diagram of the induction machine in the negative slip region [8], it is seen that the machine draws a current, which lags the voltage by more than 90. This means that real power flows out of the machine but the machine needs the reactive power. To build up voltage across the generator terminals, excitations must be provided by some means; therefore, the induction generator can work in two modes. In case of a grid-connected mode, the induction generator can draw reactive power either from the grid but it will place a burden on the grid or by connecting a capacitor bank across the generator terminals [6], [9]. For an isolated mode, there must be a suitable capacitor bank connected across the generator terminals. This phenomenon is known as capacitor self-excitation and the induction generator is called a "SEIG" [5]. Fig 1shows a schematic arrangement of self-Exited induction generator as a isolated system.

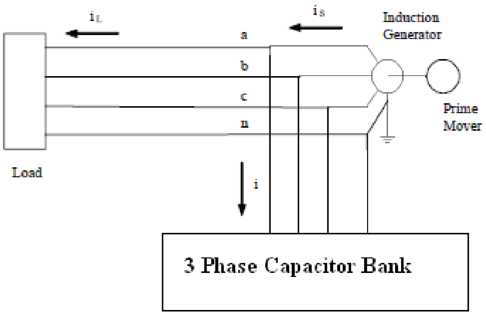

Fig. 1. Self exited induction generator system.

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3. Steady-State and Performance Analysis

In the present paper, the standard steady state equivalent circuit of a SEIG with the usual assumptions considering the variation of magnetizing reactance with saturation as the basis for calculation. The equivalent circuit is normalized to the base frequency by dividing all the parameters by the p.u. frequency as shown in Fig 2.

The total current at node ‘a’ in the above figure can be written as

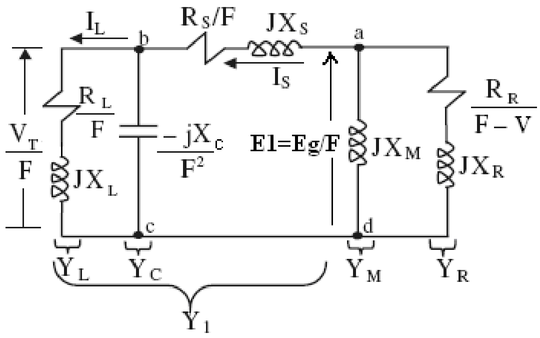

Fig. 2. Per-phase equivalent circuit oh a SEIG.

$$E_1(Y_1 + Y_M + Y_R) = 0 \qquad \text{---------------- (1)}$$

Therefore, under steady-state self-excitation, the total admittance must be zero,

$$(Y_1 + Y_M + Y_R) = 0 \qquad \text{---------------- (2)}$$

Where

$$Y_1 = \frac{(Y_C + Y_L)(Y_S)}{Y_C + Y_L + Y_S} \qquad Y_C = \frac{1}{-(jX_C/F^2)}$$

$$Y_L = \frac{1}{(R_L/F)} \qquad Y_S = \frac{1}{(R_S/F) + jX_S}$$

$$Y_M = \frac{1}{jX_M} \qquad Y_R = \frac{1}{\frac{R_R}{F-V} + jX_R}$$

By separating the real and imaginary components of equation (2) and putting separately equal to zero, two equations is obtained in term of machine parameters shaft speed and generated frequency.

$$\mathrm{G_0(F)} = A_5F^5 + A_4F^4 + A_3F^3 + A_2F^2 + A_1F + A_0 = 0 \qquad \text{-------------- (3)}$$

$$\mathrm{H_0(V)} = B_2V^2 + B_1V + B_0 = 0 \qquad \text{-------------- (4)}$$

The coefficients (A_0-A_5) and (B_0-B_2) of two characteristics equation are obtained by solving above two equation mathematically and given in appendix –I and X_M can be obtained from imaginary parts of equation (2) as

$$X_M = -1/\left\{\frac{X_R}{[R_R/(F-V)]^2 + {X_R}^2} + \frac{X_{ac}}{{R_{ac}}^2 + {X_{ac}}^2}\right\} \qquad \text{-------------- (5)}$$

Where

$$X_{ac} = X_s - X_{bc} \qquad R_{ac} = \frac{R_s}{F} + R_{bc}$$

$$X_{bc} = {R_L}^2X_C/(F^2{R_L}^2 + {X_C}^2) \qquad R_{bc} = R_L{X_C}^2/[F(F^2{R_L}^2 + {X_C}^2)]$$

Now by solving the equivalent circuit of SEIG, the analysis of machine is simple and straight. Branch currents, terminal voltage input power and output power is computed as under:

$$I_S = \frac{E_g/F}{\frac{R_S}{F} + jX_S - \frac{jX_CR_L}{F^2R_L - FX_C}} \qquad I_R = \frac{-E_g/F}{\frac{R_R}{F-V} + X_R}$$

$$I_L = \frac{-jX_CI_S}{R_LF - jX_C} \qquad V_T = I_LR_L$$

$P_{in} = \frac{-3R_R F|I_R|^2}{F-V}$ $\qquad$ $P_{out} = 3|I_L|^2 R_L$

4. Generating Schemes of Induction Generators

Depending upon the prime movers used (constant speed or variable speed) and their locations (near to the power network or at isolated places), generating schemes can be broadly classified as under:

- constant-frequency schemes
- constant- speed schemes
- variable-speed variable-frequency schemes

4.1. Constant frequency schemes

The variable-speed operation of wind electric system yields higher output for both low and high wind speeds [5]. This results in higher annual energy yields per rated installed capacity. Both horizontal and vertical axis wind turbines exhibit this gain under variable-speed operation. For constant frequency, shaft speed and magnetizing reactance will vary with the load and taken as variable and calculate using equation (4) & (5). These variations are shown in fig. 3 and fig. 4. The load range and speed regulation for constant frequency is summarized in Table 1.

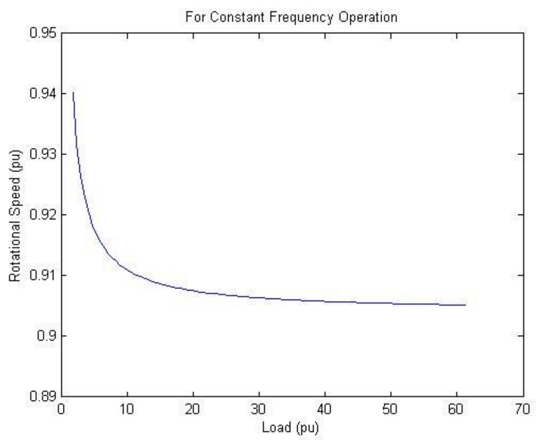

Fig. 3. Variation of rotational speed with load.

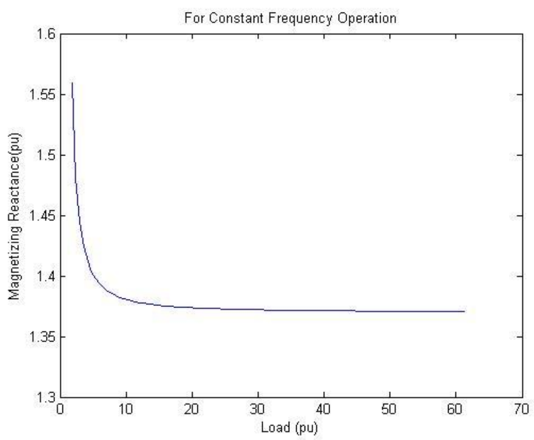

Fig. 4. Variation of magnetizing reactance with load.

Table 1. Load Impedance and Shaft Speed of SEIG with Constant Output Frequency.

Load impedance at unity power factor (pu value)	Shaft speed (pu value)	Output frequency (pu value)
1.80	1.0379	0.9
5.40	1.0105	0.9
10.20	1.0037	0.9
13.80	1.0016	0.9
21.00	0.9996	0.9
24.60	0.9991	0.9
29.40	0.9985	.09
33.00	0.9982	0.9
37.20	0.9979	0.9
39.60	0.9978	0.9
43.80	0.9976	0.9
52.80	0.9973	0.9
56.40	0.9972	0.9
61.20	0.9971	0.9

4.2. Constant speed schemes

To achieve constant speed operation, the generator should be driven by a fixed shaft speed turbine. In this scheme, the prime mover speed is held constant by continuously adjusting the blade pitch and/or generator characteristics [5]. An induction generator can operate on an infinite bus bar at a slip of 1% to 5% above the synchronous speed. Induction generators are simpler than synchronous generators. They are easier to operate, control, and maintain, do not have any synchronization problems, and are economical [6]. For constant shaft speed, generated frequency and magnetizing reactance will vary with the load and taken as variable and calculate using equation (3) & (5). These variations are shown in fig. 5 and fig. 6. The load range and frequency regulation for constant speed is summarized in Table 2.

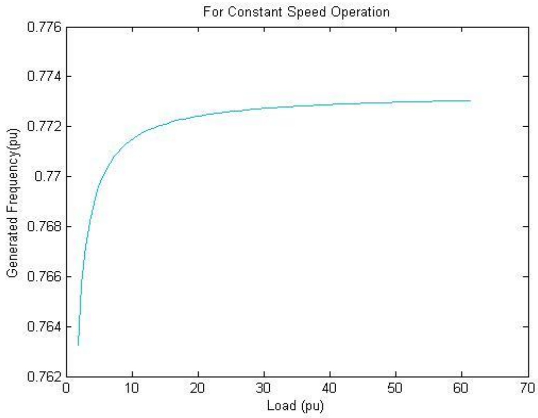

Fig. 5. Variations of Generated Frequency with Load

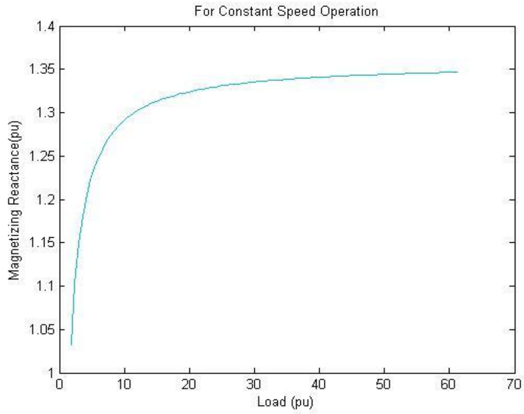

Fig. 6. Variation of Magnetizing Reactance with Load

Table 2. Load Impedance and Output Frequency of SEIG with Constant Shaft Speed.

Load impedance at unity power factor (pu value)	Output frequency (pu value)	Shaft speed (pu value)
1.80	0.7632	0.95
5.40	0.7699	0.95
10.20	0.7715	0.95
13.80	0.7720	0.95
21.00	0.7725	0.95
24.60	0.7726	0.95
29.40	0.7727	0.95
33.00	0.7728	0.95
37.20	0.7728	0.95
39.60	0.7729	0.95
43.80	0.7729	0.95
52.80	0.7730	0.95
56.40	0.7730	0.95
61.20	0.7730	0.95

4.3. Variable speed variable frequency schemes

For variable speed corresponding to the changing derived speed, SEIG can be conveniently used for resistive heating loads, which are essentially frequency insensitive. This scheme is gaining importance for stand-alone wind power applications [4], [6]. In this operation generated frequency and magnetizing reactance will vary with the load and shaft speed both taken as variable and calculate using equation (3), (5). These variations are shown in fig. 7, fig. 8 and fig. 9.

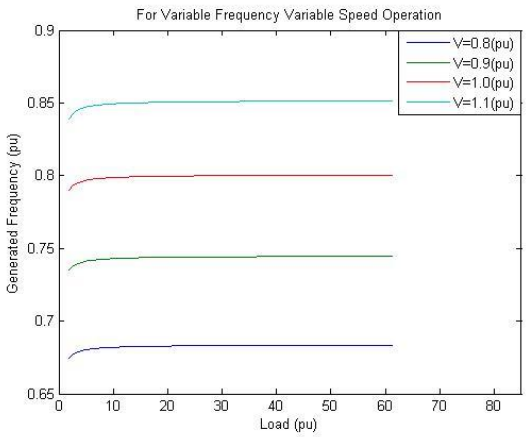

Fig. 7. Variations of Generated Frequency with Load

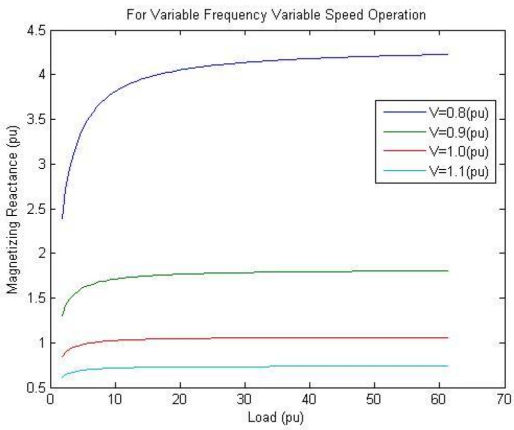

Fig. 8. Variation of Magnetizing Reactance with Load

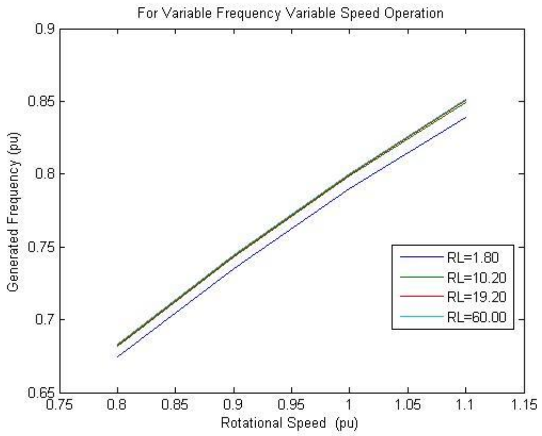

Fig. 9. Variations of Generated Frequency with Rotational Speed

5. Conclusions

Self Excited Induction Generators seem to be the right choice for remote windy locations for supplying power. It is found that proposed analysis results in to a estimation for generated frequency, magnetizing reactance and load variation at different condition. In this work many operating schemes of SEIG are discussed, which are useful to installing SEIG as an isolated systems provided low maintenance cost.

Analysis proposed may be helpful for researchers to think over the implementation of such generators successfully in windy remote locations and various mini and micro hydro plaint.

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Nomenclatures

R_S, R_R, R_M, R_L, R_C	P.U. stator, rotor, magnetizing, load and exciting resistances, respectively
X_S, X_R, X_M, X_L, X_C	P.U. stator, rotor leakage, magnetizing, load and exciting reactance respectively
Y_S, Y_R, Y_M, Y_L, Y_C	P.U. stator, rotor, magnetizing, load and exciting admittances, respectively
f_s	Synchronous frequency
F	P.U. frequency
V	P.U. rotational speed
E_g, V_T	P.U. air gap and terminal voltage, respectively
I_S, I_R, I_L	P.U. stator, rotor and load current per phase, respectively
P_{out}	Output electrical power
P_{in}	Input mechanical power
Z_c	Capacitor bank impedance

Appendix – I

Coefficients ($A_0 – A_5$) of equation $G_0(F)$

$$A_0 = -VR_R\left(\frac{R_3}{R_L}\right)^2$$
$$A_1 = R_R\left(\frac{R_3}{R_L}\right)^2 + R_3\left(\frac{R_R}{R_L}\right)^2 + V^2R_3\left(\frac{X_R}{R_L}\right)^2$$
$$A_2 = -2VR_3\left(\frac{X_R}{R_L}\right)^2 - VR_R\left\{\left(\frac{R_S}{X_C}\right)^2 + \left(\frac{X_S}{R_L}\right)^2 - 2\left(\frac{X_S}{X_C}\right)\right\}$$
$$A_3 = R_R\left[\left(\frac{X_S}{R_L}\right)^2 + \left(\frac{R_S}{X_C}\right)^2 - 2\left(\frac{X_S}{X_C}\right)\right] + R_3\left(\frac{X_R}{R_L}\right)^2 + R_S\left(\frac{R_R}{X_C}\right)^2 + V^2R_S\left(\frac{X_R}{X_C}\right)^2$$
$$A_4 = -V\left[R_R\left(\frac{X_S}{X_C}\right)^2 + 2R_S\left(\frac{X_R}{X_C}\right)^2\right]$$

$$A_5 = R_R\left(\frac{X_S}{X_C}\right)^2 + R_S\left(\frac{X_R}{X_C}\right)^2$$

Where

$$R_3 = R_S + R_L$$

Coefficients (B_0 – B_2) of equation $H_0(V)$

$$B_0 = R_R F\left(R_{ac}{}^2 + X_{ac}{}^2\right) + R_{ac}\left(R_R{}^2 + F^2 X_R{}^2\right)$$
$$B_1 = -\left[R_R\left(R_{ac}{}^2 + X_{ac}{}^2\right) + 2F\,R_{ac}X_R{}^2\right]$$
$$B_2 = R_{ac}X_R{}^2$$

Appendix – II

The details of induction machine are:

- Specifications

3-phase, 4-pole, 60 Hz, star connected, squirrel cage induction machine
1kw, 380 V, 2.27A

- Parameters

The equivalent circuit parameters for the machine are
R_S =0.1 X_S =0.2 R_R = 0.06 X_R = 0.2
Base values
Base voltage =219.3 V
Base current =2.27 A
Base Impedance=96.6 Ω
Base frequency=60 Hz
Base speed=1800rpm
The magnetization curve is represented mathematically as

$$\frac{E_g}{F} = 1.12 + .078X_M - 0.146X_M\ ; \qquad 0 < X_M < 3$$

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