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Analysis of Self Excited Capacitances for Self Excited Induction Generator for Different Operating Conditions Using Fuzzy Systems

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ASTRACT:- Self-excited induction machine seem to be the most suitable generators for wind energy conversion in remote and windy areas. Steady state analysis for such machines is essential to estimate the behaviour under actual operating conditions. Excitation analysis of a three phase self excited induction generator feeding balanced unity power factor load is proposed. Iterative technique has been used to find the generated frequency. When load and speed is increased then value of capacitance and generated frequency are calculated keeping Xm fixed. It is observed that the value of capacitance is decreasing with increase in load and speed and value of frequency is decreasing. Then fuzzy system is applied to these values of Self excited induction generator (SEIG). Simulation results showed the effectiveness of the proposed work**.**

KEYWORDS: Self-exited induction generator; magnetization characteristics; fuzzy system.

I.INTRODUCTION

Most of the electrical power generation across the world is due to the use of fossil fuel, which are limited in reserve. These may vanish from earth if continued to be used at the same pace. A rapid depletion of fossil fuels as well as a fast growing power. Most of the electrical power generation across the world is due to the use of fossil fuel, which are limited in reserve. These may vanish from earth if continued to be used at the same pace. A rapid depletion of fossil fuels as well as a fast growing power demand has pressurized the scientists to think about non conventional sources of energy such as wind energy, solar energy, tidal energy, etc. Use of such sources may be helpful to retain our resources of fossil fuel for some additional years. Scientists have observed that out of all potential non conventional sources wind energy seems to be more attractive and viable. It is observed that winds carry enormous amount of energy and the regions in which strong winds prevail for a sufficient time during the year may use it for electrical energy generation. In addition to this wind energy generation provides a clean and pollution free environment and does not lead to global warming. Further a wind turbine generator may be a worthwhile proposition for an isolated remote area due to absence of power grid. There are many considerations in the choice of generators for the wind turbine applications and several views prevail. However most of the researchers are in the favour of induction generators in self-excited mode due to its ability to convert mechanical power over a wide range of rotor speeds. Induction generators are also preferred due to several other advantages such as low cost, less maintenance and easy operation. The self-excited induction generators (SEIG) are also found suitable for few other applications such as tidal and mini hydroelectric energy conversion. Operation of induction generator in self excited mode is useful under variable speed operation especially when wind speed is fluctuating within a wide range. Therefore it becomes the duty of researchers to investigate the behaviour of specific problem related issues of SEIG. To compute the steady state performance of SEIG, researchers adopted different models [1-13]. However, [10-11] suggested a new equivalent circuit model representation. In this paper fuzzy system along with iterative technique has been proposed to analyze the steady state performance of SEIG through conventional equivalent circuit. Iterative modelling estimates the unknown frequency and magnetising reactance. Fuzzy system has been applied to calculated values and results obtained have been compared with the calculated results.

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For the machine to self-excite, the excitation capacitance must be larger than some minimum value. In order to obtain a stable output voltage, the machine must operate at an appreciable level of magnetic saturation. Accordingly, the magnetizing reactance Xm is not constant, but varies with the load and circuit conditions. For successful voltage build-up, the load-capacitance combination should result in a value of Xm which is less than the unsaturated value, hence the condition Xm = Xmax yields the minimum value of excitation capacitance below which the SEIG fails to self-excite.
There are two different approaches in the steady-state analysis of self-excited induction generators. They are the loop impedance method as used by Malik et al and the nodal admittance method as used by Mcpherson et al. If the machine speed is specified and the condition Xm = Xmax prevails, then the only variables in the equivalent circuit are the per-unit frequency f and the capacitive reactance Xc.
The nodal admittance method will be used instead, the advantage being that the load and excitation capacitance branches can be easily decoupled, which enables the per unit frequency f to be determined independent of the value of Xc.

II.CAPACITOR SELF-EXCITATION, ANALYSIS

The equivalent circuit commonly used for the steady-state analysis of the SEIG [1] is shown in figure 1. For the machine to self-excite, the excitation capacitance must be larger than some minimum value. In order to obtain a stable output voltage, the machine must operate at an appreciable level of magnetic saturation. Accordingly, the magnetizing reactance Xm is not constant, but varies with the load and circuit conditions. For successful voltage build-up, the load-capacitance combination should result in a value of Xm which is less than the unsaturated value, hence the condition Xm = Xmu yields the minimum value of excitation capacitance below which the SEIG fails to self-excite.
There are two different approaches in the steady-state analysis of self-excited induction generators. They are the loop impedance method as used by Malik et al. [1,5] and the nodal admittance method as used by McPherson et al. [8]. If the machine speed is specified and the condition Xm = Xmu prevails, then the only variables in the equivalent circuit of figure 2 are the per- unit frequency f and the capacitive reactance Xc.
The nodal admittance method will be used instead, the advantage being that the load and excitation capacitance branches can be easily decoupled, which enables the per unit frequency f to be determined independent of the value of Xc

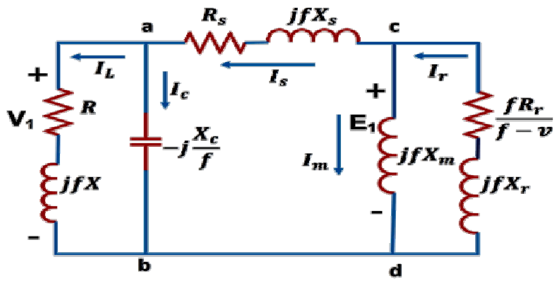

Figure 1: Equivalent circuit of SEIG

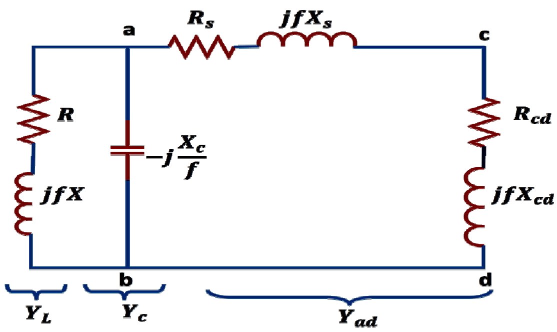

Figure 2: Simplified Equivalent circuit of SEIG

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For this purpose, figure 3 is redrawn as figure 4, where

$$Z_{cd} = \left[\frac{fR_r}{(f-v)} + jfX_r\right] // jfX_m \quad (1)$$

Separating real and imaginary parts

$$R_{cd} = \frac{f(f-v)R_r X_m^2}{R_r^2 + (f-v)^2 (X_r + X_m)^2} \quad (2)$$

$$X_{cd} = \frac{f[R_r^2 X_m + (f-v)^2 . X_r X_m (X_r + X_m)]}{R_r^2 + (f-v)^2 (X_r + X_m)^2} \quad (3)$$

The total impedance Z_{ad} of branch acd is then given by

$$Z_{ad} = R_{ad} + jX_{ad} \quad (4)$$

$$R_{ad} = R_s + R_{cd} \quad (5)$$

$$X_{ad} = fX_s + fX_{cd} \quad (6)$$

$$Z_L = R + jfX$$

The admittancesY_L and Y_{ad} are given by

$$Y_L = \frac{R}{R^2 + f^2 X^2} - j\frac{fX}{R^2 + f^2 X^2} \quad (7) \qquad Y_{ad} = \frac{R_{ad}}{R_{ad}^2 + X_{ad}^2} - j\frac{X_{ad}}{R_{ad}^2 + X_{ad}^2} (8)$$

By Kirchhoff's Law, the sum of current at node 'a' should be equal to zero, hence

$$V_1(Y_c + Y_L + Y_{ad}) = 0 \quad (9)$$

For successful voltage build-up, $V_1 \neq 0$, hence

$$Y_c + Y_L + Y_{ad} = 0 (10)$$

Equating the real and imaginary part to zero

$$\frac{R}{R^2 + f^2 X^2} + \frac{R_{ad}}{R_{ad}^2 + X_{ad}^2} = 0 \quad (11)$$

$$\frac{f}{X_c} - \frac{fX}{R^2 + f^2 X^2} - \frac{X_{ad}}{R_{ad}^2 + X_{ad}^2} = 0 \ (12)$$

It is noted that (11) is independent of X_c& the only variable is the per unit frequency f. Once the value of f has been determined the X_c can be determined using (12).
Equation (11), after a series of algebraic manipulation can be expressed as a 6th degree polynomial in f is

$$P_6 f^6 + P_5 f^5 + P_4 f^4 + P_3 f^3 + P_2 f^2 + P_1 f + P_0 = 0 \quad (13)$$

The derivation of these constant (coefficients) P_0 to P_6 are given below. Equation (13) can be solved numerically to yield the entire real and complex root. Only the real root have physical significance and the largest positive real root yields the per unit frequency that corresponds to C_{min} i.e.

$$f_{max} = max\{f_i, i \leq 6\} \quad (14)$$

Where $\{f_i, i \leq 6\}$ is the set of positive real root of (13)
Having determined f_{max} equation (12) may be used to calculate C_{min} as follows:

$$C_{min} = \frac{1}{2\pi f_b Z_b f_{max}} \left[\frac{f_{max} X}{R^2 + f_{max}^2 X^2} + \frac{X_{ad}}{R_{ad}^2 + X_{ad}^2}\right] (15)$$

To compute the coefficient P_0 and P_6, the following are first defined;

$$X_3 = X_m + X_r \quad (16)$$

$$DENOM = R_r^2 + (f-v)^2 X_3^2 \quad (17)$$

$$NUM1 = R_s DENOM + f(f-v)R_r X_m^2 \quad (18)$$

$$NUM2 = f[X_s DENOM + X_m f\{R_r^2 + (f-v)^2 X_r X_3\}] \ (19)$$

$$Z_{ad} = R_{ad} + jX_{ad} = \frac{NUM1 + jNUM2}{DENOM} \quad (20)$$

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Equating (11), upon cross-multiplication, becomes

$R(NUM1^2 + NUM2^2) + (R^2 + f^2X^2)DENOM.NUM1 = 0$ (21)

DENOM, NUM1 and NUM2 can be reduced to the following forms:

$$DENOM = g_2f^2 + g_1f + g_0 \quad (22)$$
$$NUM1 = h_2f^2 + h_1f + h_0 \quad (23)$$
$$NUM2 = k_3f^3 + k_2f^2 + k_1 \quad (24)$$

Where

$$\left.\begin{aligned} g_0 &= R_r^2 + v^2X_3 \\ g_1 &= -2vX_3^2 \\ g_2 &= X_3^2 \end{aligned}\right\} \quad (25)$$

$$\left.\begin{aligned} h_0 &= R_s(R_r^2 + v^2X_3^2) \\ h_1 &= -v(R_rX_m^2 + 2R_sX_3^2) \\ h_2 &= R_rX_m^2 + R_sX_3^2 \end{aligned}\right\} \quad (26)$$

$$\left.\begin{aligned} k_1 &= (X_sR_r^2 + X_mR_r^2) + v^2(X_sX_3^2 + X_rX_3X_m) \\ k_2 &= -2v(X_sX_3^2 + X_rX_3X_m) = -2vk_3 \\ k_3 &= X_sX_3^2 + X_rX_3X_m \end{aligned}\right\} \quad (27)$$

Each of the terms in (11), after expansion reduces to a 6th degree polynomial, whose coefficient P_0 to P_6 are given below:

$$P_6 = k_3^2R + g_2h_2X^2$$
$$P_5 = g_2h_1X^2 + g_1h_2X^2 + 2k_2k_3R$$
$$P_4 = (h_2^2 + k_2^2 + 2k_1k_3)R + (g_2h_0 + g_1g_0 + g_0h_2)X^2 + R^2g_2h_2$$
$$P_3 = (g_1 h_0 + g_0 h_1) X^2 + (g_2h_1 + g_1h_2)R^2 + (2h_1h_2 + 2k_1k_2)R$$
$$P_2 = (g_2h_0 + g_1h_2 + g_0h_2)R^2 + g_0h_0X^2 + (h_1^2 + k_1^2 + 2h_0h_2)R$$
$$P_1 = (g_1h_0 + g_0h_1) R^2 + 2 h_0 h_1 R$$
$$P_0 = h_0^2R + g_0h_0R^2$$

The coefficients P_0 and P_6 are systematically expressed in terms of R, X and the constants defined in (25) to (27)

For resistive load

Substitute X=0 in (16) to (27). The modified coefficients are as follows:

$$P_6 = k_3^2R$$
$$P_5 = 2k_2k_3R$$
$$P_4 = (h_2^2 + k_2^2 + 2k_1k_3)R + R^2g_2h_2$$
$$P_3 = (g_2h_1 + g_1h_2)R^2 + (2h_1h_2 + 2k_1k_2)R$$
$$P_2 = (g_2h_0 + g_1h_1 + g_0h_2)R^2 + (h_1^2 + k_1^2 + 2h_0h_2)R$$
$$P_1 = (g_1h_0 + g_0h_1) R^2 + 2 h_0 h_1 R$$
$$P_0 = h_0^2R + g_0h_0R^2$$

III.COMPUTED AND EXPERIMENTAL RESULTS

In this paper computed and experimental results refer to three phase,4 pole,50 Hz star connected squirrel cage induction machine, 750KW/1HP, 380V, 1.9A whose per phase equivalent circuit constants in per unit are as follows:

R_s=.0823p.u, R_r=.06967p.u, X_s= X_r=.0766p.u

Non linear relationship between X_m and E_1 using experimental data for machine may be represented by PLA as below:

E_1=2.3378-1.12 X_m $\quad X_m<1.466$

E_1=4.066-2.3 X_m $\quad 1.5547\leq X_m\geq 1.466$

E_1=3.583-1.989 X_m $\quad 1.5984\leq X_m\geq 1.554$

E_1=0 $\quad X_m>1.5984$

Now X_m is fixed.

X_m=1.2133p.u

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When X_m is fixed capacitance is calculated for different load and speed.

R(Ω)	b(r.p.m)	a(Hz)	C(µf)
200	1450	46.025	29.765
220	1460	46.55	28.57
235	1465	46.835	27.92
250	1490	47.1	27.33
262	1480	47.495	26.7
275	1490	47.895	26.09
282	1500	48.26	25.615
295	1510	48.615	25.1
305	1530	49.345	24.276
318	1442	49.795	23.73
326	1550	50.07	23.4
345	1560	50.49	22.88
360	1570	50.865	22.45
380	1575	51.095	22.13
400	1600	51.94	21.33
420	1635	53.175	20.277
435	1650	53.7	19.83

Table-1: Calculated data of SEIG

A fuzzy modelling is developed to determine the generated frequency and excitation capacitance of the IG according to the rotor speed and desired value of load resistance of the Induction Generator (IG) using the values given in table-1.Considering the possible parameter variations of the IG , a fuzzy control rule using the desired speed and load resistance as the linguistic variable in the antecedent part and the generated frequency, capacitance as the variable in the consequent part is derived first. The proposed membership functions can be described. The linguistic values, membership functions, fuzzy control rules and defuzzification of the proposed modelling as chosen as follows:

IV.BASIC STRUCTURE OF FUZZY LOGIC

Two inputs: Load and Speed

Load range: 200Ω - 435Ω
Low: 200 – 220 – 250
Med: 235 – 275 – 305
High: 295 – 345 – 380
Very high: 360 – 400 – 435

Speed range:1450-1650r.p.m

Low: 1450 – 1460 – 1470
Med: 1465 – 1490 – 1510
High: 1500 – 1550 – 1575
Very high: 1570 – 1600 – 1650

Two outputs: frequency and capacitance

Frequency range : 46.025 - 53.700Hz
Low: 46.025 - 46.550 - 47.100
Med: 46.835 - 47.895 – 48.615
High: 48.260 - 49.795 - 50.865

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Very High: 50.490 - 51.940 - 53.700

Capacitance range:19.83-29.765µf

Low: 19.830 - 21.330 - 22.450
Med: 22.130 - 23.400 - 25.100
High: 24.276 - 26.090 - 27.330
Very high: 26.700 - 27.920 - 29.765

$R_L(\Omega)$	b(r.p.m)	a(Hz)	C(µf)
Low	Low	Low	V. High
Low	Med	Med	V. High
Low	High	High	High
Low	V. High	V. High	Med
Med	Low	Med	V. High
Med	Med	Med	High
Med	High	High	Med
Med	V. High	V. High	Low
High	Low	Med	High
High	Med	Med	High
High	High	High	Med
High	V. High	V. High	Low
V. High	Low	Med	High
V. High	Med	Med	High
V. High	High	High	Med
V. High	V. High	V. High	Low

Table 2: Rule base table of input and output data

Linguistic values*:* Low, Medium, High, Very high. Membership functions: Depending on the special applications and the performance of the user, many type of membership functions can be selected. In this study, the triangle shaped functions are used [14-18].

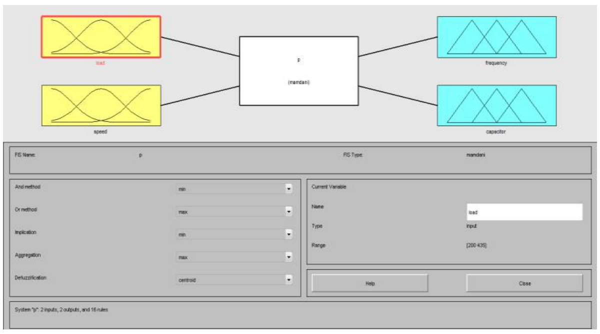

Figure 3: Linguistic variables

Construction of fuzzy rules*:* On the basis of experience and knowledge concerning the IG system to be controlled, linguistic rules for the fuzzy modelling of IG which are IF-THEN forms are formulated and listed in table-2 . The load resistance and speed are the linguistic variable in the antecedent part and capacitance, generated frequency are the

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linguistic variable in the consequent part.

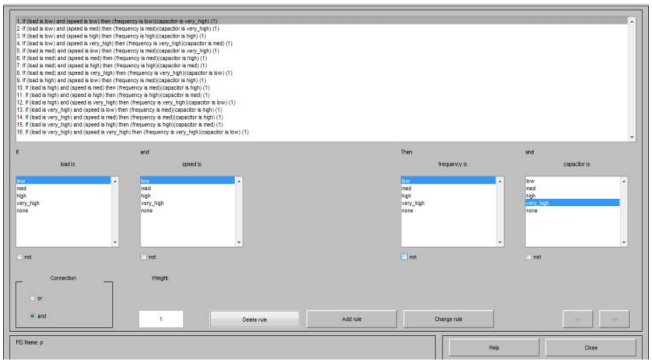

Figure 4: Rule base for given data

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V. RESULT AND DISCUSSION

Defuzzification: The centroid of area method is implemented to result in the output

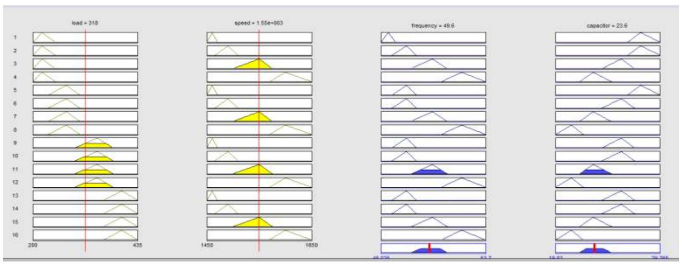

Figure 5: Fuzzy Logic output results of SEIG

Figure 5 shows the fuzzy logic output results of self excited induction generator.As self excited capacitance plays important role in improving voltage regulation, as the value of load and speed changes it affects the value of generated frequency and capacitance .

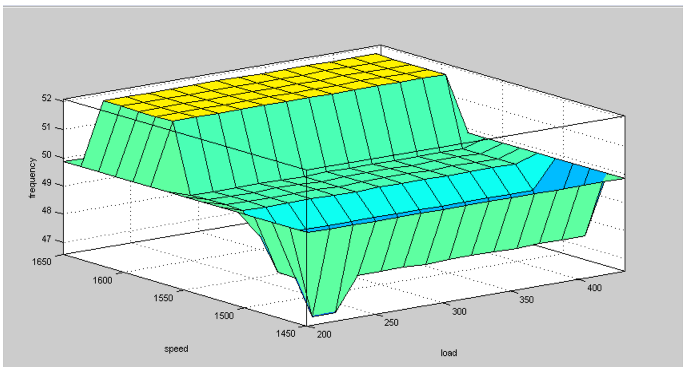

Figure 6: Surfaceview of SEIG

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VI.CONCLUSION

In this paper attempt has been made to realize the value of self excited capacitances and generated frequency for self excited induction generator, when X_m is fixed for the computation of steady state performance of SEIG using iterative technique. As self excited capacitance plays an important role in improving voltage regulation, as the value of load and speed changes it affects the value of generated frequency and capacitance. In this paper attempt has been made to realize that as the value of load and speed increases, the value of capacitance decreases and generated frequency increases. A close agreement between the computed and experimental results confirms the validity and accuracy of the analysis of SEIG using fuzzy system.

APPENDIX

The details of machine

Specifications

3-phase, 4-pole, 50 Hz, star connected, squirrel cage induction machine

0.750kw/1HP, 380V(rated line voltage), 1.90A.

R_1=9.5Ω, R_2=8.04Ω, X_1=X_2=8.84Ω

Base voltage=219.30V

Base current=1.90A

Base impedance=115.40Ω

Base capacitance=27.5μf

Base power=1.25kw

Base frequency=50Hz

Base speed=1500 r.p.m

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