Improvement in Voltage Profile in Self Excited Induction Generator using Fuzzy Logic

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Abstract- In this paper Improvements in the performance of a three-phase self-excited induction generator (SEIG) through series compensation are presented. Both short-shunt and long-shunt configurations, of capacitive series compensation requirement are calculated for the selection of capacitive elements. It is clearly shown that short-shunt method is more superior than long-shunt SEIG. Simulated result showed the effectiveness using Fuzzy logic.

Key words: Self excited induction generator, Short shunt & Long shunt configuration and Fuzzy logic.

NOMENCLATURE

R_1, R_2	Per phase stator and rotor
R_L	Per phase load resistance
X_1, X_2	Per phase stator and rotor
X_μ	Magnetizing reactance
X_C	Capacitive reactance of the terminal capacitor C
X_S	Capacitive reactance of the series capacitor C_{sh}
a	Frequency
b	Speed
I_1, I_2	Per phase stator and rotor current
I_L	Per phase load current
V_L	Per phase load voltage
E_1	Air-gap voltage

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I. INTRODUCTION

Development on distributed power system is increasing day by day in remote areas. The Self-excited induction generator is considered as viable option due to specific advantage over conventional synchronous generator. Main advantage is over load protection occurrence at fault. Current will be limited by the excitation, and the machine voltage will collapse immediately. SEIG builds its voltage from residual magnetism, with the help ana.c. Capacitor bank that provides the required reactive power from the Induction machine. These capacitors are connected in parallel with the SEIG. Other important advantages of SEIG are brushless construction (squirrel-cage rotor), reduced size, absence of DC power Supply for excitation as in synchronous generators, reduced maintenance cost, good over speed capability, self short circuit protection capability and no synchronizing problem. Lahcene [1] presented in this paper analysis of self-excited induction generator.

Different methods have been proposed for regulating the voltage of the SEIGs .The scheme based on switched capacitors finds limited application because it regulates the terminal voltage in discrete steps and it may create switching transients. Also a shunt connected saturable core reactor may be used as a variable VAR generator. The static VAR compensators (SVC) use a capacitor and inductor with fast switches (GTO´s, thyristors or IGBT´s). Most recent methods are mainly based on either voltage-or-current static capacitors STATCOM that are based on a DC/AC converter (or inverter), which is able to generate leading or lagging reactive power. These last two methods are often found to be complex with reduced reliability as electronic circuits used therefore are prone to failure in field application, and the switching injects harmonics in the line current of the system. Yogesh K. [2] has described the Performance of self-excited induction generator with cost effective static compensator. Use of additional passive elements to provide self-regulating features therefore was considered worthy of exploration. Inclusion of series capacitors to provide additional reactive power with loading is one of the attractive options to improve the regulation of SEIGs.

II. MODELLING OF SHORT-SHUNT SELF-EXCITED INDUCTION GENERATOR WITH SERIES COMPENSATION

Model used to analyze self-excited induction generators has been classified into two major categories (loop impedance and nodal admittance method). N.H. Malik [3] represented study-state analysis of self-excited induction generator. S.S. Murthy [4] described the loop impedance method and Jesus Frail-Ardanuy1 [5] presented nodal admittance method and T.F. Chan [6] used an iterative method to describe the steady-state analysis of self-excited induction generator. D.Joshi [7] used Iterative technique to find the generated frequency and Artificial Neural Network (ANN) has applied to capture the non-linear magnetization characteristics of induction machine.

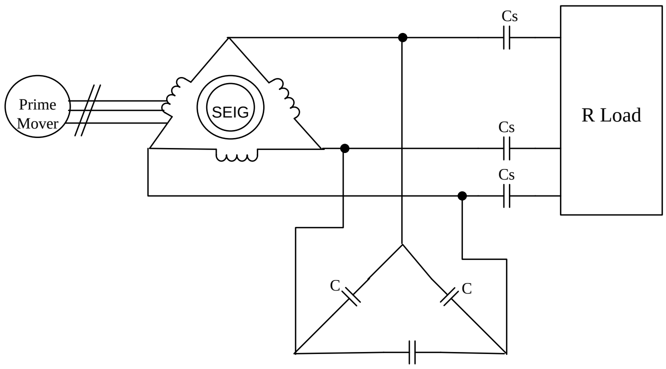

Fig 1: Schematic diagram of the Short-Shunt self-excited induction generator with series compensation.

The basis of system design is, firstly, to determine the value of shunt capacitors to produce the self-excitation of the generator and, secondly, to calculate the value of series capacitors to ensure that the voltage and frequency of the induction generator are within the desired range. The steady-state analysis of the SEIG involves solution of the following problem: given the machine parameters, speed, excitation capacitance, series capacitance and load resistance, it is necessary to determine the value of per-unit electric frequency '*a*' and the magnetizing reactance 'Xμ'.

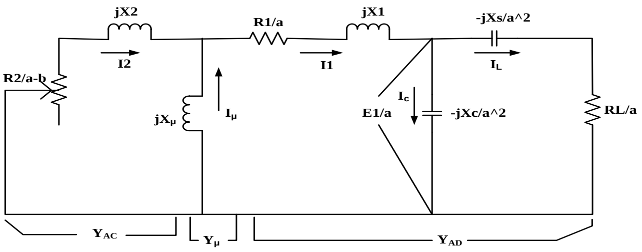

Fig 2: Steady-state equivalent circuit of the short-shunt SEIG.

The total current at node may be given by:

$$E_1/a\left(Y_{AC}+Y_{\mu}+Y_{AD}\right)=0 \tag{1}$$

Therefore under steady-state self excitation the total admittance must be zero. Since E1≠0

$$Y_{AC}+Y_{\mu}+Y_{AD}=0 \tag{2}$$

$$Y_{AC}=\frac{\left(\frac{R_2}{a-b}\right)-jX_2}{\left(\frac{R_2}{a-b}\right)^2+X_2^2} \tag{3}$$

$$Y_{\mu}=\frac{1}{jX_{\mu}}=-J\frac{1}{X_{\mu}} \tag{4}$$

And admittance

$$Y_{AD}=\frac{1}{Z_{AB}+Z_{BD}}=\frac{\left(\frac{R_1}{a}+R_t\right)-J\left(X_1-X_t\right)}{\left(\frac{R_1}{a}+R_t\right)^2+\left(X_1-X_t\right)^2} \tag{5}$$

Where R_t and X_t are

$$R_t=\frac{R_L X_C^2}{a\left(a^2R_L+X_T^2\right)},\quad X_t=\frac{a^2R_L^2X_C+X_SX_CX_T}{a^2\left(a^2R_L^2+X_T^2\right)}\ \text{and}$$

$X_T=X_C+X_t$ Total admittance is rewritten as.

$$\frac{\frac{R_2}{a-b}-JX_2}{\left(\frac{R_2}{a-b}\right)^2+X_2^2}-J\frac{1}{X_{\mu}}+\frac{\left(\frac{R_1}{a}+R_t\right)-J\left(X_1-X_t\right)}{\left(\frac{R_1}{a}+R_t\right)^2+\left(X_1-X_t\right)^2}=0 \tag{6}$$

Equating to zero the real and imaginary part, in (6) the following two equations are obtained;

$$\frac{\frac{R_2}{a-b}-JX_2}{\left(\frac{R_2}{a-b}\right)^2+X_2^2}+\frac{\left(\frac{R_1}{a}+R_t\right)}{\left(\frac{R_1}{a}+R_t\right)^2+\left(X_1-X_t\right)^2}=0 \tag{7}$$

$$\frac{X_2}{\left(\frac{R_2}{a-b}\right)^2+X_2^2}+\frac{1}{X_{\mu}}+\frac{\left(X_1-X_2\right)}{\left(\frac{R_1}{a}+R_t\right)^2+\left(X_1-X_t\right)^2}=0 \tag{8}$$

Therefore for magnetizing reactance can be written as from equation (8)

$$X_{\mu}=\frac{\frac{R_1}{a}+R_t\left[\left(\frac{R_1}{a-b}\right)^2+X_2^2\right]}{\left(X_1-X_t\right)\frac{R_2}{a-b}-X_2\left(\frac{R_1}{a}+R_t\right)}$$

From these equations (7) and (8) frequency and magnetizing reactance can be calculated. If Xμ is less than the saturated value an operating point exists and corresponding air-gap e.m.f. E1 can be calculate from magnetizing curve of generator and estimated by equation

$$\frac{E_1}{a}=1.714-0.4X_{\mu}$$

Stator current given by-

$$I_1=\frac{E_1}{a}Y_{AD}$$

Load current and Terminal voltage given by equation

$$I_L = I_1 \cdot \frac{-JX_C}{aR_L - JX_T}$$

Voltage $V_L = R_L I_L$

By using this analysis theoretical results calculate, using following base values. Determined calculated value as excitation and series capacitor value taken as input and frequency, terminal voltage and current taken as output for Fuzzy-Logic analysis.

$$V_{base} = rated\ voltage = 230V$$

$$I_{base} = rated\ phase\ current = 4.74V$$

$$Z_{base} = \frac{V_{base}}{I_{base}} = 48.52\Omega$$

Base speed $N_{base} = 1500\, rev/\min$

Table.1: For terminal voltage and Current.

	INPUT		OUTPUT		
S.No	Cs(µF)	C(µF)	a(Hz)	I_L(Amp)	V_L(Volt)
1	20	26	49.37	0.8231	175.93
2	25	28	49.25	0.9843	201.14
3	30	30	49.16	1.1036	217.33
4	35	32	49.09	1.1975	229.00
5	40	34	49.04	1.2692	237.24
6	45	36	48.99	1.3325	245.50
7	50	38	48.95	1.3929	252.23
8	55	40	48.92	1.4454	258.79
9	60	42	48.89	1.4884	264.13
10	65	44	48.87	1.5300	269.44
11	70	46	48.84	1.5692	274.69
12	75	48	48.82	1.5806	275.20

From this table.1: It is clear that as increasing the value of capacitor, Voltage profile increasing.

III. MODELLING OF LONG-SHUNT SELF EXCITED INDUCTION GENERATOR WITH SERIES COMPENSATION

It is worth comparing the performance of the short-shunt SEIG with that of the long-shunt SEIG. In the long shunt SEIG, the series capacitance is placed between the generator terminals and the shunt capacitance, as shown in Fig.3: The performance of the long-shunt SEIG is analyzed by extending the technique described for the short-shunt SEIG.

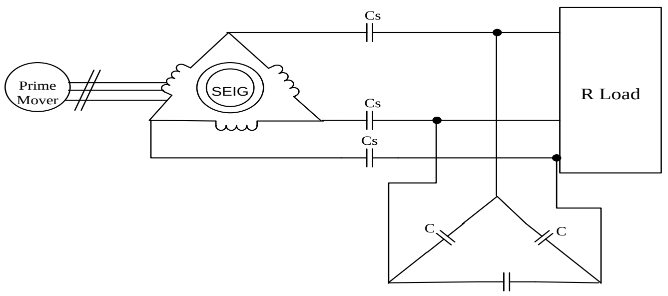

Fig.3: Schematic diagram of the Long-Shunt self-excited induction generator with series compensation

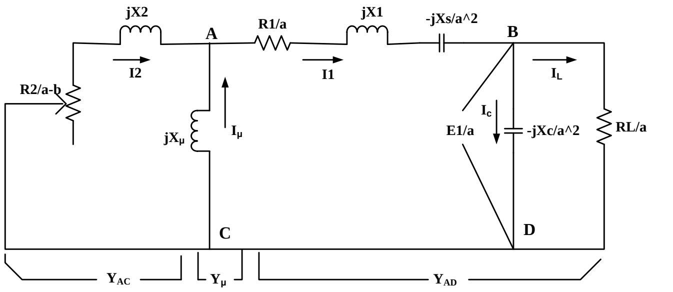

Fig.4: Steady-state equivalent circuit of the short-shunt SEIG.

The total current at node A may be given by:

$$E_1/a\left(Y_{AC} + Y_\mu + Y_{AD}\right) = 0 \tag{9}$$

Therefore under steady-state self excitation the total admittance must be zero. Since $E_1 \neq 0$

$$Y_{AC} + Y_\mu + Y_{AD} = 0 \tag{10}$$

$$Y_{AC} = \frac{\left(\frac{R_2}{a-b}\right) - JX_2}{\left(\frac{R_2}{a-b}\right)^2 + X_2^2} \tag{11}$$

$$Y_\mu = \frac{1}{JX_\mu} = -J\frac{1}{X_\mu} \tag{12}$$

And admittance

$$Y_{AD} = \frac{1}{Z_{AB} + Z_{BD}} = \frac{\left(\frac{R_1}{a} + R_t\right) - J\left(X_1 - X_t - \frac{Xs}{a^2}\right)}{\left(\frac{R_1}{a} + R_t\right)^2 + \left(X_1 - X_t - \frac{Xs}{a^2}\right)^2} \tag{13}$$

Where R_t and X_t are

$$R_t = \frac{R_L X_C^2}{a\left(a^2 R_L^2 + X_C^2\right)}, \quad X_t = \frac{R_L^2 X_C}{\left(a^2 R_L^2 + X_T^2\right)}$$

Total admittance is rewritten as.

$$\frac{\frac{R_2}{a-b} - JX_2}{\left(\frac{R_2}{a-b}\right)^2 + X_2^2} - J\frac{1}{X_\mu} + \frac{\left(\frac{R_1}{a} + R_t\right) - J\left(X_1 - X_t - \frac{X_S}{a^2}\right)}{\left(\frac{R_1}{a} + R_t\right)^2 + \left(X_1 - X_t - \frac{X_S}{a^2}\right)^2} = 0 \tag{14}$$

Equating to zero the real and imaginary part, in (14) the following two equations are obtained;

$$\frac{\frac{R_2}{a-b} - JX_2}{\left(\frac{R_2}{a-b}\right)^2 + X_2^2} + \frac{\left(\frac{R_1}{a} + R_t\right)}{\left(\frac{R_1}{a} + R_t\right)^2 + \left(X_1 - X_t - \frac{X_S}{a^2}\right)^2} = 0 \tag{15}$$

$$\frac{X_2}{\left(\frac{R_2}{a-b}\right)^2 + X_2^2} + \frac{1}{X_\mu} + \frac{\left(X_1 - X_t - X_S\right)}{\left(\frac{R_1}{a} + R_t\right)^2 + \left(X_1 - X_t - \frac{X_S}{a^2}\right)^2} = 0 \tag{16}$$

Therefore for magnetizing reactance can be written as

$$X_{\mu}=\frac{\left(\frac{R_1}{a}+R_t\right)\left[\left(\frac{R_2}{a-b}\right)^2+X_2^2\right]}{\left(X_1-X_t-\frac{X_S}{a^2}\right)\frac{R_2}{a-b}-X_2\left(\frac{R_1}{a}+R_t\right)}$$

From these equations (15) and (16) frequency and magnetizing reactance can be calculated. If Xμ is less than the saturated value an operating point exists and corresponding air-gap e.m.f. E1 can be calculate from magnetizing curve of generator and estimated by equation

$$\frac{E_1}{a}=1.714-0.4X_{\mu}$$

Stator current given by-

$$I_1=\frac{E_1}{a}.Y_{AD}$$

Load current and Terminal voltage given by equation

$$I_L=I_1.\frac{-JX_C}{aR_L-JX_T}$$

Voltage $V_L=R_L I_L$

Table.2: For terminal voltage and Current

	INPUT		OUTPUT		
S.No.	Cs(μF)	C(μF)	a(Hz)	IL(Amp)	VL(Volt)
1	200	36	49.19	0.9875	167.83
2	300	38	49.10	1.1230	190.69
3	400	40	49.05	1.2163	206.62
4	500	42	49.01	1.2909	219.34
5	600	44	48.98	1.3522	229.80
6	700	46	48.95	1.4084	239.51
7	800	48	48.92	1.4575	247.92
8	900	50	48.90	1.4995	255.17
9	1000	52	48.88	1.5415	262.42
10	1100	54	48.86	1.5778	268.70
11	1200	56	48.84	1.6113	274.57
12	1300	58	48.82	1.6429	280.05

As compared to the short-shunt configuration, the value of total capacitance, i.e. sum of series and shunt capacitances required to achieve a desired performance, is much higher for the long-shunt configuration. B.singh, L. shridhar [8] presented comparison result between short-shunt and long-shunt SEIG.

IV RESULT AND ANALYSIS

A Short-shunt configuration

With reference table.1: following short shunt SEIG simulated result are shown. In Fig.5 two input variable series capacitor & excitation capacitor and three output variable namely frequency, terminal voltage and load current. Triangular membership function taken in mamdani system. In Fig.6: making sixteen rule-bases with combination of 'Low', 'medium', 'high', and 'very high'. With making these rule-bases final experimental result is shown in fig.7. With this simulated result it is clearly investigated that as increasing value of either excitation capacitor or series capacitor terminal voltage and current is increasing and frequency is reducing.Fig.8 shown surface view of input and output result. The comparison of computed results with simulated one gives the validity and accuracy of proposed modeling for SEIG using fuzzy-logic. Faa-Jeng [9] presented in this paper induction generator with Fuzzy modeling.

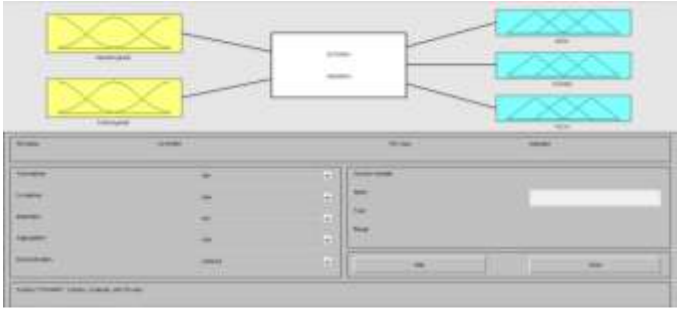

Fig .5: Input & output of short shunt mamdani system.

Fig. 6: Rule-Base for short-shunt SEIG.

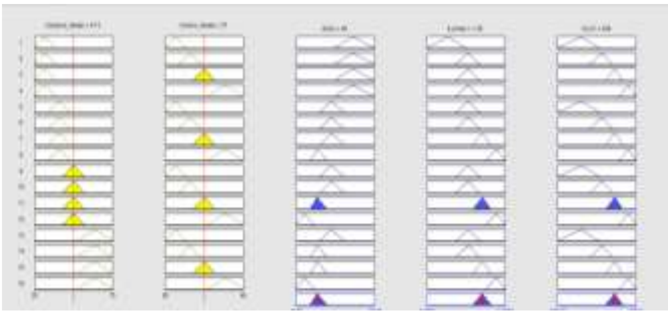

Fig. 7: Fuzzy logic output result of short-shunt SEIG.

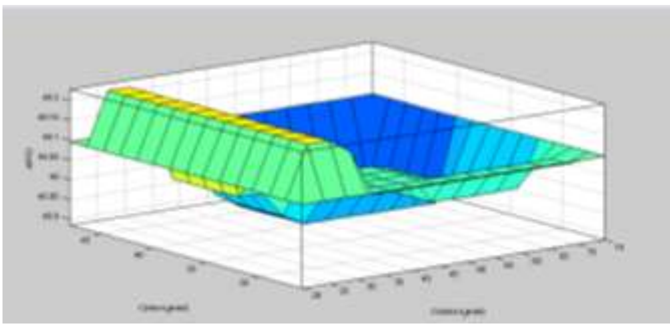

Fig .8: Surface view of short-shunt SEIG

B Long-shunt configuration

With reference table.2: following simulated result shown. Fig.8 shows two input variable series capacitor and excitation capacitor, three out-put variable frequency, terminal voltage and load current. Fig.9 depict rule base with combination of input and out-put variable. Fig.10 shows output result, with increasing of shunt or series capacitor terminal voltage and load current is increasing. Li-wang

[10] presented effect of capacitor in long shunt self-excited SEIG. E.Bhim [11] presented voltage compensation in long shunt configuration.

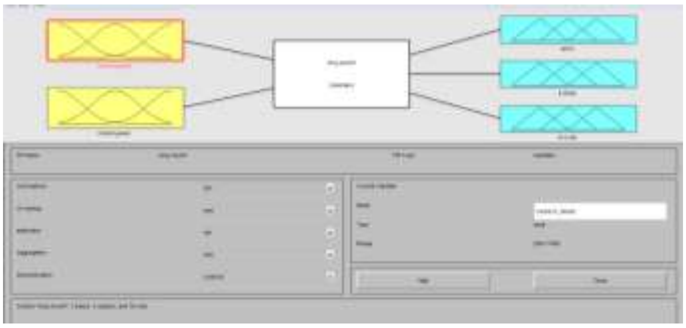

Fig. 9: Input –output of long shunt mamdani system.

Fig .10: Rule-Base for long-shunt SEIG.

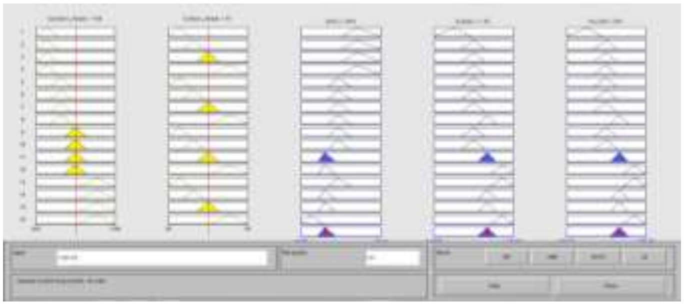

Fig.11: Fuzzy logic output result of long-shunt SEIG.

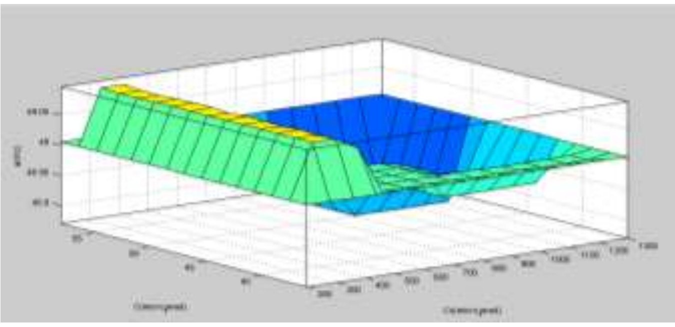

Fig .12: Surface view of long-shunt SEIG.

V. CONCLUSIONS

The possibility of improving voltage regulation of the SEIG by using an additional capacitance in series with the load has been investigated. This paper presented a simple analytical method based on nodal admittance to obtain the steady state characteristics of an isolated self-excited induction generator using Fuzzy logic. The preference of the short-shunt over long-shunt configuration is clearly demonstrated by the values of the capacitances with economic point of view. It is clearly shown by computational and simulated result using Fuzzy-logic.

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