A Simple Approach to Estimate the Steady-State Performance of Self-Excited Induction Generator

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Abstract:- *This paper presents a new and simple model for the steady-state analysis of self-excited induction generators (SEIG). In this paper an attempt has been made to incorporate the unjustified assumptions in an existing (Watson's) model. This has resulted into an improved model for the estimation of performance of SEIG. A close agreement of simulated results using proposed modeling with experimental values on a test machine proves the validity and superiority of proposed model.*
Keywords:- Asynchronous generator, Renewable Energy, Steady state analysis, self-excited induction generator (SEIG), Wind energy conversion.

Nomenclature

a	per unit frequency
b	per unit speed
C	terminal excitation capacitance per phase
I_m	magnetizing current per phase
R_L	load resistance per phase
R_s	stator resistance per phase
R_r	rotor resistance per phase
V	load voltage per phase
X_s	stator reactance per phase
X_r	rotor reactance per phase, referred to stator
X_C	capacitive reactance due to C at rated frequency
X_m	magnetizing reactance per phase at rated frequency

1. Introduction

Self-excited induction generators have attained a lot of attraction in recent years & it is due to the suitability of these machines in many applications including wind energy and small hydro energy systems. Further, these machines and specially cage induction machines exhibit many advantages such as low cost, brushless and rugged construction, self-protection capability etc.

To estimate the steady-state performance of a SEIG, most of the researchers used the conventional equivalent circuit representation of an induction motor [1-13]. Some of the researchers used the impedance model, and a few used the admittance-based model for the treatment of these circuits. Whereas [10, 12] developed a new circuit representation, which includes an active power source in the rotor circuit.

Apart from this, [14] developed the simple most approach to describe the autonomous and parallel operation of self excited induction generators. Simplicity is the main attraction of Watson's [14] model.

In the present paper an attempt has been made to improve the results of [14] with few modifications but without loosing the simplicity of the approach. Close agreement of simulated results with experimental results, confirms the validity of proposed modeling. Further an attempt has been made to include the core loss component, which is generally omitted by research persons.

2. Steady-State Analysis

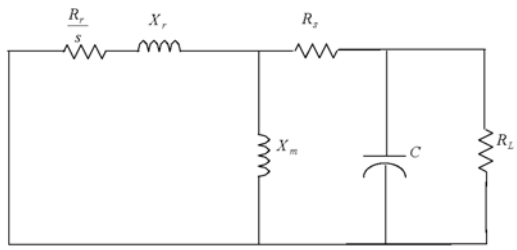

Fig.1 Equivalent circuit representation.

Fig.1 shows the per phase equivalent circuit representation for self-excited induction generator, as adopted by Watson [14].
This circuit representation may be modified as given in Fig.2 with the provision of followings, which were found to be missing;

- Inclusion of stator reactance
- Inclusion of pu frequency to make all leakage reactances and excitation capacitance more effective.
- Further magnetizing branch has been shifted to stator side, as usually adopted in motoring case.

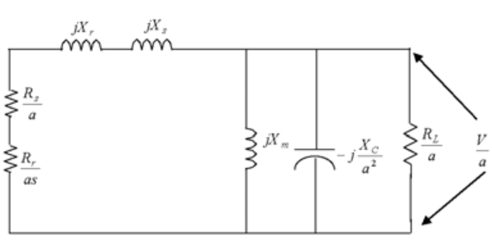

Fig.2 Modified equivalent circuit.

Analysis of circuit as given in Fig.2, in terms of real power gives;

$$P=\left(\frac{k\left(\frac{V}{a}\right)^2}{\frac{R_s}{a}+\frac{R_r}{as}}\right)+\left(\frac{\left(\frac{V}{a}\right)^2}{\frac{R_L}{a}}\right) \tag{1}$$

Where k is a fractional value and depends upon the design of the machine.
In the absence of power source (1) may be written as;

$$s=-\frac{R_r}{R_s+kR_L} \tag{2}$$

Where;

$$s=\frac{a-b}{a} \tag{3}$$

Rotor speed and slip determines the frequency of the generated voltage.

$$a=\left(\frac{b}{1-s}\right) \tag{4}$$

At no-load ($R_L \rightarrow \infty$), therefore the generated frequency is same as the driven frequency. However, as evident from above expressions, slip increases and generated frequency falls with load.
For self-excitation, magnetizing current is supplied by the capacitor and is given as;

$$I_m = Va\omega C \tag{5}$$

Further, magnetization characteristics of SEIG (Appendix-I) may be expressed in the form as;

$$I_m = 9\times10^{-5}V^2 - 0.02V + 1.8448 \tag{6}$$

Rearrangement of (5) and (6) results in to the quadratic equation in terms of unknown voltage as;

$$9X10^{-5}V^2 - (0.02 + a\omega C)V + 1.8448 = 0 \quad (7)$$

(1) to (7) may be used to determine the generated frequency and terminal voltage for any operating speed and excitation capacitance. Further analysis of the generator including core loss is given in Appendix 2.

3. Results and Discussions

Table 1 Comparison of results.

Sr. No.	R (pu)	b	Using Wattson Model		Using Modified Model		Experimental Results	
			V(pu)	a	V(pu)	a	V(pu)	a
1.	6.4951	0.9760	0.8885	0.9657	0.9065	0.9616	1.0	0.9606
2.	2.5980	1.0330	0.8807	1.0060	0.9331	0.9967	1.0	0.9992
3.	2.5114	1.0366	0.8803	1.0087	0.9349	0.9990	1.0	1.0022
4.	2.4248	1.0400	0.8792	1.0109	0.9363	1.0010	1.0	1.0040
5.	2.3382	1.0440	0.8784	1.0138	0.9382	1.0035	1.0	1.0080
6.	2.1910	1.0553	0.8796	1.0228	0.9443	1.0119	1.0	1.0164
7.	2.0871	1.0613	0.8782	1.0270	0.9470	1.0157	1.0	1.0196
8.	2.0005	1.0677	0.8774	1.0318	0.9501	1.0201	1.0	1.0242
9.	1.9139	1.0746	0.8765	1.0369	0.9535	1.0247	1.0	1.0292
10.	1.8143	1.0840	0.8755	1.0439	0.9580	1.0312	1.0	1.0360
11.	1.7233	1.0916	0.8730	1.0492	0.9614	1.0360	1.0	1.0416

Table 1 gives the comparison of simulated results with experimental test results as an induction generator (Appendix 1). Simulated results with modifications as suggested in this paper are found to be more close to experimental one in comparison to simulated results as obtained using Watson model. This proves the validity and superiority of the proposed modeling. In addition to that, it needs only a quadratic solution of equation in contrast to other research papers involving higher order polynomial equations. Fig.3 to Fig.6 gives the variation of terminal voltage and frequency with load for different values of excitation capacitance and operating speed. It is observed that these two affects the performance of the machine to a great extent and may be used to control the terminal conditions. Results as obtained in Table 2 indicates that speed may be used as control variable to maintain the voltage as 1pu. Table 3 gives the simulated results on the test machine with core loss component using proposed modeling.

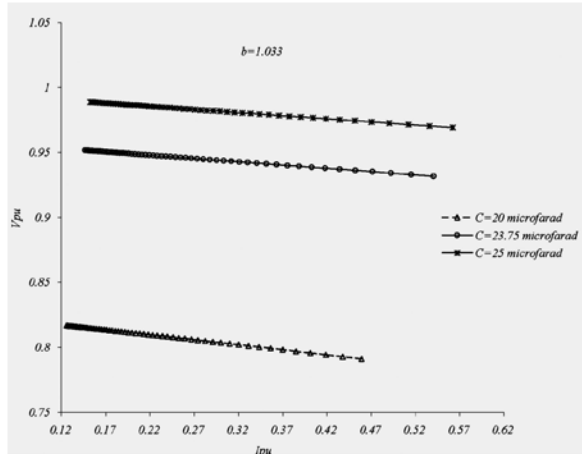

Fig.3. Variation of terminal voltage with load for different excitation capacitance.

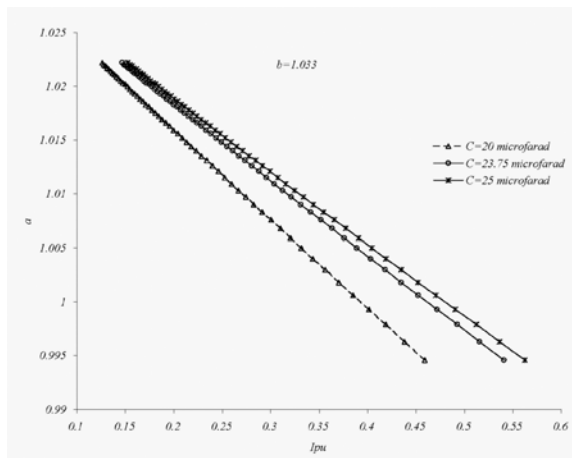

Fig.4. Variation of generated frequency with load for different excitation capacitance.

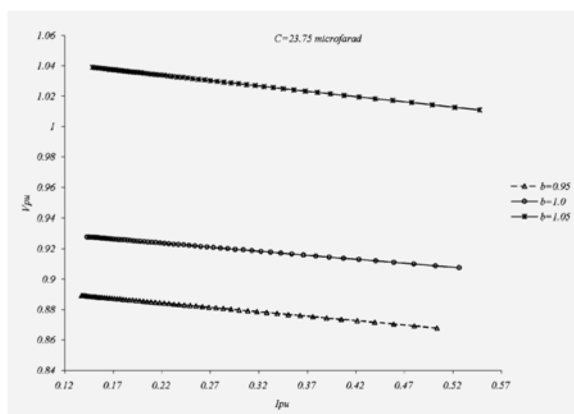

Fig.5. Variation of terminal voltage with load for different operating speed.

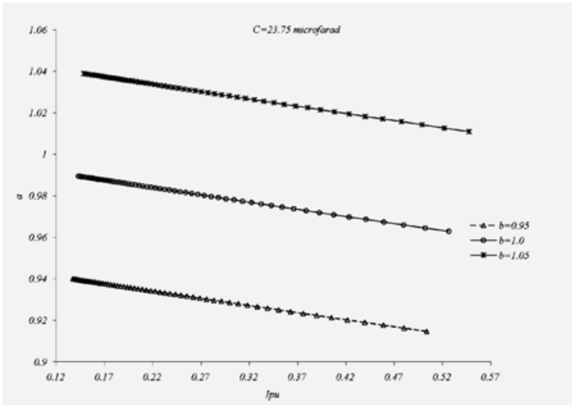

Fig.6. Variation of terminal voltage with load for different operating speed.

4. Conclusion

In this paper an attempt has been made to prepare a new model to investigate the steady-state performance of self-excited induction generator. The main attraction of the model is its simplicity to obtain the final solution. Results obtained are found to be close agreement to the experimental results obtained on a test machine. Efforts are made to include the core loss component, which is generally neglected. Inclusion of core loss branch makes the model more realistic.

Appendix 1

SPECIFICATIONS;
Number of poles= 4
Base speed =1500 rpm
R_s = 9.5 ohm
R_r = 8.04 ohm
$X_s = X_r$ = 8.84 ohm

Table 2 Specifications of machine.

Line Voltage (Volts)	Line Current (Amps)	Rating (HP)	Stator Connection	Frequency (Hz)
380	1.9	1.0	Y	50

Magnetizing characteristics

$I_m = 9\times10^{-5}V^2 - 0.02V + 1.8448$

Appendix 2

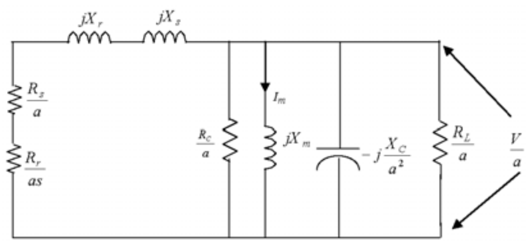

Fig.7. Modified equivalent circuit including core losses.

Analysis of circuit as given in Fig.7, in terms of real power gives;

$$P = \left(\frac{k\left(\frac{V}{a}\right)^2}{\frac{R_s}{a} + \frac{R_r}{as}} \right) + \left(\frac{\left(\frac{V}{a}\right)^2}{\frac{R_c}{a}} \right) + \left(\frac{\left(\frac{V}{a}\right)^2}{\frac{R_L}{a}} \right)$$

Where k is a fractional value and depends upon the design of the machine.
In the absence of power source may be written as;

$$s = -\frac{R_r}{R_s + \frac{k}{a\left(\frac{1}{R_c} + \frac{1}{R_L}\right)}}$$

Table 3 Simulated results including core losses.

Sr. No.	R (pu)	b	V(pu)	a
1.	6.4951	0.9760	0.9060	0.9610
2.	2.5980	1.0330	0.9324	0.9957
3.	2.5114	1.0366	0.9341	0.9980
4.	2.4248	1.0400	0.9356	1.0000
5.	2.3382	1.0440	0.9374	1.0024
6.	2.1910	1.0553	0.9433	1.0105
7.	2.0871	1.0613	0.9459	1.0141
8.	2.0005	1.0677	0.9489	1.0183
9.	1.9139	1.0746	0.9520	1.0227
10.	1.8143	1.0840	0.9564	1.0288
11.	1.7233	1.0916	0.9596	1.0334

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