Performance Analysis of Self-Excited Induction Generator Using Artificial Neural Network

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Abstract—Due to increasing demand of energy and limitation of non-renewable energy resources, the need of using renewable energy sources is increasing very rapidly. The three-phase self excited Induction Generator are very useful for generating power by use of non-renewable resources. The paper presents the analysis of SEIG by using artificial intelligence technique which states that at certain value of speed there is a set of voltage, frequency and magnetizing reactance predicted by the ANN. ANN model is trained by different set of data obtained from simulation of machine using a suitable MATLAB program. The comparison of calculated and predicted data confirms the validity and accuracy of the ANN based model.

Keywords— Artificial Neural network, Self-excited induction generator, magnetizing reactance, MATLAB

NOMENCLATURE

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>per unit frequency</td>
</tr>
<tr>
<td>b</td>
<td>per unit speed</td>
</tr>
<tr>
<td>Rs, Rr</td>
<td>per phase stator &amp; rotor resistance</td>
</tr>
<tr>
<td>Xm</td>
<td>magnetizing reactance</td>
</tr>
<tr>
<td>X1s</td>
<td>per phase stator leakage reactance</td>
</tr>
<tr>
<td>X1r</td>
<td>per phase rotor leakage reactance</td>
</tr>
<tr>
<td>Xc</td>
<td>per phase capacitance reactance</td>
</tr>
<tr>
<td>Rl</td>
<td>per phase load resistance</td>
</tr>
<tr>
<td>f, v</td>
<td>per unit frequency &amp; speed</td>
</tr>
<tr>
<td>s</td>
<td>slip, (a-b)/a</td>
</tr>
<tr>
<td>N</td>
<td>speed</td>
</tr>
</tbody>
</table>

I. INTRODUCTION

The basic element required in the progress of a country is its power capacity. Most of the electric power generation today uses fossil fuels. The fossil fuels as we know are limited in nature and are going to decay, we need another source of energy which are cheaper and are also reliable as compared to the conventional sources of energy. This has pressurized researchers to think about non-conventional sources of energy. Non-conventional sources include solar energy, wind energy, tidal energy, geothermal heat, hydro etc. Another reason or adaption of non-conventional sources of energy is that they are easy to handle eco-friendly and require less maintenance. The main feature of non-conventional sources of energy is that they create very less amount of pollution.

Induction Generators are increasingly used with the non-conventional sources for power generation. The main reason behind the popularity of Induction Generator for using it with non-conventional sources of energy are reduced unit cost, reduced size, ruggedness, brushless construction, absence of DC power supply, ease of maintenance etc. Such generators may be used for the electrification purpose in remote areas. The operation of Self Excited Induction Generator (SEIG) is useful under variable speed operation; therefore it becomes the duty of a researcher to investigate the behavior of specific problem related issues of Induction Generator.

A proper circuit representation and accurate mathematical modeling is essential in evaluating the steady-state performance of SEIG for different operating conditions. To calculate the steady state performance of Self Excited Induction Generator, analysts adopted different models, some researchers [3]-[4] adopted the impedance model while some
used the admittance based model for such calculations. It was found that most researchers used the modeling which resulted in a single polynomial equation of higher order in unknown generated frequency and magnetizing reactance. An active power source based new equivalent circuit model was suggested by. In [5], an iterative technique has been used to obtain the generated frequency of the Self-excited Induction Generator. In order to compute the non linear magnetization characteristics of Induction Generator it is essential to develop a mathematical model, terminal voltage can also be computed with such modeling. Researchers have adopted various techniques to estimate the performance of SEIG such as piecewise linear approximation, genetic algorithm etc. However in this context Artificial Neural Network technique can prove to be a simple and efficient method of modeling the SEIG.

In this paper ANN modeling to analyze the steady-state performance of SEIG has been proposed through the conventional circuit. The ANN model is trained by different set of data obtained from the simulation of machine. The comparison of the data gives the validity and accuracy of the proposed model.

II. MODELLING OF SEIG

The per phase equivalent circuit of SEIG for the analysis of steady state operation is shown in fig.1

In this circuit, all the parameters are thought to be autonomous of saturation aside from magnetizing reactance. Analysis of equivalent circuit results in the following equations for the steady-state operation.

\[
\frac{(R_L + R_1)}{X_m} + \frac{R_2}{(X_1 - X_L) + (R_L + R_1)^2} = 0
\]

\[
\frac{1}{X_m} - \frac{X_2}{X_m} - \frac{(X_1 - X_L)}{X_2^2 + \left(\frac{R_2}{a-b}\right)^2} = 0
\]

Where,

\[
R_L = \frac{R_Xe^2}{(a^2R^2 + X_e^2)}
\]

And

\[
X_L = \frac{R^2X_e^2}{(a^2R^2 + X_e^2)}
\]

With low operating slips, above equation can be written as

\[
s = -\frac{R_2(aR_L + R_1)}{a^2(X_1 - X_L)^2 + (aR_L + R_1)^2}
\]

Where generated frequency is

\[
a = \frac{b}{1-s}
\]

Omitting stator impedance and rotor reactance by using approximate equivalent circuit gives the operating slip as

\[
s = \frac{R_2}{R}
\]

Initial value of frequency \(a_0\) will be

\[
a_0 = \frac{b}{1 + \frac{R_2}{R}}
\]

From above, the value of magnetizing reactance can be calculated

\[
X_m = -\frac{1}{X_2^2 + \left(\frac{R_2}{a-b}\right)^2} \frac{(X_1 - X_L)^2 + (R_L + R_1)^2}{(X_1 - X_L)^2 + (R_L + R_1)^2}
\]

The proposed model of the Self Excited Induction Generator has been shown in fig.2
I. ANN BASED MODELLING

Artificial Neural Network also called parallel distributed processing systems and connectionist are generally used for the non-linear modeling, system identification and pattern association etc. In this paper, the multilayer back propagation feed forward neural network is used that gives a good approximation of magnetization characteristics. The structure of ANN is shown in fig 3.

![Fig.3 non-linear model of Artificial Neuron](image)

The number of input and output neurons depends on the designer and the type of problem. In this paper two layer feed forward back propagation neural network has been used. The design of network and selection of optimum training parameters are performed by trial and error. Further, Levenburg Marquardt training function is used which causes fewer epochs as compared to other training function. Therefore approximate results will be produced when an input is applied to the network. This Training method has been discovered to be exceptionally powerful for calculating the non linear characteristics of the Induction Machine.

II. RESULTS AND DISCUSSIONS

Table 1 shows the comparison of proposed ANN technique and results obtained from the simulation model of Induction Generator (36µF & 160Ω). To test the general capabilities of the neural network, training is done with 100 samples, out of which 70% samples are used for training purpose, 15% are used for testing and 15% samples are used for validation purposes.
Table 1 Comparison of Results of data set calculated and predicated

<table>
<thead>
<tr>
<th>Speed N (rpm)</th>
<th>Voltage , $V$ (volts)</th>
<th>Frequency , $f$ (Hz)</th>
<th>Magnetizing Reactance , $X_m$ (ohm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$V$ (calculated)</td>
<td>$V$ (predicated)</td>
<td>$f$ (calculated)</td>
</tr>
<tr>
<td>1400</td>
<td>103.01</td>
<td>103.50</td>
<td>46.13</td>
</tr>
<tr>
<td>1420</td>
<td>120.56</td>
<td>116.10</td>
<td>46.72</td>
</tr>
<tr>
<td>1440</td>
<td>138.72</td>
<td>138.90</td>
<td>47.43</td>
</tr>
<tr>
<td>1460</td>
<td>153.9</td>
<td>155.04</td>
<td>47.98</td>
</tr>
<tr>
<td>1480</td>
<td>166.13</td>
<td>166.49</td>
<td>48.74</td>
</tr>
<tr>
<td>1500</td>
<td>179.32</td>
<td>180.52</td>
<td>49.55</td>
</tr>
<tr>
<td>1520</td>
<td>191.63</td>
<td>191.54</td>
<td>50.24</td>
</tr>
<tr>
<td>1540</td>
<td>202.71</td>
<td>202.25</td>
<td>50.81</td>
</tr>
<tr>
<td>1560</td>
<td>213.65</td>
<td>212.54</td>
<td>51.47</td>
</tr>
<tr>
<td>1580</td>
<td>225.1</td>
<td>233.41</td>
<td>52.16</td>
</tr>
<tr>
<td>1600</td>
<td>234.57</td>
<td>271.93</td>
<td>52.79</td>
</tr>
</tbody>
</table>

The closeness of the results indicates the accuracy of the proposed ANN technique.

Fig.4 Comparison of simulated and neural network data of generated voltage

Fig.5 Comparison of simulated and neural network data of generated frequency
This paper attempts to use the given speed in order to generate the suitable terminal voltage, frequency and magnetizing reactance by the development of ANN model which has been trained from the data obtained from the data obtained by the test performed on the simulation model of the machine. Comparison of the results shows a close agreement between the experimental data and that predicted by ANN, which shows that such a simple and accurate model will be useful to analyze the behavior of Self Excited Induction Generator.

IV. APPENDIX

Details of the machine:
- Specifications
  3-phase, 4-pole, star connected, squirrel cage induction machine
  2.2 kW/3HP, 230V, 8.6A
- Parameters
  \( R_1=R_2=8.04\,\Omega,\quad X_1=X_2=8.84\,\Omega \)
- Base Values
  Base voltage =220V
  Base current =4.96A
  Base impedance =46.32Ω

V. REFERENCES


Joshi and Sandhu, 2009.“Excitation Control of Self Excited Induction Generator using Genetic Algorithm and Artificial Neural Network” International Journal of Mathematical models and methods in applied sciences Issue 1, Volume 3.


