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# Analysis of Single Phase Self-Excited Induction Generator with One Winding for obtaining Constant Output Voltage

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## Abstract

This paper describes the steady state analysis of single phase self-excited induction generator with one winding. These generators are suitable for wind driven application. A computer algorithm is developed for computing the performance of the machine while obtaining constant output voltage.

**Keywords:** Single Winding, Self-Excited Induction Generator (SEIG), Resistive Load, Magnetizing Reactance, Air Gap Voltage.

## List of symbols

F, v : p.u. frequency and speed;
$I_L$ : Load current referred to Stator per phase;
Ic : Current in Capacitor per phase;
$I_M$ : Stator Current per phase;
$R_L$ : Load Resistance per phase per phase;
$R_M$ : Main Winding Resistance per phase;
$R_r$ : Resistance of Rotor Winding per phase;
$V_t$ : p.u. Terminal Voltage;
$V_g$ : p.u. Air Gap Voltage;
$X_C$ : per phase Capacitive Reactance of the terminal capacitor C;
$X_M$ : Magnetizing Reactance per phase;

$X_{lm}$ : Magnetizing Leakage Reactance per phase;

$X_{lr}$ : Rotor Leakage Reactance per phase;

## Introduction

The increasing concern to the environment and fast depleting conventional resources have motivated the researchers towards rationalizing the use of conventional energy resources and exploring the non-conventional energy resources to meet the ever-increasing energy demand. A number of renewable energy sources like small hydro, wind, solar, industrial waste, biogas, geothermal etc. are explored. Since small hydro and wind energy sources are available in plenty, their utilization is felt quite promising to accomplish the future energy requirements. Harnessing mini-hydro and wind energy for electric power generation is an area of research interest and at present, the emphasis is being given to the cost-effective utilization of these energy resources for quality and reliable power supply. Induction generators are often used in wind turbines and some micro-hydro installations due to their ability to produce useful power at varying speeds [4].

Induction generators are increasingly being used these days because of their relative advantageous features over conventional synchronous generators. Induction generators require an external supply to produce a rotating magnetic flux. The external reactive supply can be supplied from the electrical grid or from the externally connected capacitor bank, once it starts producing power. Induction generators are mechanically and electrically simpler than other generator types. Induction generators are rugged in construction, requiring no brushes or commutators, low cost & low maintenance, operational simplicity, self-protection against faults, good dynamic response, and capability to generate power at varying speed. These features facilitates the induction generator operation in stand-alone/isolated mode to supply far flung and remote areas where extension of grid is not economically viable; in conjunction with the synchronous generator to fulfill the increased local power requirement, and in grid-connected mode to supplement the real power demand to the grid by integrating power from resources located at different sites [2, 3].

Due to its reduced unit cost, brush-less rotor construction, absence of separate sources of excitation, ruggedness, ease of maintenance self protection against severe overload and short circuit, a capacitor self-excited induction generator is being considered suitable for isolated power generation so the method of analysis and performance characteristics of such machine are of considerable practical interest.

A number of papers have been discussed method of analysis for three phase balanced operation of isolated self-excited induction generator. Only few papers have been published on an investigation of self excited induction generator with one winding.

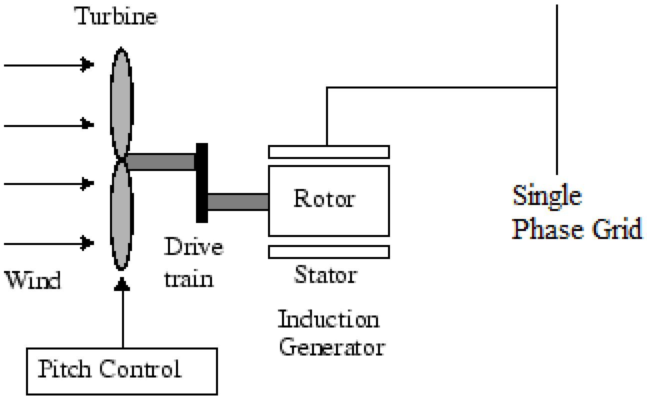

**Figure 1:** Wind Turbine with Induction Generator.

The Figure 1 shows wind turbine and the induction generator. The stator winding is connected directly to the grid and the rotor is driven by the wind turbine[5]. The power captured by the wind turbine is converted into electrical power by the induction generator and is transmitted to the grid by the stator winding [7].

An induction generator is a type of AC electrical generator that uses the principles of induction motors to produce power. Induction generators operate by mechanically turning their rotor in generator mode, giving negative slip.

Induction generators and motors produce electrical power when their shaft is rotated faster than the synchronous frequency.

In generator operation, certain prime mover(turbine, engine) is driving the rotor above the synchronous speed. Stator flux still induces currents in the rotor, but since the opposing rotor flux is now cutting the stator coils, active current is produced in stator coils and motor is now operating as a generator and sending power back to the electrical grid.

## Method of Analysis

The following are the assumptions made in the analysis [6]:

1. Except the magnetizing reactance all other parameter are considered constant with the level of saturation.
2. The mmf space harmonics and time harmonics in the induced voltage and current waveform are ignored.
3. The core loss in machine is neglected.
4. Leakage reactance of stator and rotor are taken to be equal.
5. Magnetizing reactance relating to backward field is eliminated.

The primary elements that influence regulation of the SEIG are its resistances and leakage reactances. Therefore, these parameters automatically become choice for sensitivity study for design modifications. As the load increases, the drop of voltage across these elements become prominent and the already weakened excitation provided by fixed valued capacitor bank along with other supplementary processes further reduce the terminal voltage drastically to result in poor regulation.

To maintain the terminal voltage to a desired level additional capacitance is required to compensate the increased VAR requirement at higher loads. The use of a soft core saturable reactor connected in parallel with the capacitor has been suggested for improved regulation of SEIG. This is altogether a different way of tackling the problem, which in effect is meant to flatten the overall magnetization characteristics of the system. Design modifications should be carried out in such a way that this magnetization characteristics of the combination of SEIG and saturable core reactor is simulated as closely as possible by the newly designed machine alone. That is to say, the effect of saturable core reactor should be incorporated inside the machine. This may influence other performance indices of the generator and therefore, the design may be a little constrained [9, 10]

Figure 2(a) [8, 1] & 2(b), shows the steady state equivalent circuit of an isolated Self-Excited Induction Generator supplying a resistive load.

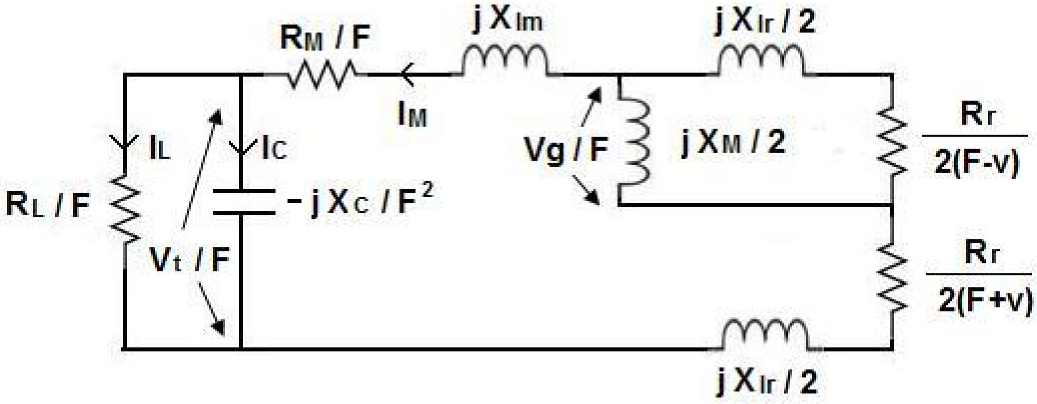

**Figure 2(a):** Steady State Equivalent circuit of one winding Self Winding Induction Generator.

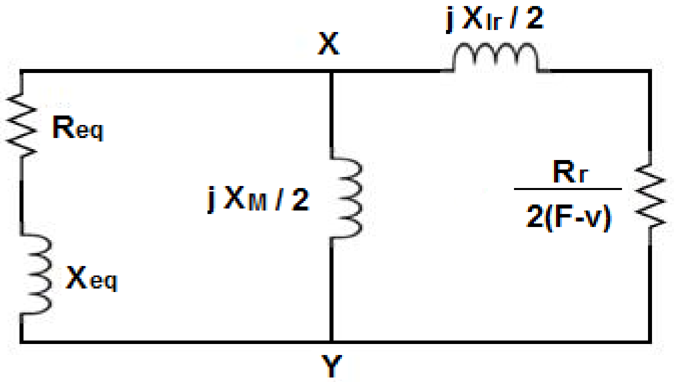

**Figure 2(b):** Simplified Equivalent circuit of one winding Self Winding Induction Generator.

## Mathematical Model

In the Simplified Equivalent circuit of one winding Self Winding Induction Generator, the equivalent impedance across (X-Y) of Figure 2(a):

$$R_{eq} + j\,X_{eq} \quad = \quad \frac{R_M}{F} + \frac{R_r}{2\,(F + v)} + j\,(X_{lm} + \frac{X_{lr}}{2}) + \frac{R_L X_C}{F\,X_C + j\,F^2 R_L}$$

on solving this equation, we get,

$$R_{eq} \quad = \quad \frac{R_M}{F} + \frac{R_r}{2\,(F + v)} + \frac{R_L Xc^2}{F^3 R_L^2 \; + \; F X_C^2} \qquad \text{------- (1)}$$

$$X_{eq} \quad = \quad \frac{2\,X_{lm}\,(F^2 R_L^2 + X_C^2) + X_{lr}\,(F^2 R_L^2 + X_C^2) - 2 R_L^2\,X_C^2}{2\,(F^2 R_L^2 + X_C^2)} \qquad \text{------- (2)}$$

In figure 2(b) the nodal equation for the voltage $V_g$ can be written as :

$$V_g . Y = 0 \qquad (3)$$

Where, $Y = Y_1 + Y_2 + Y_3$

Since under steady state self excitation $Vg \neq 0$, it follows from equation (1) that $Y = 0$ or which means both the real and imaginary parts of Y are zeros.

$$Y = Y_1 + Y_2 + Y_3 = 0 \qquad (4)$$

So, $$\frac{1}{R_{eq} \; + \; X_{eq}} - \frac{j\,2}{X_M} + \frac{2\,(F - v)}{R_r \; + \; j\,(F\text{-}v)\,X_{lr}} \; = \; 0$$

After subsituting the values we get,

$$X_M \; = \quad - \frac{(F - v)\,R_{eq}\,X_{lr} + X_{eq}\,R_r}{(F - v)\,R_{eq} + R_r / 2} \qquad \text{------- (5)}$$

and

$$(F - v)^2\,X_{lr}\,R_{eq} / 2 + (F - v)\,(X_{eq}^2 R_r + R_{eq}^2 R_r) + R_{eq}\,R_r^2 / 2 = 0 \qquad (6)$$

This equation is a polynomial in (F-v), the quadratic equation can be written as,

$$A_1 P^2 + A_2 P + A_3 = 0 \qquad (7)$$

Where $P = (F - v)$

This equation is a quadratic equation of the unknown variable P can be solved for its roots.

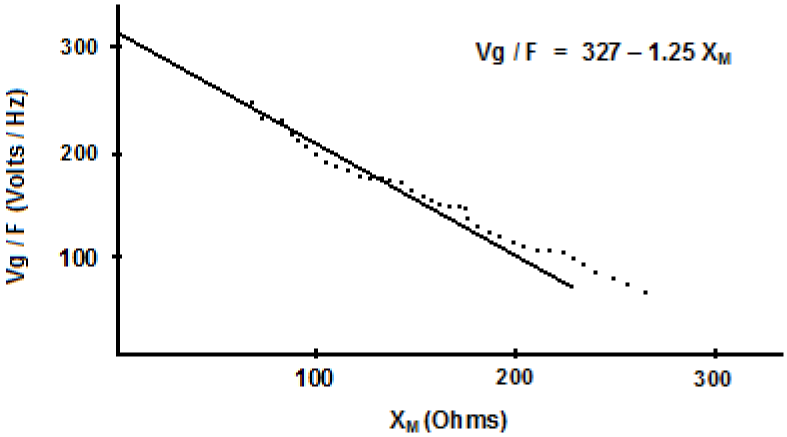

**Figure 3:** Variation of Air gap flux (Vg / F) with Magnetizing Reactance ($X_M$) for SEIG.

From obtained values of $X_M$ and F, the performance of single winding SEIG suitable for computer simulation for one winding system can be calculated:

$$I_M = \frac{V_g / F}{\frac{R_M}{F} + \frac{R_r}{2\,(F+v)} + j\,\frac{X_{lr}}{2} + j\,X_{lm} + \left(\frac{R_L}{F} \,\Big|\Big|\, \frac{-\,j\,X_C}{F^2}\right)} \qquad \text{------- (8)}$$

Now $I_L$, $I_C$ can be calculated.

$$V_t = I_L .\, R_L \qquad (9)$$

The requited capacitive VAR is

$$VAR = V_t .\, I_C \qquad (10)$$

The output power is

$$P_{out} = I_L^{\;2} .\, R_L \qquad (11)$$

## Computer Solution

The flow-chart for the prediction of performance of induction generator is shown in figure 4. By this procedure, a new method for obtaining constant terminal voltage of a single phase self-excited induction generator with one winding has been presented.

The method described here is only for the resistive load. We can extend our work to the case when the load is complex load and in this case we also obtain the similar graphs as we obtained in resistive load.

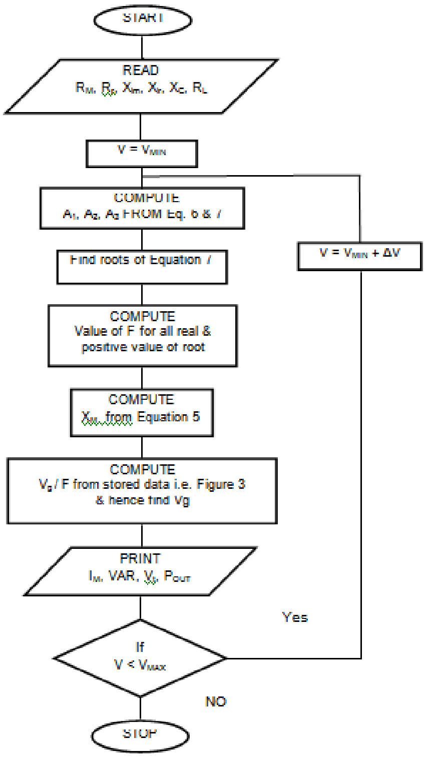

**Figure 4:** Flow Chart for computation of performance of a SEIG with one winding.

## Obtained Graphs

Analytical and experimental results indicating the performance in an induction machine used as SEIG are discussed in this section, shown in Figure 5-7.

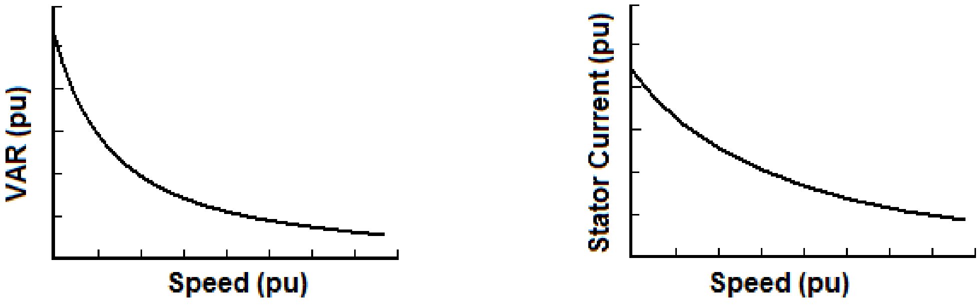

**Figure 5:** Variation of VAR and Stator Current with Speed at no load for Single Winding SEIG.

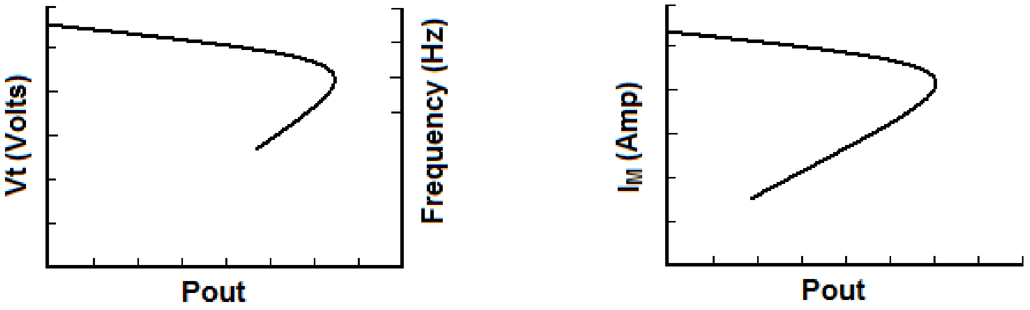

**Figure 6:** Load Performance of Single Phase Single winding SEIG.

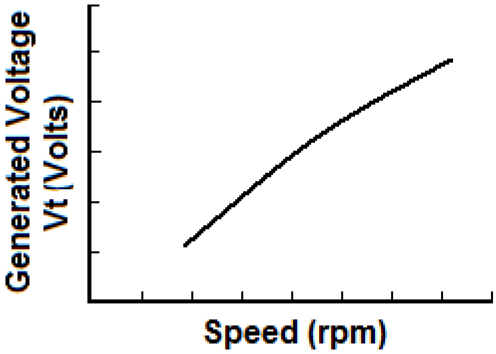

**Figure 7:** Variation of Terminal Voltage with Speed for Single Winding SEIG.

## Conclusion

In this paper, a new method for obtaining constant terminal voltage of a single phase self-excited induction generator with one winding has been presented. The method described here is only for the resistive load. We can extend our work to the case when the load is complex load and in this case we also obtain the similar graphs as we obtained in resistive load.

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