Reactive Power Requirements of GCIG in a Weak Grid

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Abstract -: Induction generators are gaining the popularity due to its simplicity and no synchronization problem. However the major drawback of this machine is its additional reactive burden on the system, where it is connected. In this paper an attempt is made to explore the performance of a grid connected induction generator (GCIG) due to weak grid conditions i.e. voltage and frequency fluctuations. Iterative model developed by the authors is used to predict the reactive burden of the generator due to voltage and frequency fluctuations. The comparison between experimental and simulated results proves the validity of technique proposed. Further proposed modeling is also used to include the effects of saturation.

Key-Words-: Grid connected induction generator, Iterative technique, Magnetizing reactance, Saturation, Weak grid

Nomenclature

E_1=Air gap voltage per phase
f_s=System frequency
I_1 = Stator current per phase
I_2= Rotor current per phase
I_m= Magnetizing current per phase
pf = power factor
P_{fw} = Friction and windage losses.
P_g = Air gap power.
P_{in} = Input Power.
P_m = Mechanical Power.
P_{out} = Output power.
P_{rcu} = Rotor copper losses.
P_{score} = Stator core losses.
P_{scu} = stator copper losses.
R_1 = Stator resistance per phase
R_2= Rotor resistance per phase referred to stator
s=Operating Slip
V_1=Rated terminal voltage per phase or grid voltage
X_1= Stator leakage reactance per phase
X_2= Rotor leakage reactance per phase referred to stator
X_m= Saturated magnetizing reactance per phase
X_{mu}=Unsaturated magnetizing reactance per phase

1. Introduction

Energy pervades every part of our lives. Our over dependence on the energy which is mainly being fuelled by coal, oil and nuclear is causing global warming, ozone depletion, smog, acid rain, and mercury contamination. Henceforth at this juncture, people are turning more and more to environmentally clean and safe renewable energy sources like wind, hydro, photovoltaic and fuel cells. Of all the renewable sources, wind energy has become the workhorse around the world. A state of art has been established in wind harnessing and has far outpaced any previously imagined bounds. Induction Generators with cage rotors are by far the most common type of mechanical-electrical energy conversion devices used in wind turbines. The preference of induction generators over synchronous generators in such applications are attributed owing to its inherent advantages such as low unit cost, reduced maintenance, rugged and brushless rotors, absence of a separate dc source for excitation, absence of moving contacts, inherent overload protection, natural protection against short circuit etc.

In induction generator the saturation state of the magnetic circuit has a significant influence over its performance. Asynchronous machines fall significantly further into the saturation state in generator operation than in motor operation. High

magnetic saturation usually results in high no-load losses. However in wind turbines no-load losses are generally undesirable, firstly because they make it more difficult to convert low wind speeds into electrical output and also increase the standstill time of the plant. Secondly for the wind turbines operated independently, the generator excitation normally occurs after turbines have run up. No-load losses caused in this manner cannot be covered at high saturation in the lower wind-speed range; thus the turbine speed can drop to the point where the generation is de-excited. Furthermore, the permissible current density of the generator is significantly increased due to high magnetic energy content and thus wind turbines with increased generator saturation operated as part of grid, faces high in rush currents which can even trip the fuses and significantly load windings.
Predicting the saturation level and hence finding the value of magnetizing reactance is the first need in accurately analyzing the GCIG. A review of the available literature reveals that although a lot of work has been reported on analysis of GCIG using the philosophy of fixed value of magnetic reactance X_m but no attempt seems to have been made in using the saturated values of X_m with corresponding change in air gap voltage (E_1). Computation of the magnetic reactance is done using thevenin equivalent circuit [2], while in [3] the value of X_m is found by carrying out variable voltage no load tests.[1]and[4-6] used the fixed value of X_m and [7] calculated the value of X_m corresponding to induced electromotive force (EMF) by using a software package of MathCAD. In this paper an attempt is made to explore the performance of a grid connected induction generator (GCIG) due to weak grid conditions. Further proposed modeling is used to analyze the effects of saturation on the steady state performance of GCIG.

2. Steady State Analysis

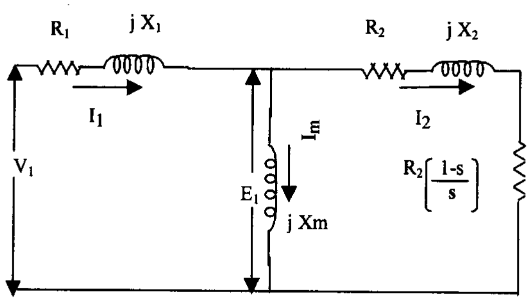

Fig. 1 Equivalent Circuit of induction machine.

Analysis of conventional equivalent circuit representation for induction machine as given by Figure 1, with any value of slip (negative for generator operation) and saturated magnetizing reactance Xm [calculated using an iterative technique (Appendix I)] results in to the following mathematical expressions:

$$Z = R_1 + jX_1 + \frac{\left(\frac{R_2}{s} + jX_2\right)\left(jX_m\right)}{\left(\frac{R_2}{s}\right) + j\left(X_2 + X_m\right)} \quad (1)$$

$$I_1 = \frac{V_1}{Z} \quad (2)$$

$$I_1 = I_{1real} + jI_{1imag} \quad (3)$$

$$E_1 = V_1 - I_1\left(R_1 + jX_1\right) \quad (4)$$

$$I_m = \frac{E_1}{jX_m} \quad (5)$$

$$I_1 = I_2 - I_m \quad (6)$$

$$P_{out} = 3V_1 I_{1real} \quad (7)$$

This results in negative power for negative slip in case of generator.

The reactive power requirement is;
$$Q = 3V_1 I_{1imag} \quad (8)$$

Power flow diagram for the induction generator is as shown in Fig.2

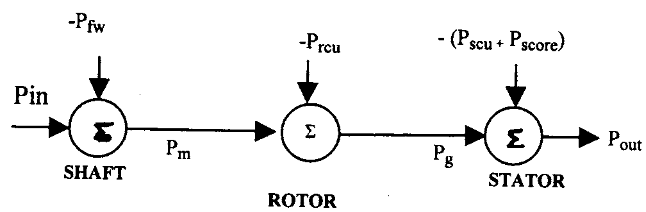

Fig.2 Power flow diagram of induction generator.

Fig.3 gives the flow chart for performance evaluation of the generator, which has been programmed in MATLAB

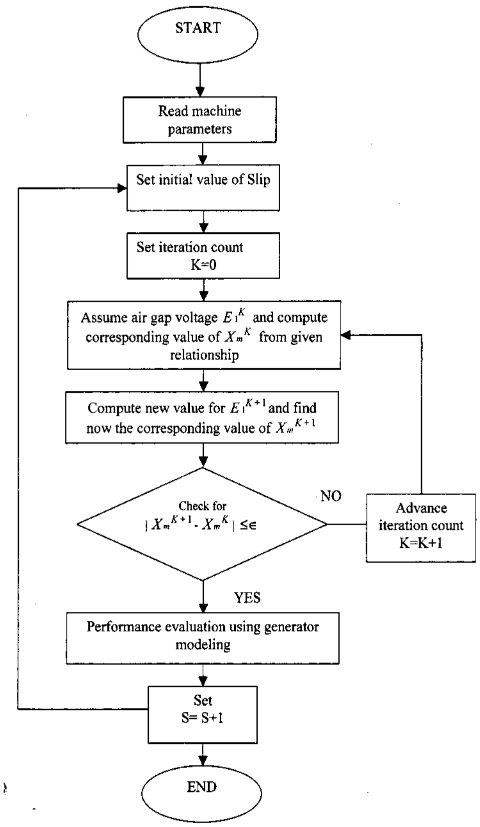

Fig.3 Flow chart for performance evaluation.

3. Results and Discussions

Proposed iterative technique is adopted to simulate the results on Machine-1 [Appendix-II]

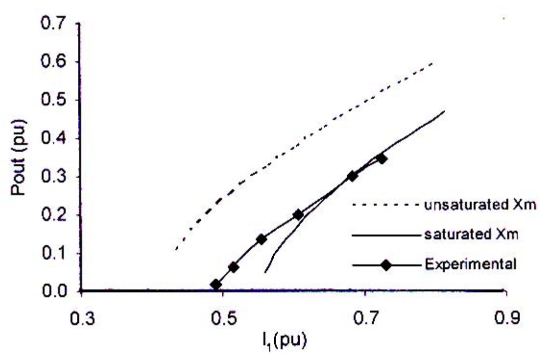

Fig.4 Variation of output Power with slip

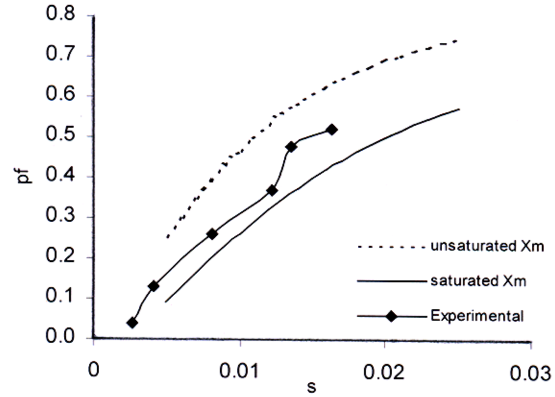

Fig.5 Variation of output Power with stator current

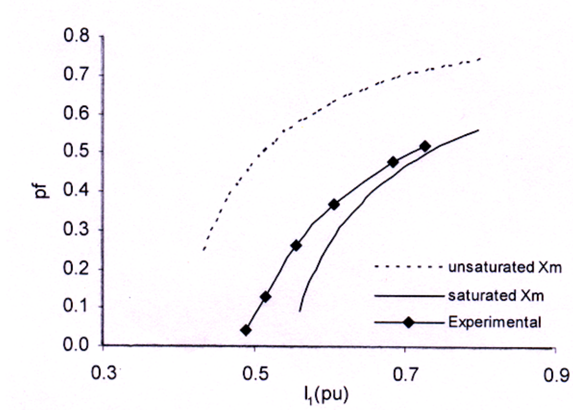

Fig.6 Variation of power factor with slip

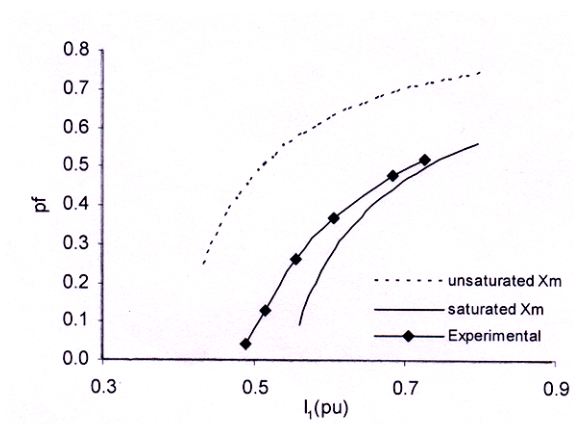

Fig.7 Variation of power factor with stator current

Fig 4 to Fig. 7 shows the comparison of computed and experimental results for output power and operating power factor. A close comparison indicates that the simulated results using proposed techniques (with saturated value of Xm) falls closer to experimental results. This proves the validity of proposed iterative technique. Further closeness of simulated results using proposed modeling in comparison to results with unsaturated value of Xm, indicates the need to compute saturated value of Xm.

Accounting for saturation in magnetic circuit, which was generally omitted by research persons, has been incorporated in this paper.

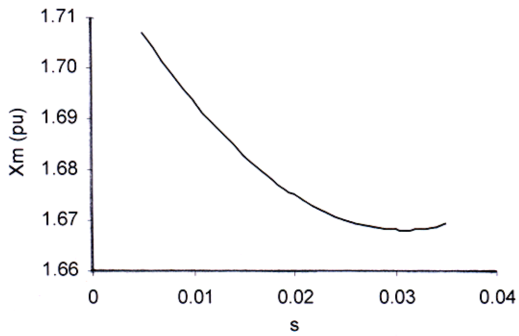

Fig.8 Variation of magnetizing reactance with slip

Fig.8 show the simulated results for variation of magnetizing reactance with operating slip. This variation in Xm is due to the saturation effect. It clearly shows the reduction in Xm with operating slip accounted due to the loading effect on generator.

Fig. 9 to Fig. 15 shows the effects of variations in grid voltage, magnetizing reactance and frequency on the reactive power requirement of the generator.

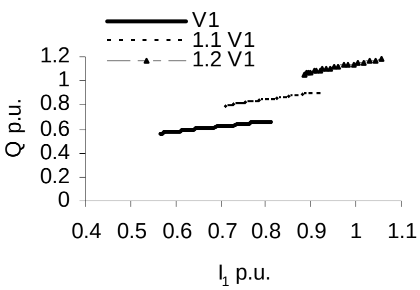

Fig. 9 Variation of reactive power with stator current

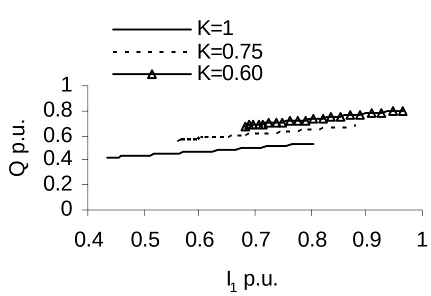

Fig. 10 Variation of reactive power with stator current, terminal voltage = V_1, magnetizing reactance=K Xmu

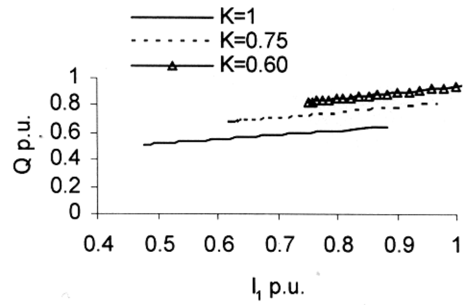

Fig. 11 Variation of reactive power with stator current, terminal voltage =1.1 V_1, magnetizing reactance=K Xmu

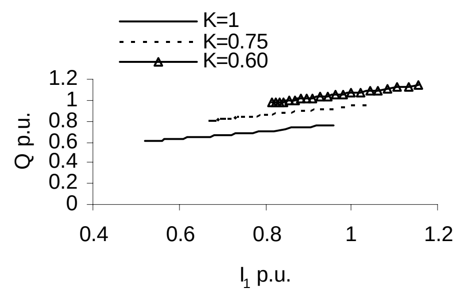

Fig. 12 Variation of reactive power with stator current, terminal voltage =1.2 V_1, magnetizing reactance=K Xmu

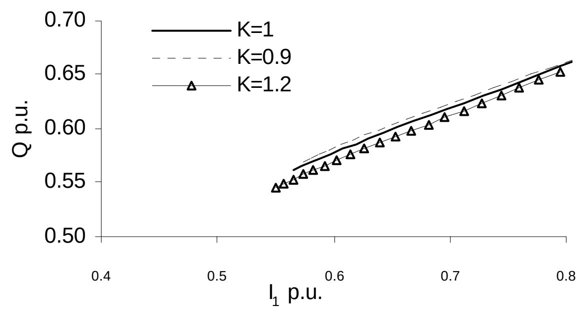

Fig. 13 Variation of reactive power with stator current, terminal voltage = V_1, frequency=K f_S

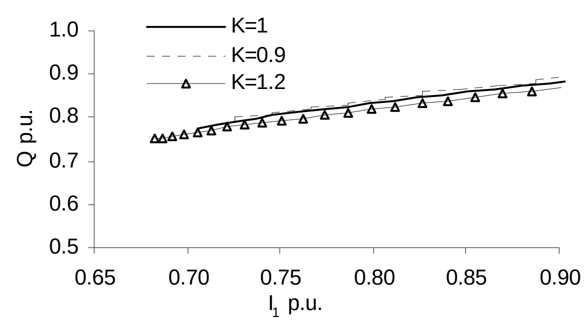

Fig. 14 Variation of reactive power with stator current, terminal voltage =1.1V_1, frequency=K f_S

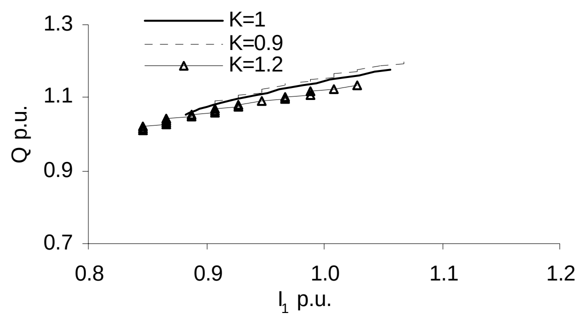

Fig. 15 Variation of reactive power with stator current, terminal voltage =1.2 V_1, frequency=K f_S

Following observations may be concluded from Fig. 9;

- It is found that reactive power required by the generator increases with an increase in the grid voltage. This is due to operation of the machine in deep saturation.
- Operating range of induction generator shifts with a change in grid voltage.

Fig.10 to Fig.12 shows the effects of saturation on reactive power requirement provided the terminal voltage is kept constant. Effect of 'grid frequency fluctuations' on the reactive power requirements of machine is shown in Fig.13 to Fig.15. It is observed that reactive power requirement of the machine is greatly effected from no load to full load operation.

4. Conclusion

In this paper an attempt is made to explore the performance of a grid connected induction generator (GCIG) due to weak grid conditions. Iterative technique as proposed for the estimation of saturated reactance of GCIG results into a close agreement for simulated and experimental results. This proves the validity of proposed modeling. The work carried out in the present paper, will attract the focus of power engineers to maintain the grid voltage and frequency for the promotion of GCIG.

Appendix-1

The procedure for the computation of magnetizing reactance Xm in generating mode is summarized as following:

Step 1. Assume Xm^0 corresponding to $E_1{}^0$ as 1.0 p.u. from the relationship between E_1 and Xm depicting the magnetic characteristics of induction machine.

Step 2. Compute $E_1{}^1$ using (1) to (8)

Step 3. Find out the new value of magnetizing reactance Xm^1 corresponding to air gap voltage computed in Step2

Step 4. If $| Xm^1 - Xm^0| \leq \in$

Then the value of Xm^1 may be used as the final magnetizing reactance needed for further computation the performance of the induction generator. Otherwise Xm^0 may be replaced by the new value of Xm^1 and the procedure may be repeated unless until the difference between successive values of magnetizing reactance comes out as desired.

Appendix- 2

Specifications;
Machine I
Three Phase, 2.2KW\3HP, 230V, 8.6A, 50Hz, Delta connected, Squirrel Cage Induction Machine.

V_{base} =230 V
I_{base} =4.96 A
N_{base} = 1500 RPM

The Machine parameters are:

R_1=3.35 Ω
R_2=1.76 Ω
X_1=4.85 Ω
X_2=4.85 Ω

Variation of magnetizing reactance Xm with air gap voltage E_1 is

$0 \leq E_1 < 117.87$	Xm=108,
$117.87 \leq E_1 < 171.052$	$Xm=135.553-0.2337E_1$,
$171.052 \leq E_1 < 211.919$	$Xm=151.160-0.325E_1$,
$211.919 \leq E_1 < 344.411$	$Xm=213.919-0.621E_1$,

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