iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH
IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 6 Issue: I Month of publication: January 2018

DOI: http://doi.org/10.22214/ijraset.2018.1465

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor :6.887
Volume 6 Issue I, January 2018- Available at www.ijraset.com

Steady-State Analysis of Three-Phase Self-Excited Induction Generator for Stand-Alone Applications

Sunil Singh[1], Rohit Kumar[2], Sandeep Kumar Goel[3]
[1, 2, 3]Department of Electrical Engineering, G.B. Pant University of Agriculture & Technology, Pantnagar, US Nagar, Uttarakhand, INDIA

Abstract: Self-excited induction generator offers certain advantages over a conventional synchronous generator as a source of isolated power supply. Main advantages are reduced cost, less maintenance, self protection from short-circuit or overload condition, and brush less rotor. It is used as variable speed generator for different applications such as wind energy conversion, micro hydropower generation. Therefore, it is now a key interest to develop an efficient and viable Generator for harnessing the energy from renewable sources. To develop an efficient, viable, economic and controllable induction generator, we must know the steady-state performance of the generator.
Using steady state equivalent circuit model excluding iron losses, steady state performance analysis has been done. Experimental investigations under steady state condition have been done in the laboratory.
Keywords: Minimum capacitance, standalone SEIG, self-excited induction generator, remote areas, rural areas, steady state analysis, operating conditions.

I. INTRODUCTION

Electrical energy is the basic necessity of any country for its overall development. Fossil fuels (Coal, Oil, and Diesel) are the main sources of electrical energy (about 60% in our country). Fast depletion of fossil fuels results insecurity of availability of fossil fuels, subsequent increase in energy cost, the environmental pollution and above all the global warming. This has brought the worldwide attention in reducing the pollution and conservation of the limited conventional fuels by encouraging more and more use of the energy available from the non-conventional/renewable sources such as the wind, the biogas, the tidal waves and the small hydro power stations on the running canals and rivulets etc. The potential of the energy available from the small hydro and the wind sources seems to be quite promising to meet the future energy demands, especially in the remote and isolated areas. However, these systems will become more viable if their cost is reduced to the minimum. Therefore, the squirrel cage rotor induction generators are receiving much attention for such applications due to its low cost and robust construction[1-4].

The Self-Excited Induction Generators (SEIGs) are receiving increased attention from the utilities over the world to obtain the energy from renewable/non-conventional sources for remote and isolated areas. The main problems in the use of induction machine as a generator are related to the varying voltage and frequency, the loss of self-excitation, the overloading of the machine, the transient over voltages due to the capacitance switching or the load loss. But, the robust construction of induction machine specially squirrel cage type rotor, offers maintenance free operation and the least cost of the generating system. This has motivated to facilitate the use of the induction generator in isolated mode with suitable low cost control which could ensure the reliable supply of good quality. Also, such system for power generation could be made efficient and cost effective to compete with the other conventional energy sources[2 - 5].

The main objectives of this work are as follows:

A. To calculate the minimum capacitance required for voltage buildup.
B. Investigate the behavior of cut off speed with minimum capacitance.
C. Investigate the behavior of voltage and frequency with capacitance speed, load and power factor.

II. METHODOLOGY

A. Major equipment used

1) Three-Phase Squirrel-Cage Induction Machine: That is used as an induction generator (a test machine) with specifications 3.7 kW, 415V, 8 A, 1440 rpm, 50 Hz, delta connected, 4 pole Induction motor.
2) D.C. Shunt Machine Used as a Prime Mover : 220 V, 3 kW, 1500 rpm

3) Four Channel Digital Storage Color Oscilloscope: It is used for capturing the waveforms in transient as well as in steady-state conditions under different loading conditions.
4) Other measuring equipments: Voltmeter, Ammeter, Wattmeter, Frequency meter etc.

B. *Self-Excited Induction Generator(Seig)*

Following may be the classification of induction generators:

1) Squirrel Cage (SC) induction machine as an induction generator.
2) Slip Ring (SR) induction machine can be used as an induction generator.

C. *These machines can be operated in two modes[2-5]*

1) *Grid Connected Mode:* In this mode, the induction machine is connected with the power supply line and machine is made to run above the synchronous speed by prime mover. The active power will be transfer to the grid but machine will draw reactive power for magnetizing from the grid. We can use a capacitor bank in parallel with the load for providing the reactive power to the machine .In this mode of operation frequency and voltage is fixed by the grid.
2) *Isolated Mode:* In this mode, the excitation supply is provided by the capacitor bank of suitable value. The induction machine is made to run by prime mover and a capacitor bank is connected across the stator terminal and then voltage is developed. This phenomenon is known as the self-excitation of induction generator. Output voltage and frequency depends upon capacitor, load and the speed. The main problem with the SEIG in isolated mode of operation is that its frequency depends upon load even if speed is kept constant.

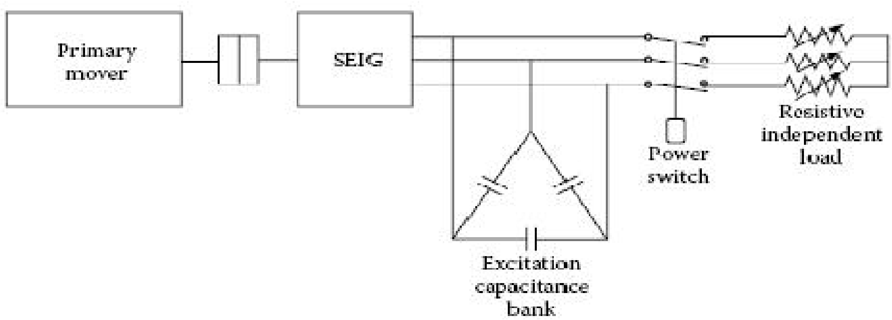


Fig. 1: Capacitor excited SEIG in isolated mode supplying resistive load.

D. *Operation Of SEIG*

An induction machine can be used as an induction generator in two ways, namely, in the externally excited mode and in the self excited mode. The externally excited induction generator draws its excitation in terms of lagging magnetizing current from power source to which it is connected, to produce its rotating magnetic field. The frequency and voltage of the externally excited induction generator is governed by the frequency and voltage of the power source with which it is excited.

However, in case of self excited mode, if an appropriate capacitor bank is connected across the terminals of rotating induction machine, a voltage is developed across the machine terminals. The residual magnetism in the magnetic circuit of the machine sets up small voltage in its stator winding. This voltage is applied to the capacitor and causes the flow of lagging current in the stator windings which produces rotating flux in its air gap. This rotating field produces the voltage across the machine terminals. Such generators are called as the Self Excited Induction Generators and can be used to generate the power from constant as well as variable speed prime movers. When an induction machine is driven at a speed greater than the synchronous speed by means of an external prime mover, the direction of induced torque is reversed and theoretically it starts working as an induction generator[3-4].

E. Tests Performed on Seig

Blocked Rotor Test: The locked rotor test is done by mechanically holding the motor shaft from turning, and applying a reduced Voltage on the stator. This test is performed to determine the short-circuit current Isc with normal applied voltage to stator; power factor on short-circuit; total equivalent resistance and reactance of the motor as referred to stator side[3-6].

Synchronous Running Test: The induction motor is made to run at no load at rated voltage and frequency at synchronous speed with help of prime mover. This test is used to determine the magnetizing characteristics and shunt branch parameters[3-6].

E. Steady State Analysis

Steady state analysis of SEIG is of interest, both from the design and operational points of view. In isolated power system both terminal voltage and frequency are unknown and have to be computed for a given speed, capacitance and load impedance[4][8][9].

F. Mathematical Modelling Of Seig

An equivalent circuit of the induction machine, also known as the per-phase equivalent model is represented in fig 2 and fig 3, which will be used further for steady state analysis of SEIG. In this figure R1 and X1 the resistance and leakage reactance respectively of the stator, Rm and Xm are the loss resistance and the magnetizing reactance, and R2 and X2 the resistance and reactance of the rotor. I1 and Ir are the stator current and rotor current respectively[10-13].

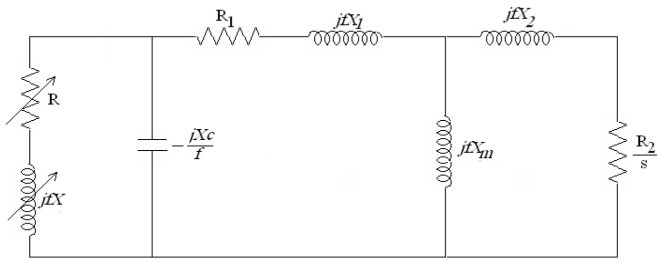


Fig 2: Steady-state equivalent circuit

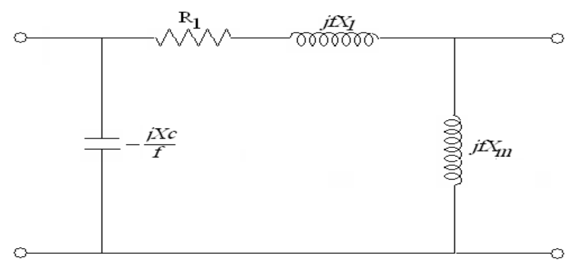


Fig 3 Equivalent circuit under no load conditions

G. Analytical Method For Determination Of Minimum Capacitance At No Load

When generator is capacitor self excited, the value of Xm lies in the saturation region. At the threshold of self excitation Xm = Xsmax. Assuming f = V, Xc = V^2 (X1+ Xsmax) or Cmin = $1/2\pi f_b V^2$ (X1+ Xsmax) Cmin is inversely proportional to the square of the per unit speed (V) of the machine. It is also inversely proportional to the unsaturated magnetizing reactance of the machine. The terminal voltage of an isolated SEIG depends upon the speed, load and terminal capacitance. If C <<Cmin voltage buildup does not occur. On the contrary if C >>Cmin, the output voltage might be excessive and dangerous. Therefore, for safe operation it is desirable to find a relationship between the output voltage, speed and the terminal capacitance[14 – 16].

III. RESULTS AND DISCUSSION

The steady state behavior of SEIG has been investigated by performing experiments. The experimental investigations have been carried out using three-phase squirrel-cage induction machine. The generator was driven by a dc shunt motor. SEIG characteristics have been obtained.

determination of machine parameters

Following results were obtained from synchronous running test:

No load Voltage=415V (L-L), No load current (I_m)=2.9 A, Power at no load = 300W.

Following results were obtained from Block rotor test:

Voltage to cause full load current= 130V, Current= 8 A (full load), Power dissipated= 700W.

Following test results were obtained from DC Resistance test:

V=19V (dc), current= 4.4A (dc), R_{ac}= 1.2 x 19/4.4= 5.18 Ω.

The machine parameters are found as below:

S. NO.	PARAMETER	VALUE
1.	R_1	5.18Ω
2.	R_2	6.42Ω
3.	X_1	12.97 Ω
4.	X_2	12.97 Ω
5.	Xm	232.3 Ω
6.	R_c	1768.89 Ω.
7.	Efficiency	81%.

A. Magnetization Curve Of Seig

Magnetization curve at synchronous speed was obtained by performing synchronous running test. Magnetization curve (induced voltage versus magnetizing current) has been shown in Fig.5.

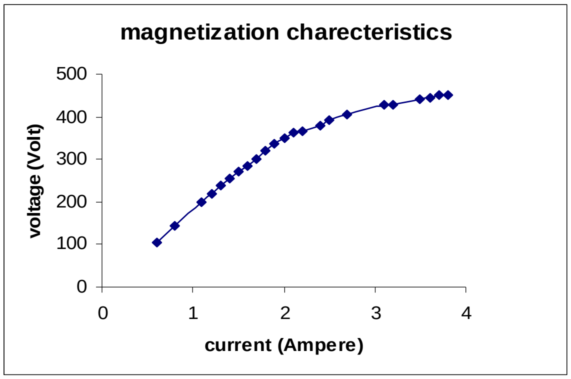


Fig 5Magnetization characteristics

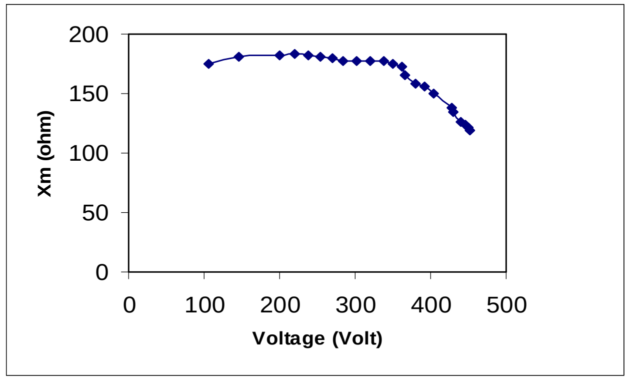


Fig 6 Voltage vsXm at synchronous speed

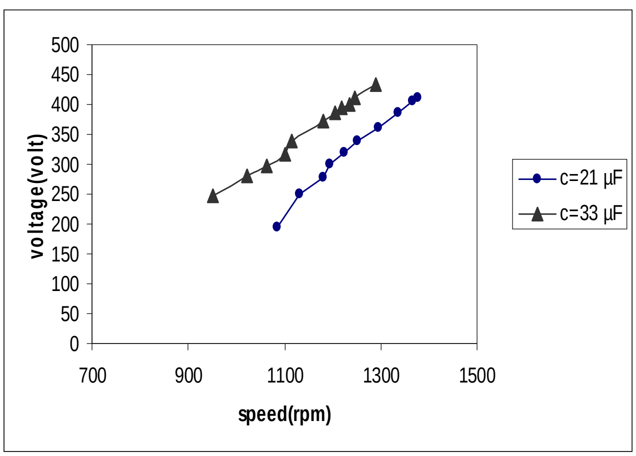
B. Variation Of Magnetizing Reactance During Self-Excitation Process

In case of self-excited induction generator the variation of magnetizing inductance with the air gap flux which is proportional to the applied voltage is the guiding factor for determining the dynamics of voltage build up and stabilization. This curve is found from the magnetization characteristics. From voltage versus X_m curve (fig. 6), we can linearize approximately as

$X_m=220-.6(E_a-337)$ 50 Hz , $E_a=0$ for $X_m > 181$ and $E_a=700-1.6\,X_m$ for $X_m < 181$

C. Steady State Analysis At No Load

Machine was made to run by prime mover. Speed of machine was varied with the help varying field resistance and varying of armature resistance of the prime mover. Reading of no load voltages, Excitation currents, and frequency were taken for investigating the behavior of voltage, frequency and excitation current with speed at particular value of capacitance.



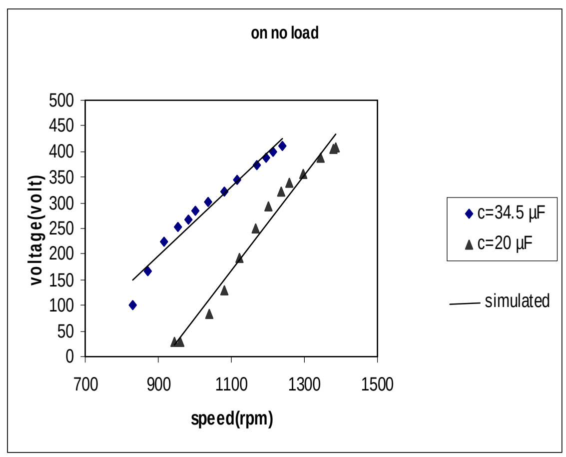


Fig. 7 Effect of speed on voltage at different capacitors

D. Effect Of Speed On Voltage At Two Different Value Of Capacitor

It was observed that as speed increases voltage also increases approximate linearly. For higher value of capacitance the graph line becomes step up position according to value of the capacitor. Fairly good resemblances found experimentally (Fig. 7), and theoretically calculated.

E. Effect Of Speed On Excitation Current At Constant Capacitor

Speed was varied keeping capacitor value constant. Same pattern have been found as in the previous graph i.e. Fig 7 because excitation current is proportional to the terminal voltage. Effect of speed on excitation current has been shown in Fig 8.

ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor :6.887
Volume 6 Issue I, January 2018- Available at www.ijraset.com

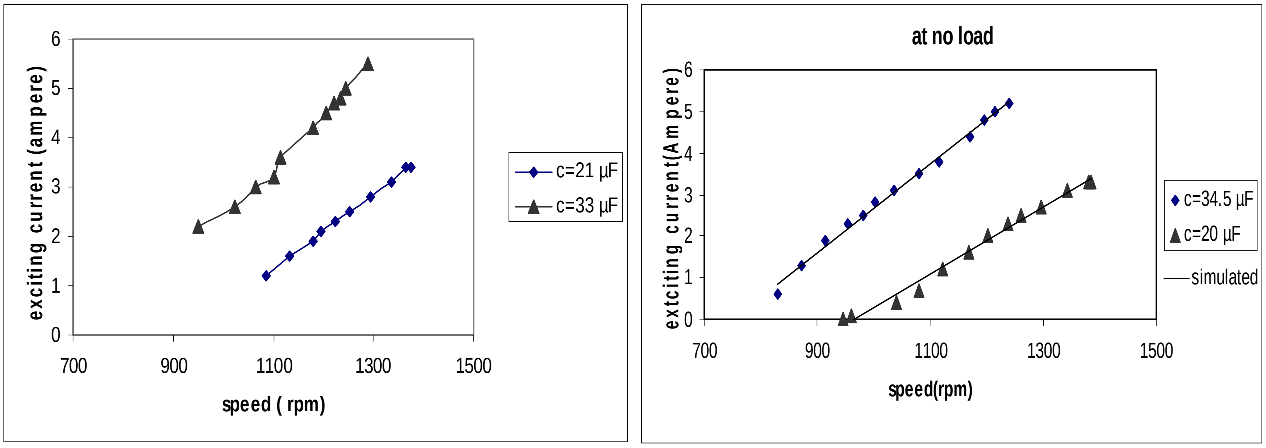


Fig 8 Effect of speed on excitation current at different capacitors

F. Effect Of Speed On Frequency At Constant Capacitor

As speed increases the frequency also increases approximately linearly but not any change is observed with the capacitance. Characteristics have been shown in Fig 9.

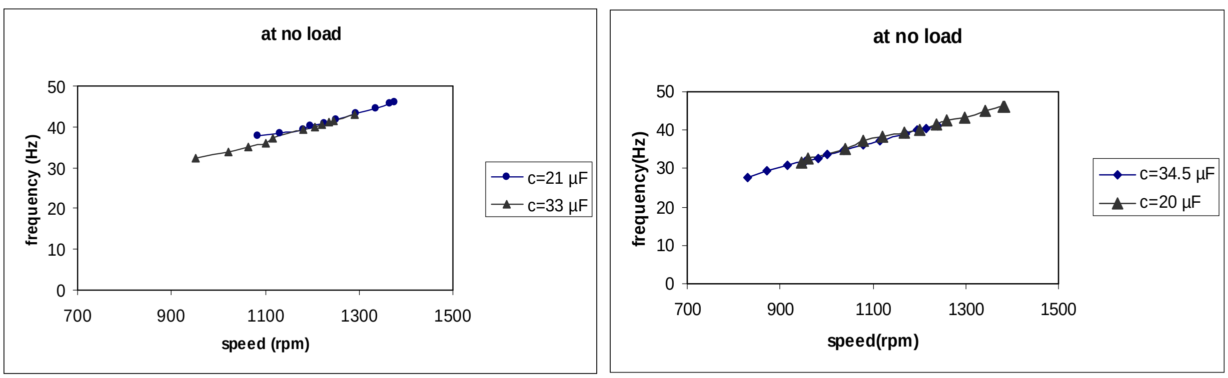


Fig9 Effect of speed on frequency at different capacitors

G. Capacitance Effect On Frequency And Voltage At Constant Speed

Speed was kept constant by field and armature control of D.C motor and readings of frequency and voltage of induction machine were taken at different values of capacitances. It was found that, at no load condition capacitor does not affect the frequency whereas, voltage increases linearly with the capacitance depending upon speed also. Characteristics have been given on Fig 10 and Fig 11.

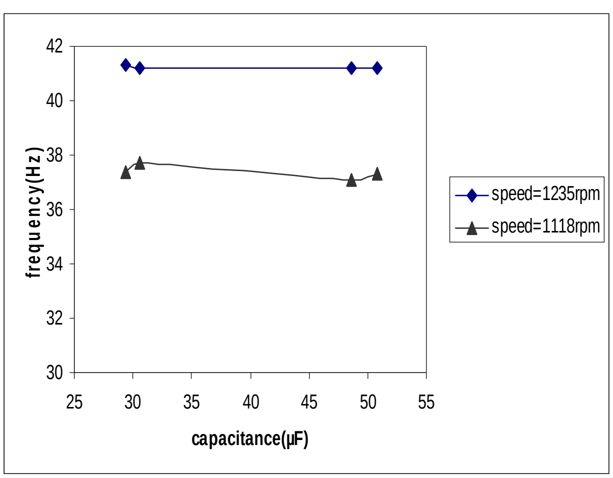


Fig 10 Effect of capacitance on frequency

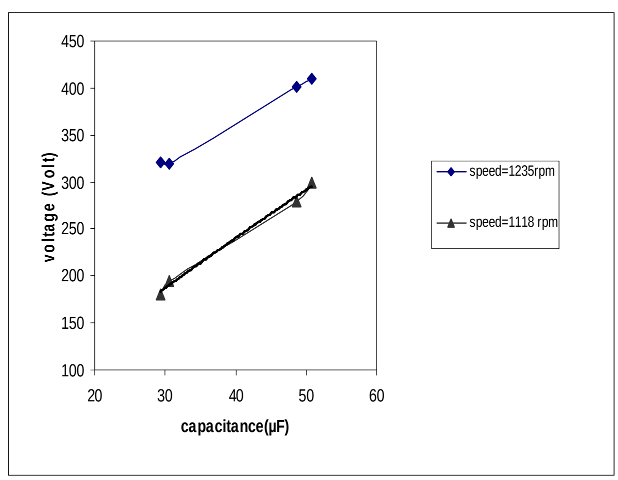


Fig 11 Effect of capacitance on voltage

H. Steady State Analysis At Loading Condition

Characteristics of the SEIG were determined experimentally and predicted theoretically under different conditions of load, power factor, and speed and excitation capacitance. Variations of load terminal voltage versus load current with excitation capacitance of 20 μF and different speeds are shown in Fig 12.

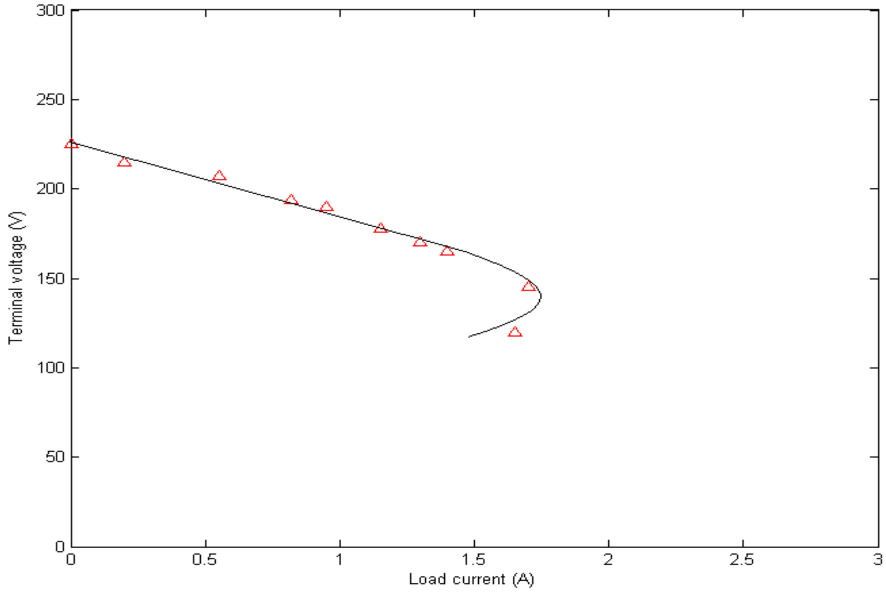


Fig. 12 Variation of load voltage versus load current for SEIG (at 20μF)

I. Variation Of Cut Off Speed N_{co} Against C_{min}

The minimum speed at which the self-excitation of the machine occurs for a particular capacitance value is called cut off speed. This is different for different capacitor banks and load conditions (impedance and power factor). At this speed, MMF is at its minimum level; therefore the saturation effects and iron losses can be neglected. Fig. 13 shows cut off speed N_{co} against excitation capacitance for specified values of delta connected unity power factor load. From this figure it is observed that the correlation is satisfactory.

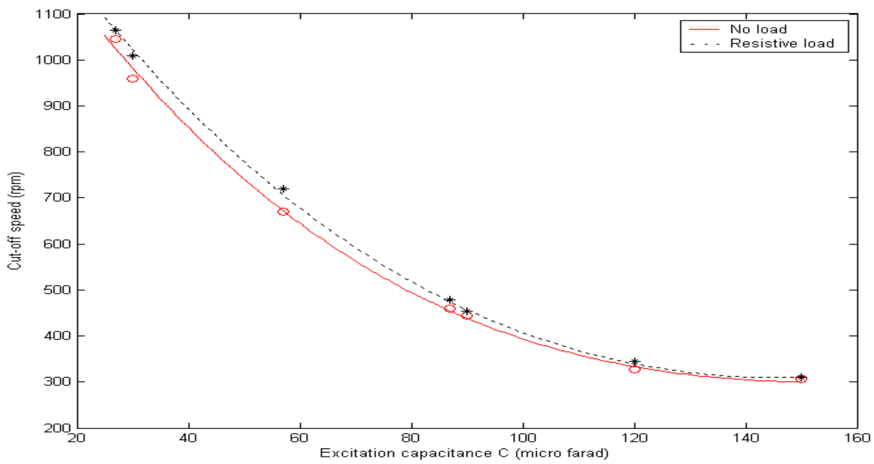


Fig 13 Variation of cut-off speed with minimum capacitance

IV. CONCLUSION

Experimental investigations of steady state performance have been emphasized in this paper. Knowing the frequency and speed, the values of voltage and other parameters may be calculated. Observations may be summarized as follows:

No load voltage varies linearly with speed and value of capacitance.

Frequency mainly depends upon speed. Capacitor value does not affect the frequency.

R-L load is frequency sensitive and R load is frequency insensitive.

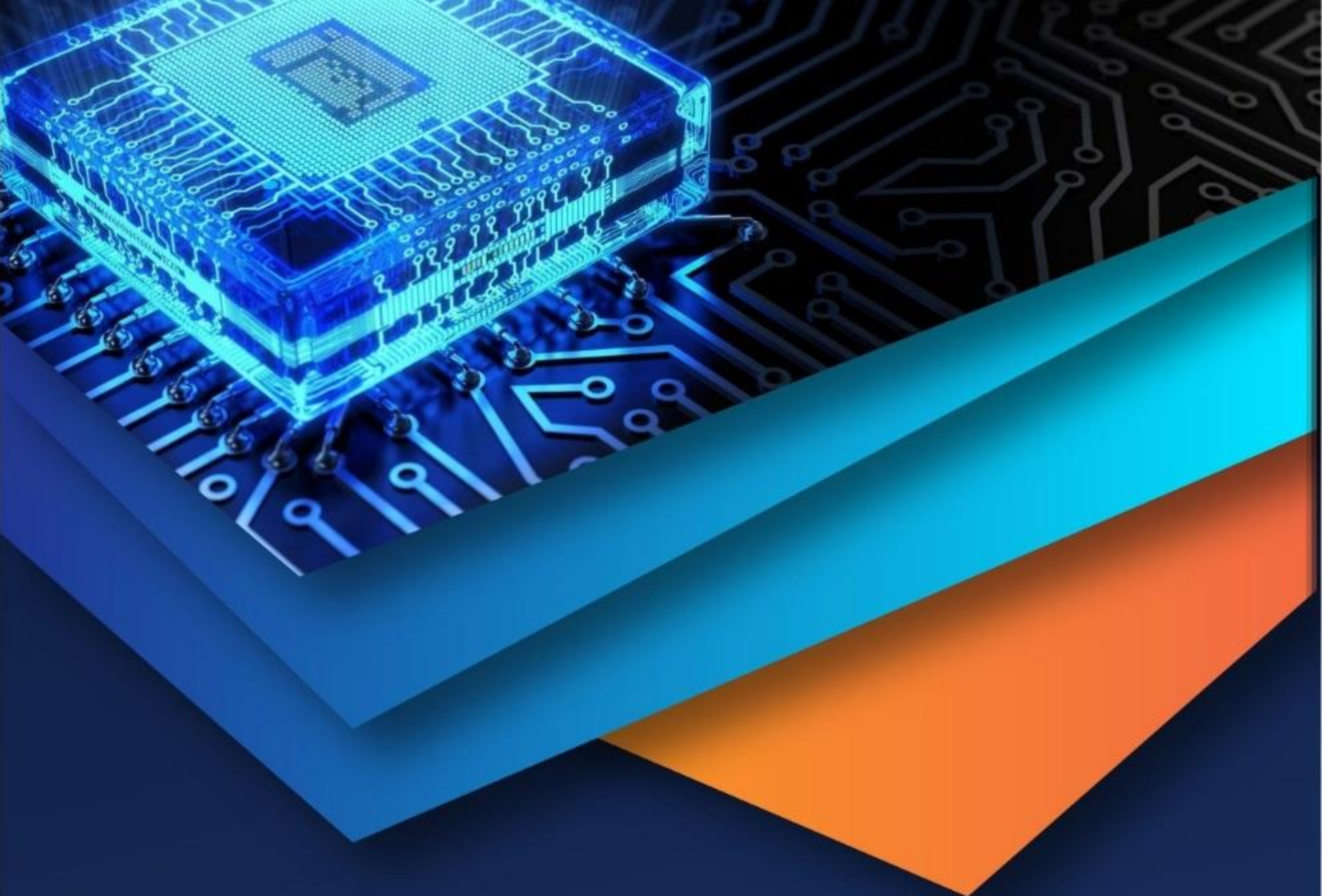
Voltage regulation becomes very poor in R-L load as it is frequency sensitive.

The value of Minimum capacitance depends upon speed and load. At no load condition it varies with $1/V^2$ and also inversely proportional to the magnetizing reactance(X_m)

The performance of self-excited induction generator is investigated here for different loads/operating conditions.

REFERENCES

[1] M. Godoy Simoes and F.A.Farret, “Renewable Energy Systems: Design and Analysis with Induction generators,” CRC Press, Boca Raton, FL, 2004.
[2] M. A. Abdel-halim, A. F. Almarshoud, and A. I. Alolah, “Control of Grid Connected Induction Generator Using Naturally C ommutated AC Voltage Controller,” IEEE Trans. Energy Convers.
[3] Ion Boldea, “Variable Speed Generators: The Electric Generator Handbook,” CRC Press, Boca Raton, FL, 2006.
[4] R. C. Bansal, “Three Phase Self Excited Induction Generator: An Overview,” IEEE Trans. Energy Convers., vol. 20, no. 2, Jun. 2005.
[5] S. Wekhande and V. Agarwal, “A new variable speed constant voltage controller for self-excited induction generator,” Electr. Power Syst. Res., vol. 59, no. , pp. 157– 164, 2001.
[6] M. S. Vicatos and J. A. Teqopoulos, “Steady state analysis of a doubly-fed induction generator under synchronous operation,” IEEE Transaction on Energy Conv., vol. 4, no. 3, pp. 495–501, Sep. 1989.
[7] R. C. Bansal, T. S. Bhatti, and D. P. Kothari, “A bibliographical survey on induction generators for application of nonconventional energy systems,” IEEE Trans. Energy Convers., vol. 18, no. 3, pp. 433–439, Sep. 2003.
[8] B.V. Gorti, G.C. Alexander, and R. Spee,“A novel, cost-effective stand-alone generator system,” IEEE Trans. Energy Conversion, vol. 2, Sept. 1996.
[9] L.Wang and C. H. Lee, “A novel analysis of the performance of an isolated self-excited induction generator,” IEEE Trans. Energy Conversion, vol. 12, pp. 109– 115, June 1997.
[10] T. M. Masaud and P. K. Sen, "Modeling and analysis of self-excited induction generator for wind energy conversion," 2015 IEEE Power & Energy Society Innovative Smart Grid Technologies Conference (ISGT), Washington, DC, 2015, pp. 1-5.
[11] J. Faiz, A.A. Dadgari, S Horning, and A. Kehyani, “Design of a three phase self excited induction generator,” IEEE Trans. Energy on Conversion, vol. 10, pp. 516 – 523, Sept. 1995.
[12] S.S. Murthy, B.P. Singh, C. Nagamani, and K.V.V. Satyanarayna, “ Studies on the use of conventional induction motors as self excited induction enerator,” IEEE Trans. Energy Conversion, vol. 3, pp. 842 – 848, Dec. 1988.
[13] R.C. Bansal, “ Three phase self excited induction generators: an overview,” IEEE Trans. Energy Conversion, vol. 20, pp. 292 – 299, June 2005.
[14] S.S. Murthy, R. Jose, and B. Singh, “ Experience in the development of microhydel grid independent power generation scheme using induction generators for Indian conditions, “ IEEE Trans., vol. 2, pp. 461 – 465, Dec. 1998.
[15] T. Ahmed, O. Noro, K. Matzuo, Y. Shindo, and M. Nakaoka, “ Minimum excitation capacitance requirements for wind turbine coupled stand-alone self-excited induction generator with voltage regulation based on SVC,” IEEE Trans., pp. 396 – 403, Oct. 2003.
[16] Li Wang and Jian-Yi Su, “Determination of minimum and maximum capacitances of an isolated SEIG using eigenvalue sensitivity approach,” IEEE POWERCON., vol. 1, pp. 610 – 614, Aug. 1998.
[17] T. F. Chan, “Capacitive requirements of self-excited induction generators,” IEEE Trans. Energy Conversion, vol. 8, pp. 304–311, June 1993.



10.22214/IJRASET

45.98

IMPACT FACTOR: 7.129

IMPACT FACTOR: 7.429

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY