



Induction Generator: Excitation & Voltage Regulation

A.C. Joshi¹, Dr. M.S. Chavan²

Lecturer, Department of Electrical Engg, ADCET, Ashta¹

Professor, Department of Electronics Engg, KIT, Kolhapur²

Abstract: Induction generators are increasingly being used in nonconventional energy systems such as wind, micro/mini hydro, etc. The advantages of using an induction generator instead of alternator are reduced cost and size, ruggedness, brushless (squirrel cage) construction, absence of separate dc source, ease of maintenance, inherent overloads and short circuit protection, etc. In isolated systems, squirrel cage induction generators with capacitor excitation, known as self-excited induction generators (SEIGs), are very popular. This paper discusses the overview of induction generator and reviews the voltage regulation techniques used for self excited induction generator.

Keywords: self-excited induction generators (SEIGs), ruggedness, squirrel cage construction, Induction Generator.

I. INTRODUCTION

Power generation becomes more increasingly popular due to the high energy costs. An induction generator is an induction motor operating above its synchronous speed. Due to its simple construction and low cost, the induction generator is well-suited for many industrial cogeneration applications. Also a past few years are experiencing an increased emphasis on renewable energy sources such as wind, mini/micro-hydro, solar, tidal etc. An increasing rate of the depletion of conventional energy sources and the degradation of environmental conditions has given rise to an increased emphasis on renewable energy sources, particularly after the increases in fuel prices. The conventional generating stations use alternator to convert mechanical energy into electrical energy. However use of an induction machine as an induction generator has attracted researchers to use it for renewable sources due to their inherent advantages. Poor voltage regulation under varying speed and load are the major drawbacks of the induction generators. [1, 2, 3]

II. INDUCTION GENERATOR: A REVIEW

Constructionally, an induction generator is nothing but an induction motor. It is made to act as a generator by providing mechanical motion through external prime mover (turbine) and the necessary excitation. When the rotor speed of induction machine is greater than the synchronous speed of air gap revolving field, then the same induction machine can be act as induction generator. [BLT]

Excitation of Induction Generator:

As a generator, induction machine has severe limitations. Because it lacks a separate dc field current, an induction generator needs ac excitation current. There are two ways to provide this required AC excitation as

- 1) Grid Excitation
- 2) Self Excitation – capacitor excitation

The excitation configurations of squirrel cage induction machine are discussed.

Grid Excitation:

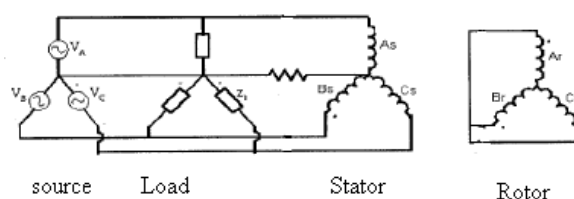


Fig 1 grid excited induction generator (equivalent circuit)



The fig 1 shows grid excitation of induction generator where, the stator windings are directly connected to the grid along with the load. When such a machine is driven above synchronous speed, it will function as a generator and supply electrical energy to the power system. The machine still requires reactive power from the ac power source to the stator windings to establish the stator rotating magnetic field. However, since the rotor is now driven above its synchronous speed, its motion relative to the stator field is in an opposite direction to that for motor operation, and the induced rotor currents and magnetic field interactions are reversed. As a result, energy is transferred from the rotor to the stator and real power flows from the stator to the connected AC power system. [4]

Self Excitation:

If an appropriate capacitor is connected across the terminals of an externally driven induction machine as shown in fig.2 an EMF is induced in the machine winding to the excitation provided by the capacitor. Induced voltage and current will continue to rise until the VAR supplied by the capacitors is balanced by the VAR demanded by the machine, a condition that is essentially divided by the saturation of the magnetic circuit.

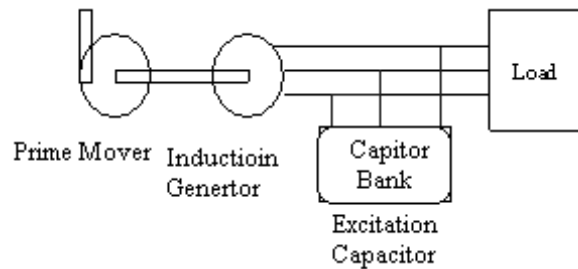


Fig 2 Self Excited induction generator

The magnetizing current required by an induction machine as a function of terminal voltage can be found by running as a motor at no load and measuring its armature current as a function of no load terminal voltage and the magnetizing curve. The point of intersection between the magnetization curve and capacitors voltage ampere characteristic represents a condition of stable self execution and defines the corresponding no load terminal voltage and exciting current.

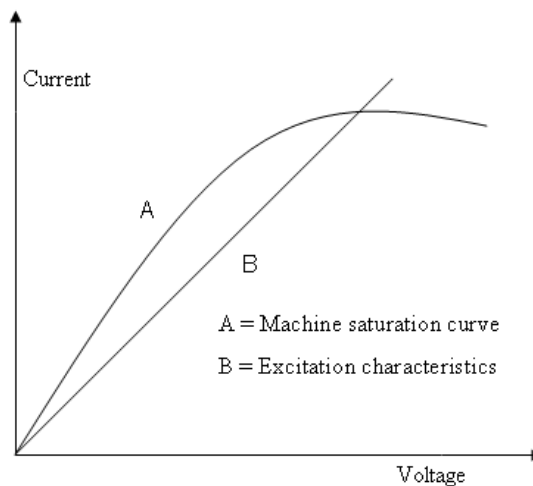


Fig 3 no load magnetization curve

There exists number of motor – capacitor configurations for self excitation. Some of them are:

- 1) Star – start
- 2) Star – delta
- 3) Delta – delta
- 4) Delta – star
- 5) C – 2C
- 6) Single capacitor excitation
- 7) Series capacitor excitation



The use of either of the above depends on the demands of the site. However all above self excitation schemes suffers from inherent drawback of poor terminal voltage regulation.

As the induction generator is started loading, the VAR demanded increases. Hence it is necessary to provide the adjustable excitation to facilitate the demand. Also as load increases, the speed of the machine drops down which is a point to be noted while using self excited induction generators because, below a certain speed induction generators cannot be self excited. Another point to be considered here is that induction generator should not be over excited since active power is generated only at the consumption of reactive power and the machine's winding are designed for a specific rating. If reactive power is increased, then the generated output active power has to be sacrificed.

III. VOLTAGE REGULATION TECHNIQUES

Some of the basic techniques for voltage regulation of self excited induction generators are discussed in the following subsection.

Series Capacitor Scheme

In series capacitor scheme, a capacitor of suitable value is connected in series with the load such that capacitor VAR increases with the load.

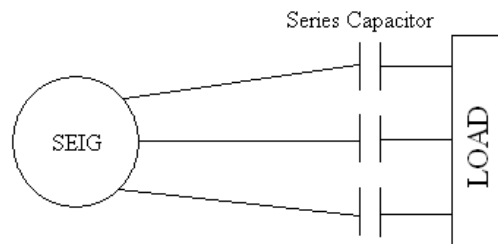


Fig 4 series capacitor scheme

The schematic is shown in fig 4. The main drawback of this method is that, as the load increases, the voltage dip also increases. This method suffers from sub-synchronous resonance which is supplying the power to the inductive & dynamic load. In practice, series capacitors are used for the variation of reactive current. Hence, to compensate the reactive component of the power, capacitors are connected in series with the load.

Switched Capacitor Controller

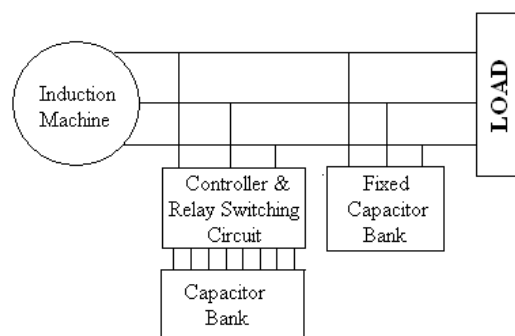


Fig 5 Switched capacitor controller

In switched capacitor controller, a fixed capacitor bank sufficient to excite the induction generator at rated speed and no load condition is permanently connected across the machine terminals. As shown in fig 5, it also uses another capacitor bank so as to excite the induction generator with various capacitor values under varying load conditions. Variable lagging VAR's are generated by switching ON the additional capacitors in discrete steps. The capacitors are binary weighted ($1\mu\text{F}$, $2\mu\text{F}$, $4\mu\text{F}$...) to minimize the number of switches required to produce a given range of capacitance. As each capacitor is switched on for an integral numbers of cycles only, the harmonic distortion production is eliminated. But this scheme produced harmonics at lower frequencies to the fundamental.



The above two methods find limited applications because it regulates the terminal voltage in discrete steps.

Inductively Loaded AC/DC Converter

This scheme uses a capacitors & inductors with thyristor switches. The fixed capacitor bank corresponds to full load and the current in the inductors I is varied by a solid state control scheme. Naturally commutated converters are able to draw only lagging VAR (i.e. Supply only leading VAR) in this case lagging VAR, as required by an induction generates are obtained by adding fixed capacitors across the converter terminals. The net lagging VAR may be controlled by continuous adjustment of the fixing angle of the controllers. This method is one of the simplest static arrangements for drawing controllers lagging reactive current. This method faces the problems of weight losses in inductors and also introduce considerable amount of harmonic distortion into the ac system.

Thyristor controlled inductors with fixed capacitor bank

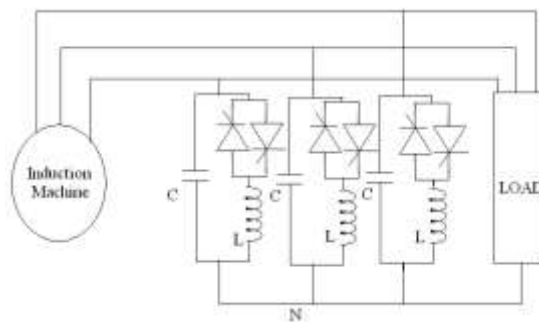


Fig 6 thyristor controlled inductors with fixed capacitor

This scheme consists of fixed a capacitor in parallel with inductor. The inductor is fed through an anti parallel thyristor pair as shown in fig 6. The variation in fixing angle results in drawing the lagging current. This confined with fixed capacitors provides variable leading VAR which can be controlled by controlling the firing angle of the thyristors. The control range of static voltage controller was found to be limited.

Voltage control using STATCOM

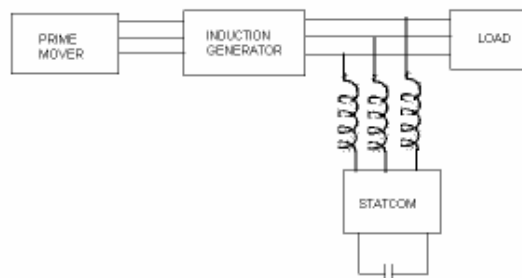


Fig 7 Voltage control using STATCOM

In this scheme, fixed excitation capacitors are selected to generate the rated voltage of SEIG at no load. STATCOM can be connected to the SEIG for meeting reactive current demand with change in load. The STATCOM consists of a VSI (voltage source inverter), DC bus capacitor and AC inductors. The AC output of the inverter is connected through the AC filtering inductor to the SEIG terminals. The DC bus capacitor is used as energy storage device and provides self-supporting DC bus.

Voltage source converter can be connected to ac mains to provide reactive power. It can be built using either thyristor or self-commutation device like IGBT. For purely reactive power flow, the inverter voltages should be in phase with system terminal voltages of SEIG. By increasing the amplitude of the inverter voltage above system voltage, leading currents can be drawn from the ac system. Whereas by decreasing the inverter voltage below the ac system voltage, lagging current can be drawn from the mains. Thus by controlling the amplitude of the inverter voltage, the reactive power can be controlled from fully leading to full lagging. The inverter can be supplied from a separated dc source or an appropriately dimensioned capacitor bank with inverter voltage slightly lagging with respect to the ac system voltage



Electronic Load Cell Controller

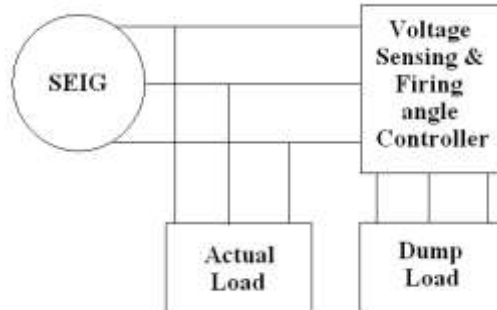


Fig 8 Electronic load cell controller

The efficiency of any machine is found to be at maximum at a single non differentiable point which is obtained from a typical load versus efficiency curve. This scheme uses this feature of induction generator. The output power of SEIG is maintained constant independent of consumer (actual) load. It uses a dump load (or a proxy load) to facilitate the scheme. Here, as the consumer switches ON his load, the corresponding dump load is switched OFF by changing the firing angle and the total load on the induction generator is maintained constant.

IV. CONCLUSION

By taking the review of the above discussed voltage regulation techniques for self excited induction generator, it is seen that the voltage regulation techniques are broadly dependent upon the site where they are used and also there is still a scope for research in this field as there is yet to develop a site independent controller for voltage regulation in SEIG

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