EE3014 POWER ELECTRONICS FOR RENEWABLE ENERGY SYSTEMS

UNIT II

ELECTRICAL MACHINES FOR WIND ENERGY CONVERSION

2.2 - IG

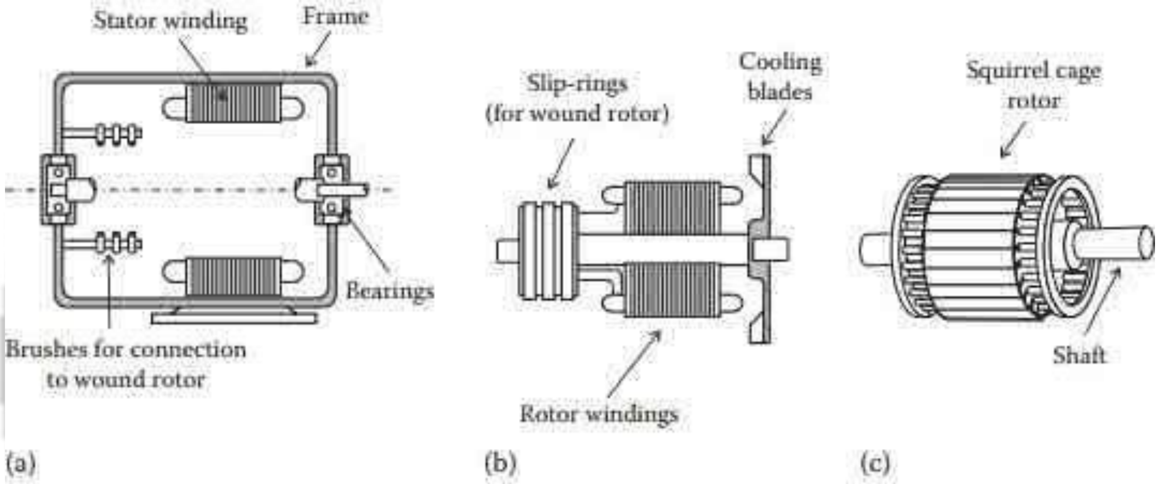
INDUCTION GENERATORS (IG)

Introduction

An induction generator or asynchronous generator is a type of alternating current (AC) electrical generator that uses the principles of induction motors to produce power. Induction generators operate by mechanically turning their rotors faster than synchronous speed. A regular AC asynchronous motor usually can be used as a generator, without any internal modifications. Induction generators are useful in applications such as mini hydro power plants, wind turbines, or in reducing high-pressure gas streams to lower pressure, because they can recover energy with relatively simple controls. An induction generator usually draws its excitation power from an electrical grid; sometimes, however, they are self-excited by using phase-correcting capacitors. Because of this, induction generators cannot usually "black start" a de-energized distribution system. Induction Generator construction is based on the very common squirrel-cage induction motor type machine as they are cheap, reliable, and readily available in a wide range of electrical sizes from fractional horse power machines to multi-megawatt capacities making them ideal for use in both domestic and commercial renewable energy wind power applications.

Induction generator is not a self excited machine therefore in order to develop the rotating magnetic field, it requires magnetizing current and reactive power. The induction generator obtains its magnetizing current and reactive power from the various sources like the supply mains or it may be another synchronous generator. The induction generator can‘t work in isolation because it continuously requires reactive power from the supply system. However we can have a self excited or isolated induction generation in one case if we will use capacitorbank for reactive power supply instead of AC supply system.

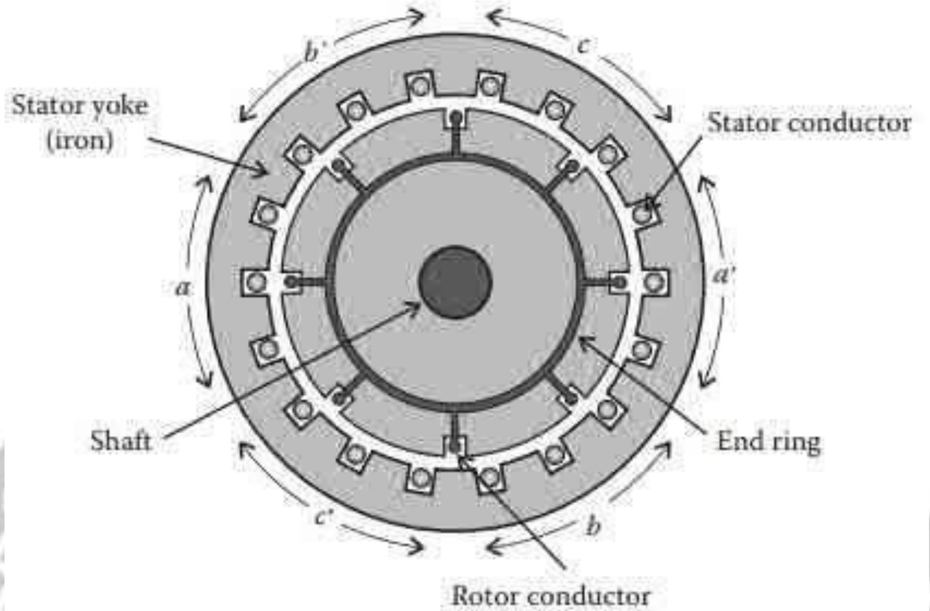
Construction



Induction machine longitudinal cut: (a) stator, (b) wound rotor, and (c) cage rotor

An induction generator is made up of two major components: the stator, which consistsof steel laminations mounted on a frame so that slots are formed on the inside diameter of the assembly as in a synchronous machine, and the rotor, which consists of a structure of steel laminations mounted on a shaft with two possible configurations:

Wound rotor or cage rotor. Figure shows a schematic cut along the longitudinal axis of a typical wound-rotor induction machine. Figure (a) shows the external case with the stator yoke internally providing the magnetic path for the three-phase stator circuits. Bearings provide mechanical support for the shaft clearance (the air gap) between the rotor and stator cores. For a wound rotor, a group of brush holders and carbon brushes, indicated on the left side of Figure (a), allow for connection to the rotor windings. A schematic diagram of a wound rotor is shown in Figure (b). The winding of the wound rotor is of the three-phase type with the same number of poles as the stator, generally connected in Y.



Cross-sectional cut for an induction machine

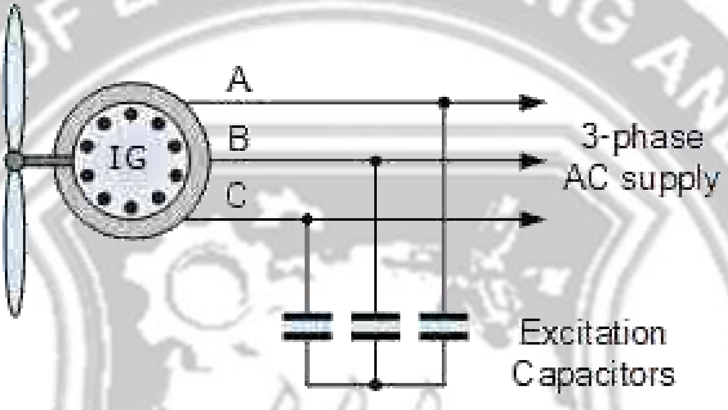
Three terminal leads are connected to the slip rings by means of carbon brushes. Wound rotors are usually available for very large power machines (>500 kW). External converters in the rotor circuit, rated with slip power, control the secondary currents providing the rated frequency at the stator. For most medium power applications, squirrel cage rotors, as in Figure (c), are used. Squirrel cage rotor windings consist of solid bars of conducting material embedded in the rotor slots and shorted at the two ends by conducting rings. In large machines, the rotor bars may be of copper alloy brazed to the end rings. Rotors sized up to about 20 inches in diameter are usually stacked in a mold made by aluminum casting, enabling a very economical structure combining the rotor bars, end rings, and cooling fan. Figure shows a cross-sectional cut indicating the distributed windings for three-phase stator excitation. Each winding (a, b, or c) occupies the contiguous slots within a 120° spatial distribution.

The stator: It is built up from silicon steel laminations punched and assembled so that it has a number of uniformly spaced identical slots, in integral multiples of six (such as 48 or 72 slots), roughly parallel to the machine shaft. Sometimes, the slots are slightly twisted or skewedin relation to the longitudinal axis, to reduce cogging torque, noise, and vibration, and to smooth up the generated voltage. Machines up to a few hundreds of KW rating and low voltage have semi closed slots, while larger machines with medium voltage have open slots.

Off-grid Induction Generator

We have seen above that an induction generator requires the stator to be magnetized from the utility grid before it can generate electricity. But you can also run an induction generator in a stand alone, off-grid system by supplying the necessary out-of-phase exciting or magnetizing current from excitation capacitors connected across the stator terminals of the machine. This also requires that there is some residual magnetism in the rotors iron laminations when you start the turbine. The excitation capacitors are shown in a star (wye) connection but can also be connected a delta (triangular) arrangement.

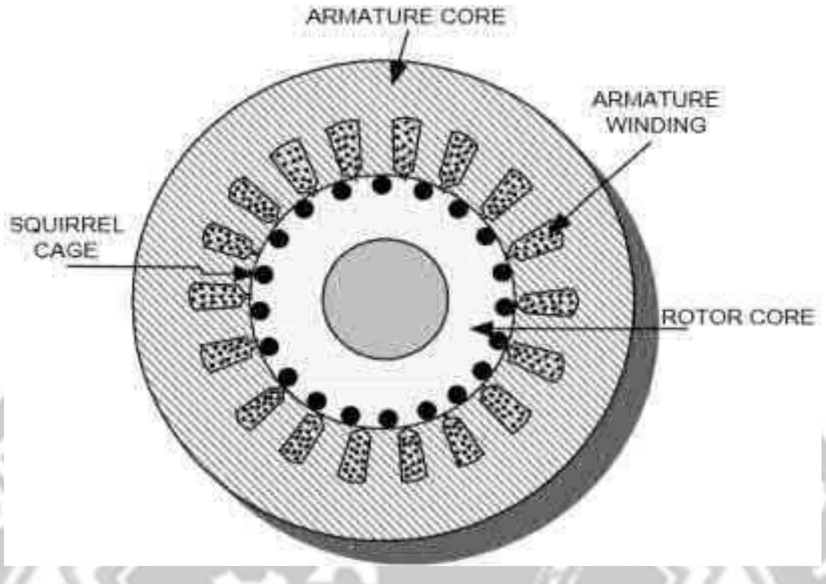
Capacitor Start Induction Generator



Capacitor Start Induction Generator

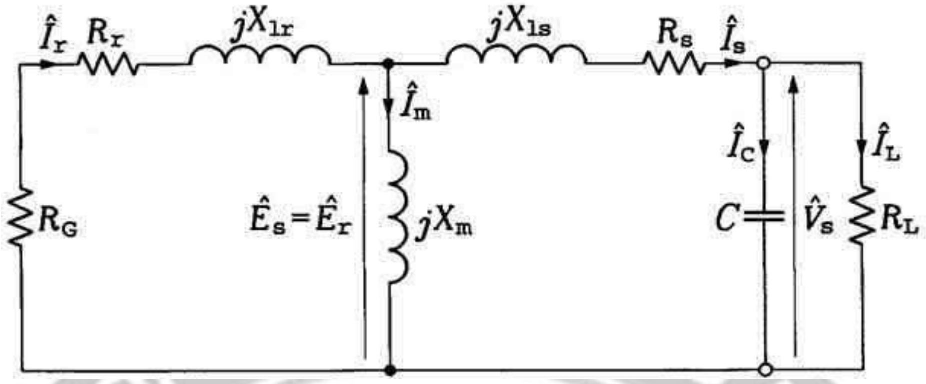
The excitation capacitors are standard motor-starting capacitors that are used to provide the required reactive power for excitation which would otherwise be supplied by the utility grid. The induction generator will self-excite using these external capacitors only if the rotor has sufficient residual magnetism. In the self-excited mode, the generator output frequency and voltage are affected by the rotational speed, the turbine load, and the capacitance value in farads of the capacitors. Then in order for self-excitation of the generator to occur, there needs to be a minimum rotational speed for the value of capacitance used across the stator windings. The –Self-excited induction generator‖, (SEIG) is a good candidate for wind powered electric generation applications especially in variable wind speed and remote areas, because they do not need external power supply to produce the magnetic field. A three-phase induction generator can be converted into a variable speed single-phase induction generator by connecting two excitation capacitors across the three-phase windings. One of value C amount of capacitance on one phase and the other of value 2C amount of capacitance across the other phase.

Principle of operation



An induction generator produces electrical power when its rotor is turned faster than the synchronous speed. For a typical four-pole motor (two pairs of poles on stator) operating ona 60 Hz electrical grid, the synchronous speed is 1800 rotations per minute (rpm). The same four-pole motor operating on a 50 Hz grid will have a synchronous speed of 1500 RPM. The motor normally turns slightly slower than the synchronous speed; the difference between synchronous and operating speed is called "slip" and is usually expressed as per cent of the synchronous speed. For example, a motor operating at 1450 RPM that has a synchronous speed of 1500 RPM is running at a slip of +3.3%. In normal motor operation, the stator flux rotation is faster than the rotor rotation. This causes the stator flux to induce rotor currents, which create a rotor flux with magnetic polarity opposite to stator. In this way, the rotor is dragged along behind stator flux, with the currents in the rotor induced at the slip frequency. In generator operation, a prime mover (turbine or engine) drives the rotor above the synchronous speed (negative slip). The stator flux still induces currents in the rotor, but since the opposing rotor flux is now cutting the stator coils, an active current is produced in stator coils and the motornow operates as a generator, sending power back to the electrical grid.

Excitation



Per-phase equivalent circuit of the stand-alone induction generator

An induction machine requires externally supplied armature current. Because the rotor field always lags behind the stator field, the induction machine always "consumes" reactive power, regardless of whether it is operating as a generator or a motor. A source of excitation current for magnetizing flux (reactive power) for the stator is still required, to induce rotor current. This can be supplied from the electrical grid or, once it starts producing power, from the generator itself. An induction machine can be started by charging the capacitors, with a DC source, while the generator is turning typically at or above generating speeds. Once the DC source is removed the capacitors will provide the magnetization current required beginning producing voltage. An induction machine that has recently been operating may also spontaneously produce voltage and current due to residual magnetism left in the core.

Active power

Active power delivered to the line is proportional to slip above the synchronous speed. Full rated power of the generator is reached at very small slip values (motor dependent, typically 3%). At synchronous speed of 1800 rpm, generator will produce no power. When the driving speed is increased to 1860 rpm (typical example), full output power is produced. If the prime mover is unable to produce enough power to fully drive the generator, speed will remain somewhere between 1800 and 1860 rpm range.

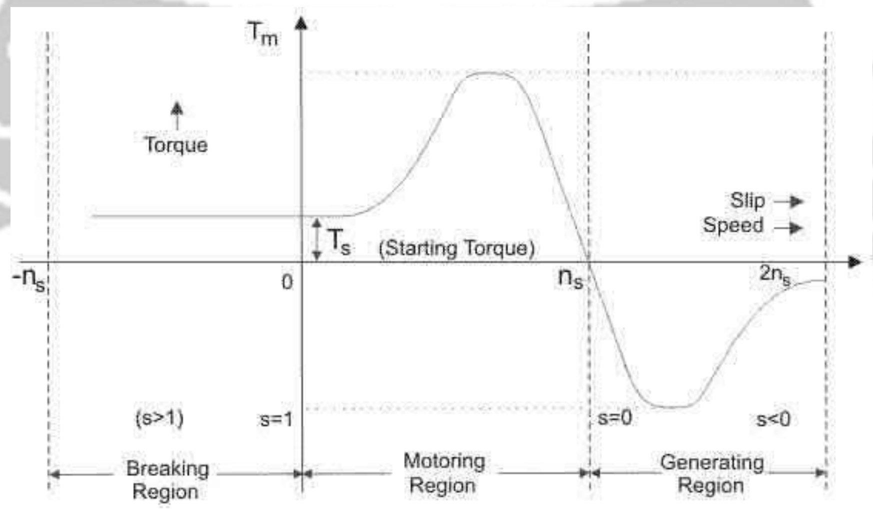
Required capacitance

A capacitor bank must supply reactive power to the motor when used in stand-alone mode. The reactive power supplied should be equal or greater than the reactive power that the machine normally draws when operating as a motor. Consider, an AC supply is connected to the stator terminals of an induction machine. Rotating magnetic field produced in the stator pulls the rotor to run behind it (the machine is acting as a motor). Now, if the rotor is accelerated to the synchronous speed by means of a prime mover, the slip will be zero and hence the net torquewill be zero. The rotor current will become zero when the rotor is running at synchronous speed.

If the rotor is made to rotate at a speed more than the synchronous speed, the slip becomes negative. A rotor current is generated in the opposite direction, due to the rotor conductors cutting stator magnetic field. This generated rotor current produces a rotating magnetic field in the rotor which pushes (forces in opposite way) onto the stator field. This causes a stator voltage which pushes current flowing out of the stator winding against the applied voltage. Thus, the machine is now working as an induction generator (asynchronous generator).

Torque-Slip characteristics

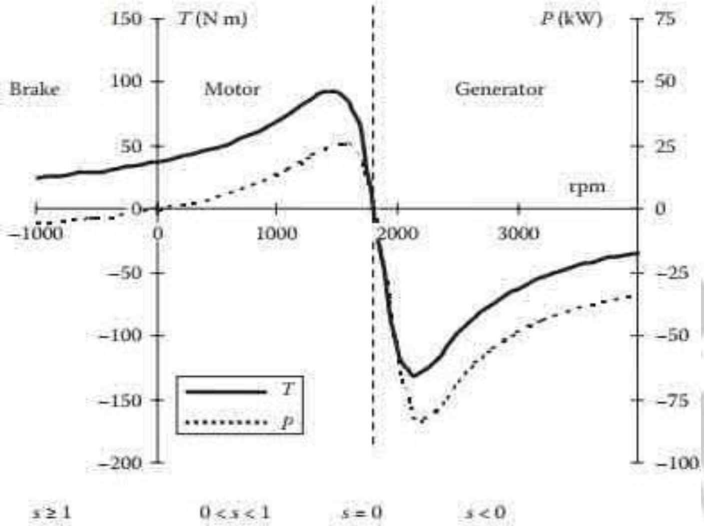
The basic fundamental of induction generators is the conversion between mechanical energy to electrical energy. This requires an external torque applied to the rotor to turn it faster than the synchronous speed. However, indefinitely increasing torque doesn't lead to an indefinite increase in power generation. The rotating magnetic



field torque excited from the armature works to counter the motion of the rotor and prevent over speed because of induced motion inthe opposite direction.

As the speed of the motor increases the counter torque reaches a max value of torque (breakdown torque) that it can operate until before the operating conditions become unstable. Ideally, induction generators work best in the stable region between the no-load condition and maximum torque region.

Torque–Speed characteristics



It can be observed that there is no torque at the synchronous speed. Both the torque– speed and the power–speed curves are almost linear since from no load to full load the machine‘s rotor resistance is much larger than its reactance. The resistance is predominant in this range, current and the rotor field as well as the induced torque increase almost linearly with the increase of the slip factors. The rotor torque varies as the square of the voltage across the terminals of the generator if the speed slows down close to the synchronous speed, the generator motorizes that is, it works as a motor; as we will show, the generated power has a maximum value for a given current drained from the generator in the same way, there is a maximum possible induced generator torque called pullout or breakdown torque, and from this torque value on, there will be over speed. The peak power supplied by the IG happens at a speed slightly different from the maximum torque, and, naturally, no electric power is converted into mechanical power when the rotor is at rest (zero speed). In the same way, in spite of the same rotation, the frequency of the IG varies with the load variation.

HIGH-EFFICIENCY INDUCTION GENERATOR

A high-efficiency induction generator is commercially available as a high-efficiency induction motor, except for some peculiarities. Therefore, the same care must be taken in design, materials selection, and manufacturing processes for building a high-efficiency generator. The main advantages of the high-efficiency induction generator compared with the conventional induction generator are better voltage regulation, less loss of efficiency. Steady-state model of Induction Generators with smaller loads, less over sizing when generators of lower power cannot be used, reduced internal losses, and, therefore, lower temperatures, less internal electric and mechanical stress, and, thus, increased useful life.

The constraints are the need for larger capacitors for self-excitation. High-efficiency induction generators should not be used for self-excited applications. The efficiency of the high- efficiency generator compared with the standard ones differs by more than about 10% for small power ratings (up to 50 kW) and about 2% for higher powers (above 100 kW). It is therefore highly recommended for micro power plants. Rated efficiencies are normalized, and they should have guaranteed minimum values stated by the manufacturer on the plate of the machine for each combination of power versus synchronous speed. High-efficiency generators are better suited to stand the harmful effects of the harmonic generated by nonlinear loads (power converters) because they have higher thermal margin and smaller losses.