INDUCTION GENERATOR

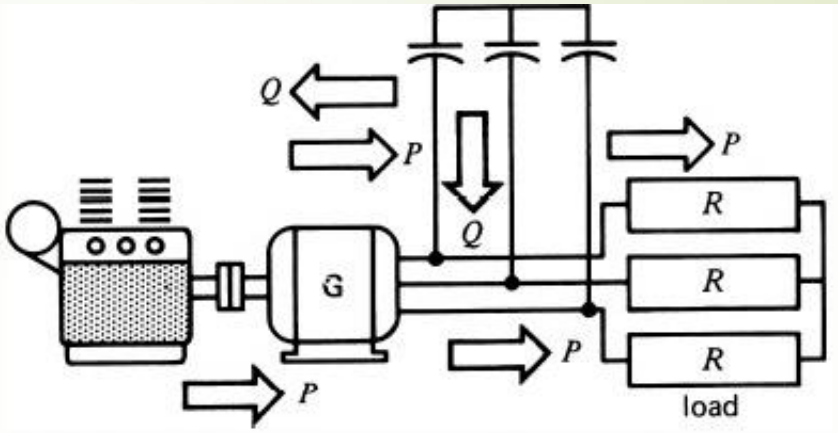
- Induction motor operating as a generator
  - consider a frictionless vehicle powered by a squirrel-cage induction motor that is directly coupled to the wheels
  - as the vehicle climbs a hill, the motor runs at slightly less than synchronous speed, delivering a torque sufficient to overcome the force of gravity
    - electric energy converts to kinetic energy then potential energy
  - at the top of the hill or on level ground, the force of gravity does not come into play and the motor runs unloaded and very close to synchronous speed
  - as the vehicle descends a hill, the motor runs slightly faster than synchronous speed and develops a counter torque that opposes the increase in speed
    - potential energy converts to kinetic energy then electric energy

INDUCTION GENERATOR- Operation

- In generator operation
  - the rotor spins above synchronous speed
  - it develops a counter-torque that opposes the over speed
    - same effect as a brake
  - the rotor returned the power as electrical energy instead of dissipating it as heat
    - referred to as asynchronous generation
    - kinetic energy is converted into electrical energy
  - the motor delivers active power to the electrical system
  - the electrical system must provide reactive power to create the stator's rotating magnetic field
- Active power delivered to the line is directly proportional to the slip
  - higher engine speed produces greater electrical output
  - rated output power is reached at very small slips, $|s| < 3\%$

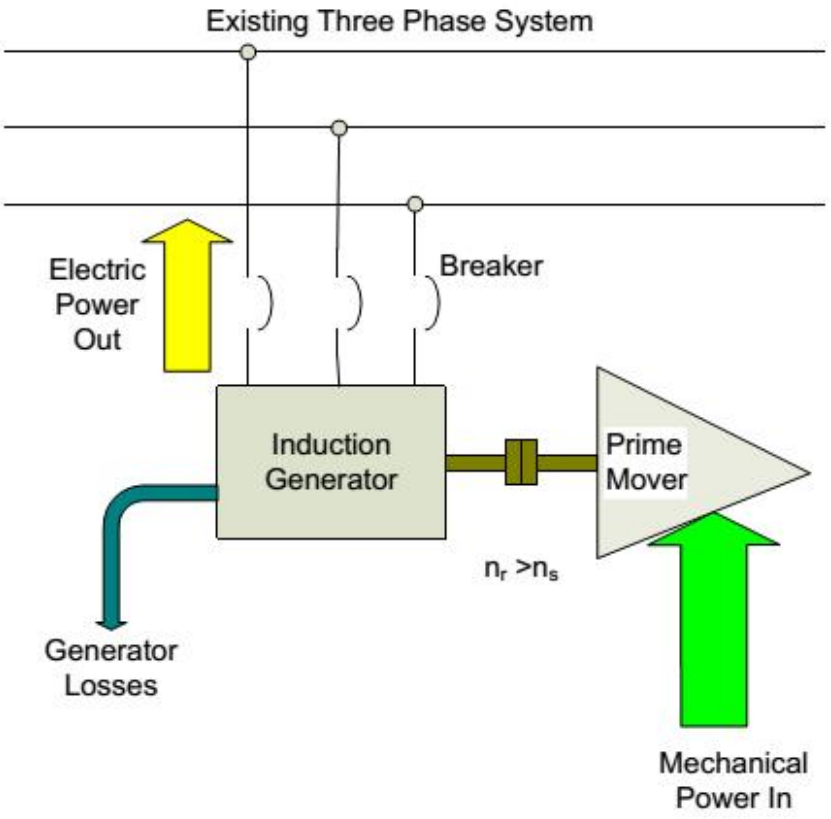
INDUCTION GENERATOR- Operation

- Reactive power sources
  - capacitors across the motor terminals may supply the vars
    - the motor supplies 3-phase electrical loads without an external 3-phase source



- the frequency generated is slightly less than corresponding to the speed of rotation
- the terminal voltage increases with capacitance, but limit by iron saturation
- insufficient capacitance causes the voltage not to build up
  - capacitors must supply at least the vars normally absorbed when the machine operates as a motor

INDUCTION GENERATOR- Starting Sequence



1.) Breaker open
2.) Increase prime mover mechanical power input until $n_r > n_s$.
3.) Close Breaker
4.) Adjust mechanical power input to match electric load.

$P_{mech} = P_e + P_{loss}$

Induction generator can not vary terminal voltage or frequency. Set by system.

INDUCTION GENERATOR- Equivalent Circuit

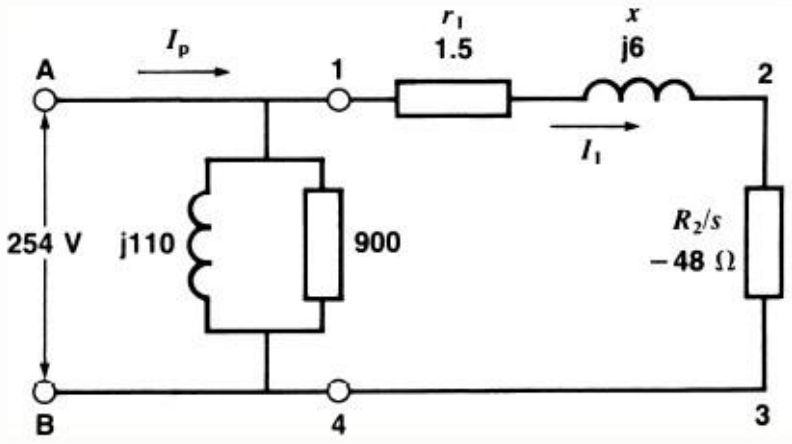
- When an induction motor is driven above synchronous speed, the slip becomes negative

$$s = \frac{(n_s - n)}{n_s} \qquad n > n_s \Rightarrow s < 0$$

  - the value of R_2/s also becomes negative

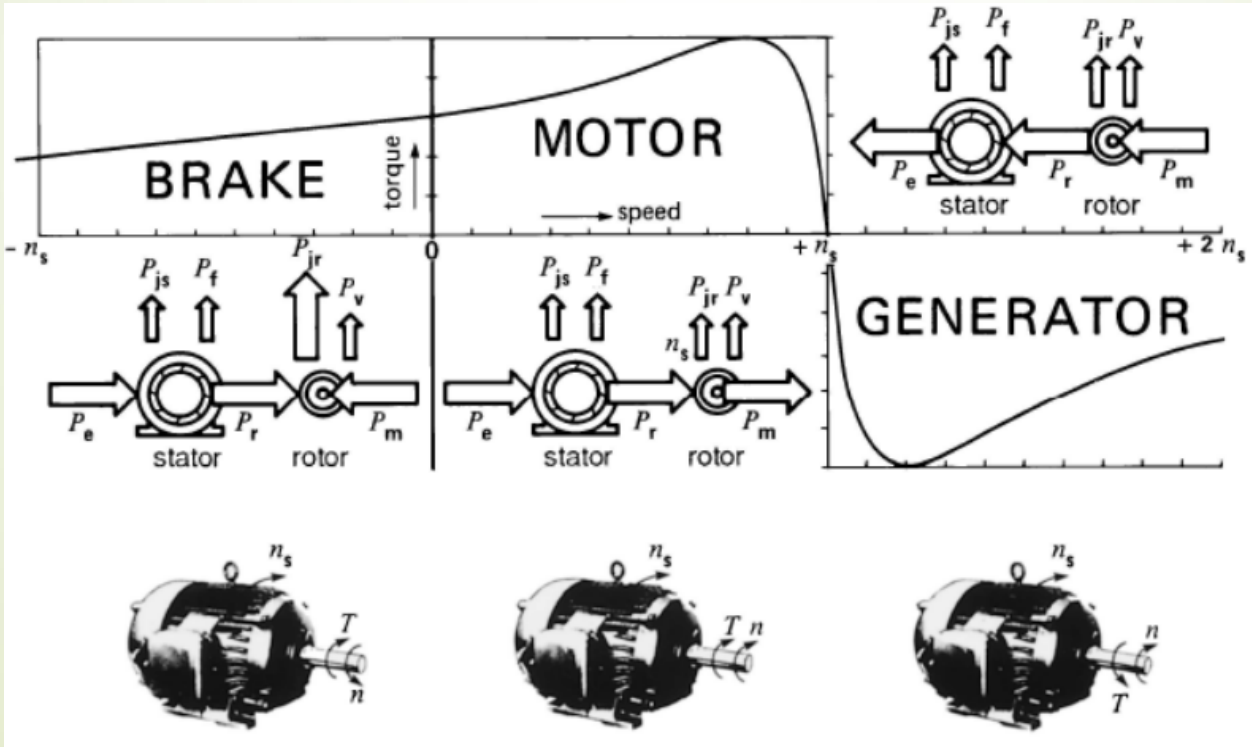
$$P_r = I_2^2 \frac{R_2}{s} \qquad s < 0 \Rightarrow P_r < 0$$

    - the negative resistance indicates that power is flowing from the rotor to the stator



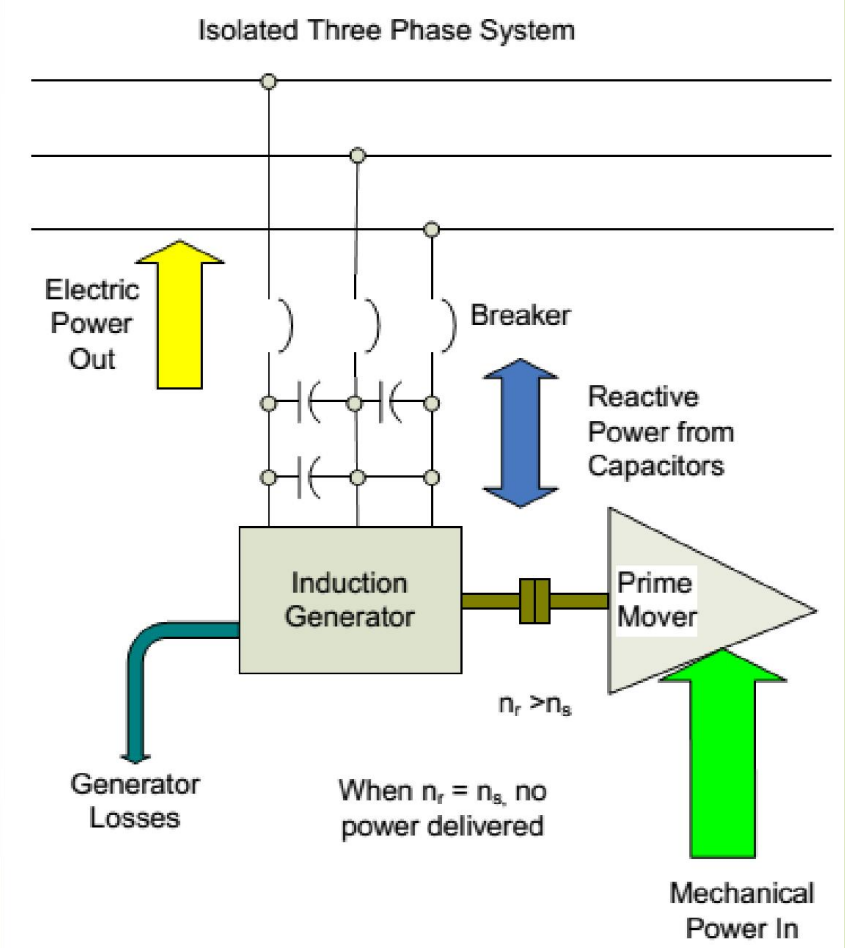
INDUCTION GENERATOR- Torque- Speed Characteristics

- In Induction machine
  - Can function as a motor, a brake, and a synchronous motor
    - All three operating modes can be seen from the torque-speed curve.



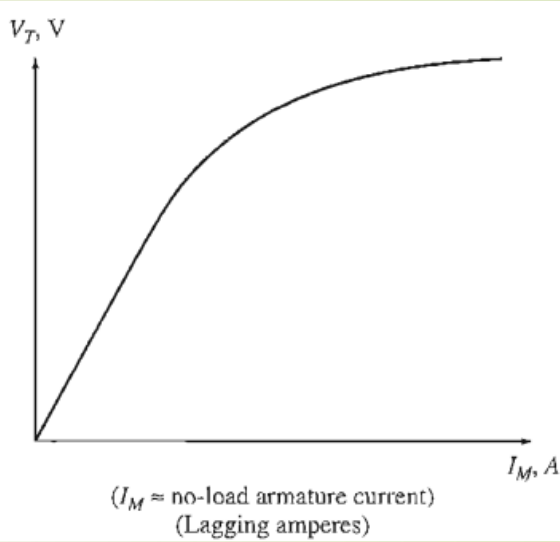
INDUCTION GENERATOR- Operating Alone

- It is also possible for an induction machine to function as an isolated generator, independent of any power system, as long as capacitors are available to supply the reactive power required by the generator and by any attached loads.

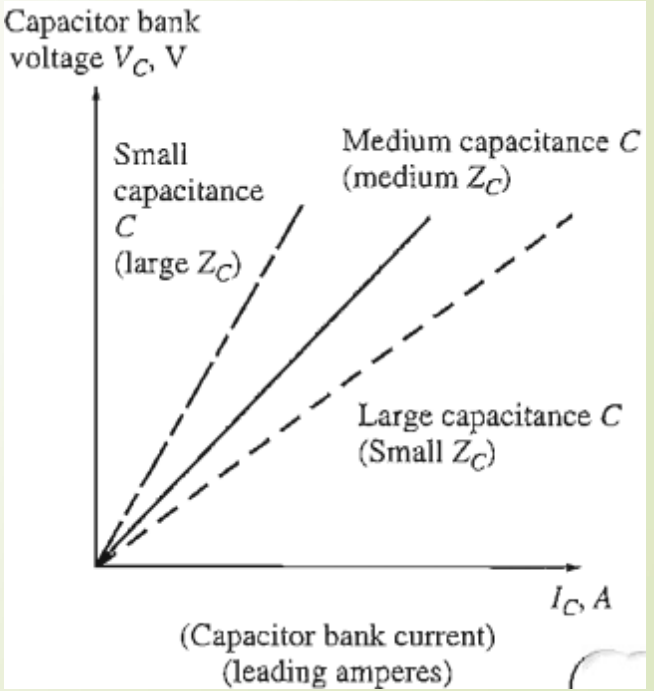


INDUCTION GENERATOR- Operating Alone

- The magnetizing current I_M required by an induction machine as a function of terminal voltage can be found by running the machine as a motor at no load and measuring its armature current as a function of terminal voltage.



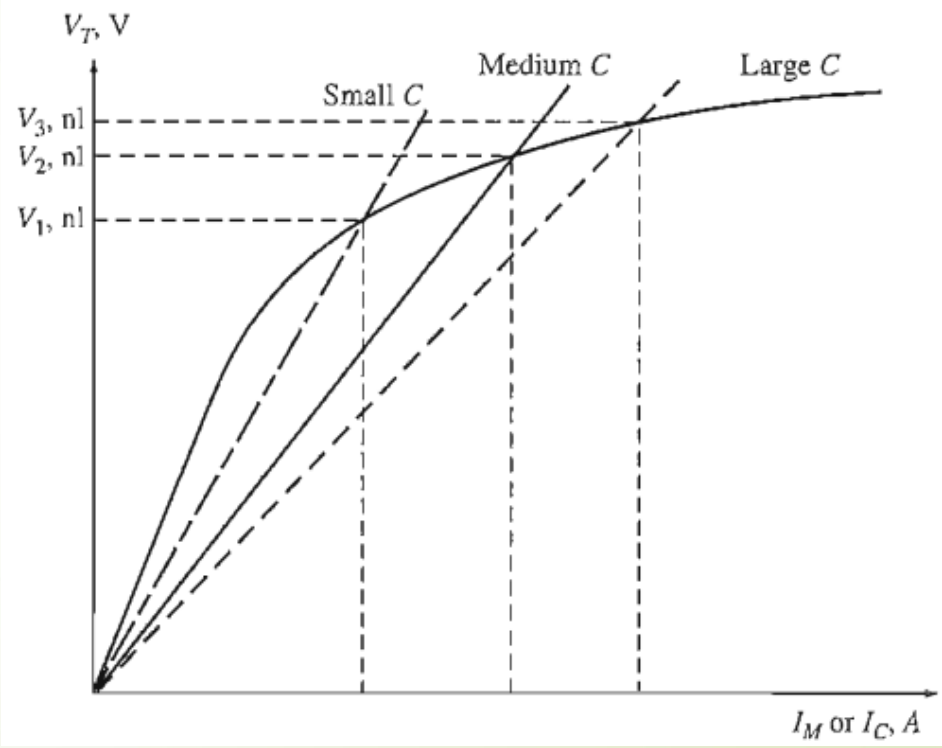
- The reactive current that a capacitor can produce is directly proportional to the voltage applied to it, the locus of all possible combinations of voltage and current through a capacitor is a straight line.



INDUCTION GENERATOR- Operating Alone

- If a three-phase set of capacitors is connected across the terminals of an induction generator, the no-load voltage of the induction generator will be the intersection of the generator's magnetization curve and the capacitor's load line.

How does the voltage build up in an induction generator when it is first started?



INDUCTION GENERATOR- Operating Alone

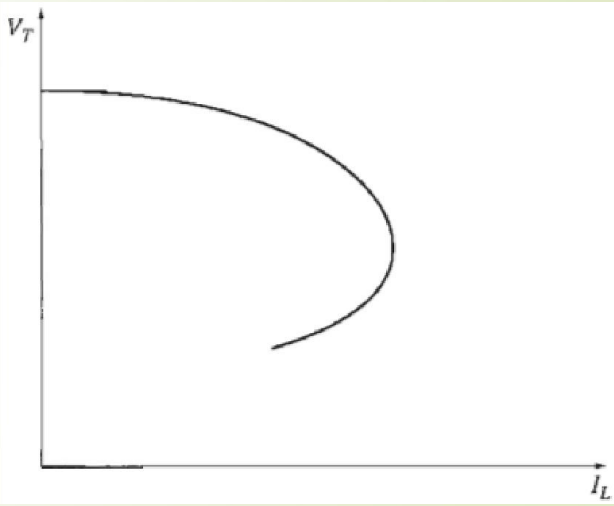
voltage build up

- When an induction generator first starts to turn, the residual magnetism in its field circuit produces a small voltage. That small voltage produces a capacitive current flow, which increases the voltage, further increasing the capacitive current, and so forth until the voltage is fully built up. If no residual flux is present in the induction generator's rotor. then its voltage will not build up, and it must be magnetized by momentarily running it as a motor.
- The most serious problem with an induction generator is that its voltage varies wildly with changes in load, especially reactive load.

INDUCTION GENERATOR- Operating Alone

voltage build up

- Typical terminal characteristics of an induction generator operating alone with a constant parallel capacitance are shown in Figure.
- In the case of inductive loading, the voltage collapses very rapidly. This happens because the fixed capacitors must supply all the reactive power needed by both the load and the generator, and any reactive power diverted to the load moves the generator back along its magnetization curve, causing a major drop in generator Voltage.
- It is therefore very difficult to start an induction motor on a power system supplied by an induction generator.



INDUCTION GENERATOR- Operating Alone

voltage build up

- Because of the nature of the induction machine's torque-speed characteristic, an induction generator's frequency varies with changing loads: but since the torque-speed characteristic is very steep in the normal operating range, the total frequency variation is usually limited to less than 5 percent.
- This amount of variation may be quite acceptable in many isolated or emergency generator applications.

INDUCTION GENERATOR

Since the induction generator is actually an induction motor being driven by a prime mover, it has several advantages.

- **Advantages**

1. It is less expensive and more readily available than a synchronous generator.
2. It does not require a DC field excitation voltage.
3. It automatically synchronizes with the power system, so its controls are simpler and less expensive.

- **Disadvantages**

1. It is not suitable for separate, isolated operation
2. It consumes rather than supplies magnetizing KVAR
3. It cannot contribute to the maintenance of system voltage levels (this is left entirely to the synchronous generators or capacitors)
4. In general it has a lower efficiency.

INDUCTION GENERATOR- Applications

- Wind Turbines,
- Hydraulic Turbines (small scale hydro),
- Gas engines fueled by natural gas or biogas

INDUCTION GENERATOR- Limitations

- Require existing power grid for synchronous operation.
  - Can not control frequency or voltage independently
- Can not operate above pushover speed
- Require a source of reactive power to operate
  - When connect to grid, system supplies reactive power to operate generator
- When operating without grid connection frequency varies with power output.
  - Parallel capacitors supply reactive power