

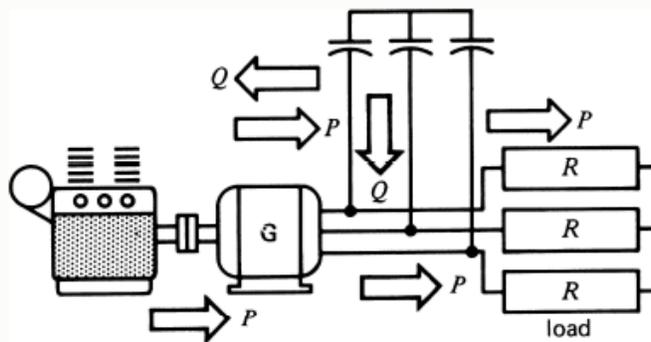
# V. Induction Generators

- 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

## Generator Operation

- In generator operation
  - the rotor spins above synchronous speed
  - it develops a counter-torque that opposes the overspeed
    - 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,  $|s| < 3\%$

- 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



## Generator Equivalent Circuit

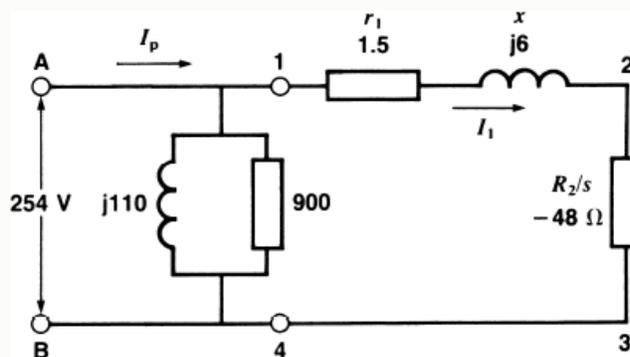
- When an induction motor is driven above synchronous speed, the slip becomes negative

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

- the value of  $R_2/s$  also becomes negative

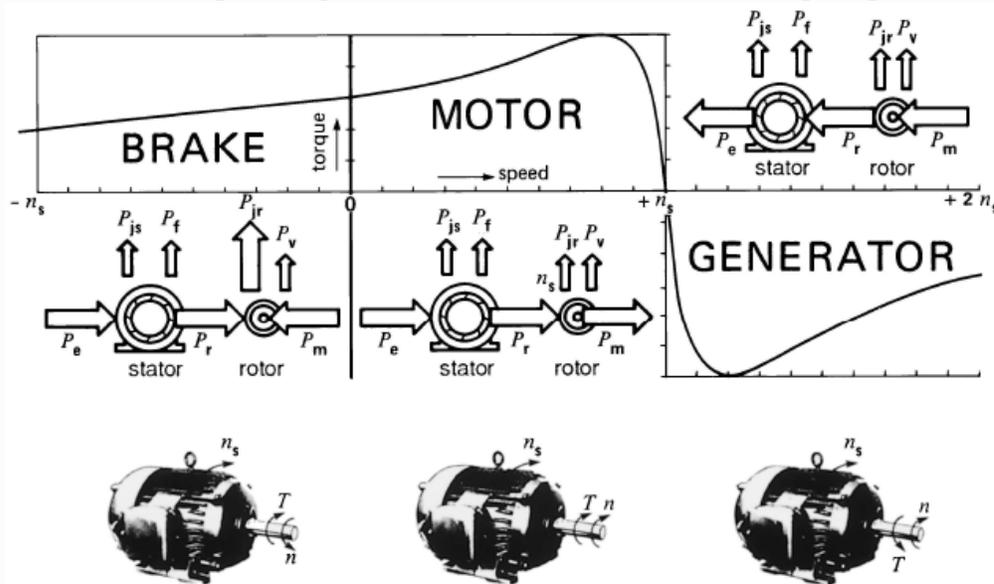
$$P_r = I_2^2 \frac{R_2}{s} \quad s < 0 \Rightarrow P_r < 0$$

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



## Complete Torque-speed Characteristics

- An induction machine
  - can function as a motor, a brake, and an asynchronous motor
    - all three operating modes can be seen from the torque-speed curve



### Comparison of synchronous and induction generators

There are two types of generators available: Synchronous and Induction types.

**Synchronous generators** have the DC field excitation supplied from batteries, DC generators or a rectified AC source. When DC generators are used they may be driven from the AC generator shaft directly or by means of a belt drive or they may be separately driven, independent from the AC generator. In any of the above applications, DC is applied to the field through brushes riding on slip rings attached to the rotor.

Brushless generators use a small AC generator driven directly from the shaft. The AC output is rectified and the DC is applied directly to the main generator field. The exciter generator configuration is reversed from the normal generator in that the armature is rotated with the main generator shaft and the field is fixed. In this way, the AC output can be fed to a rectifier assembly which also rotates and the resulting DC connected directly to the main generator field without brushes or slip rings.

Synchronous generators are rated in accordance with NEMA Standards on a continuous duty basis. The rating is expressed in KVA available at the terminals at 0.80 power factor. The corresponding KW should also be stated. For example, a 400 KW generator would be rated 500 KV A at 0.80 power factor.

**An induction generator** receives its excitation (magnetizing current) from the system to which it is connected. It consumes rather than supplies reactive power (KVAR) and supplies only real power (KW) to the system. The KVAR required by the induction generator plus the KVAR requirements of all other loads on the system must be supplied from synchronous generators or static capacitors on the system.

When a squirrel cage induction motor is energized from a power system and is mechanically driven above its synchronous speed it will deliver power to the system. Operating as a generator at a given percentage slip above synchronous speed, the torque, current, efficiency and power factor will not differ greatly from that when operating as a motor. The same slip below synchronous speed, the shaft torque and electric power flow is reversed. For example, a 3600 RPM squirrel cage induction motor which delivers full load output at 3550 RPM as a motor will deliver full rated power as a generator at 3650 RPM. If the half-load motor speed is 3570 RPM, the output as a generator will be one-half of rated value when driven at 3630 RPM, etc.

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

The principal disadvantages of an induction generator are listed.

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 Application**

- With energy costs so high, energy recovery became an important part of the economics of most industrial processes. The induction generator is ideal for such applications because it requires very little in the way of control system or maintenance.
- Because of their simplicity and small size per kilowatt of output power, induction generators are also favored very strongly for small windmills. Many commercial windmills are designed to operate in parallel with large power systems, supplying a fraction of the customer's total power needs. In such operation, the power system can be relied on for voltage & frequency control, and static capacitors can be used for power-factor correction.