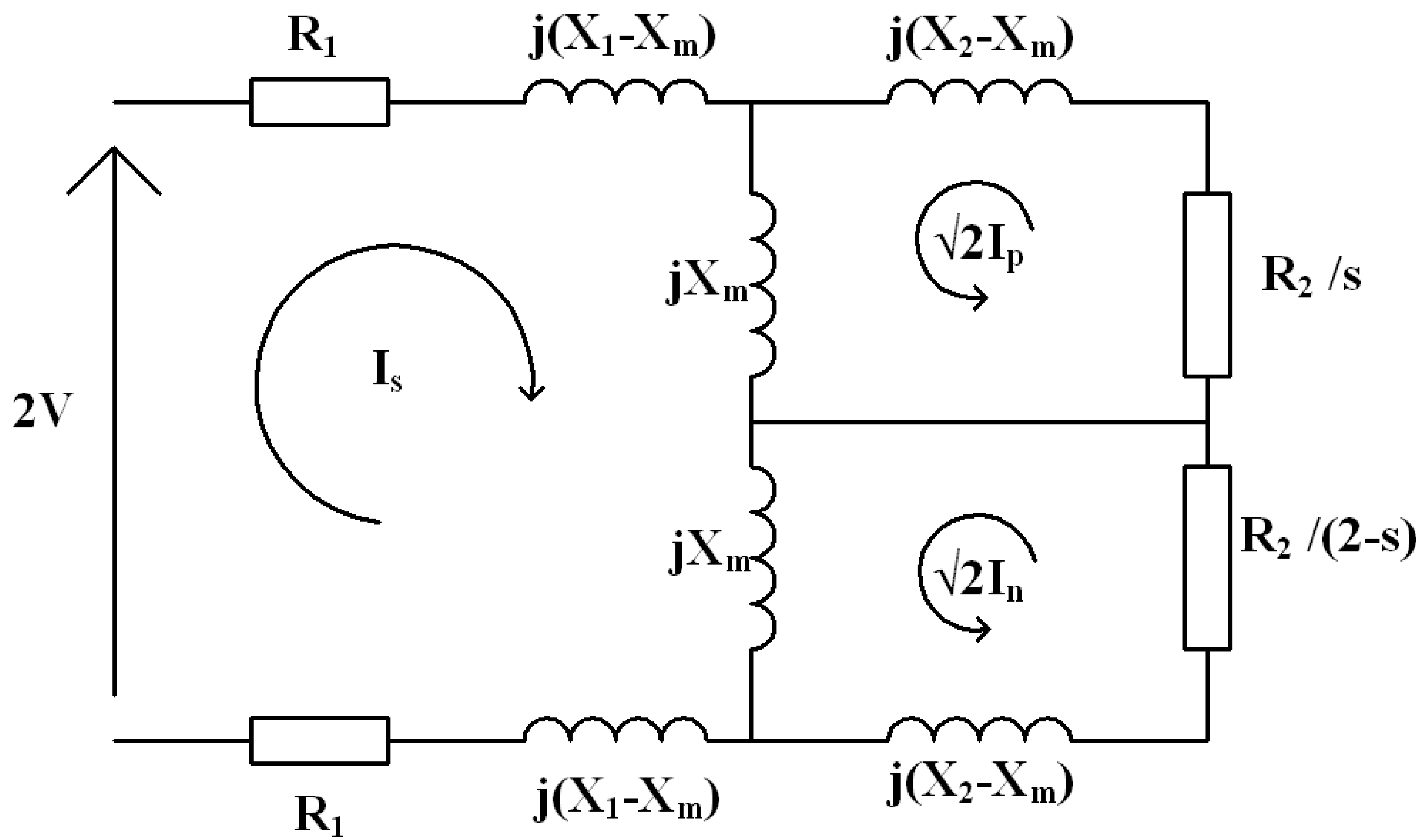
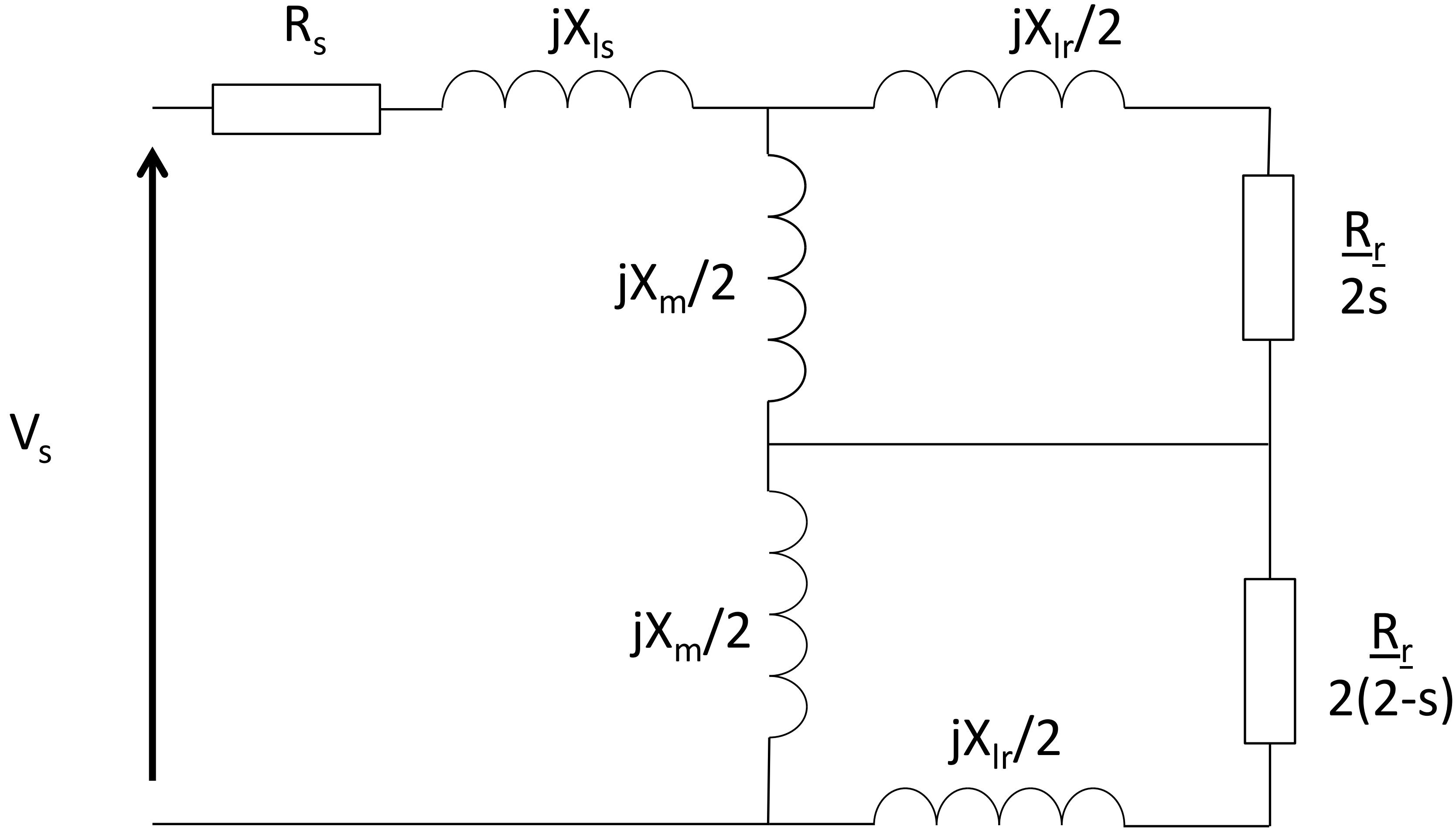
Modelling of machines
Section 11

One equivalent circuit which satisfies these equations is:



The reactances (X_1-X_m) and (X_2-X_m) are in fact the leakage reactances (in effect the difference between self flux and mutual flux) and so the equivalent circuit is often modified to the following, with X_{l1} and $X_{l2'}$ commonly being referred to as the leakage reactances

This is turn is often simplified to:



R_s – Stator winding resistance
X_{ls} – Stator **leakage** reactance

R_r – Rotor winding resistance
X_{ls} – Rotor **leakage** reactance

Performance calculations

- Given a set of parameters, i.e. Rs, Rr, X_{ls}, X_{lr} etc the equivalent circuit can be used to calculate various aspects of performance

The positive sequence equivalent impedance is:

$$Z_p = \frac{\left(\left(\frac{R_2}{2s} + j\frac{X_{lr}}{2}\right) \times \frac{jX_m}{2}\right)}{\frac{R_2}{2s} + j\frac{X_{lr}}{2} + \frac{jX_m}{2}}$$

Similarly, the negative sequence impedance is:

$$Z_n = \frac{\left(\left(\frac{R_2}{2(2-s)} + j\frac{X_{lr}}{2}\right) \times \frac{jX_m}{2}\right)}{\frac{R_2}{2(2-s)} + j\frac{X_{lr}}{2} + \frac{jX_m}{2}}$$

The input current is therefore given by:

$$I_{in} = \frac{V_s}{Total\ impedance}$$

(which includes R_s and jX_s)

The power factor can be derived from the phase of the input current and hence the input power can be calculated from $P=V_s I_{in} \cos(\phi)$

The mechanical output power and subsequently torque can be calculated from the rotor power:

$$P_{mech} = \left(I_p^2 \frac{R_2'}{2s} - I_n^2 \frac{R_2'}{(2-s)\,2}\right)(1-s)$$

Derived from total rotor power – rotor copper loss

This requires calculation the current through the rotor resistances than the input current

The most straightforward way of doing this is to calculate the voltage across the positive and negative sequene branches, i.e

$$V_p = I_{in} Z_p \qquad V_n = I_{in} Z_n$$

And hence, the current through the resistive elements of each branch can be calculated from:

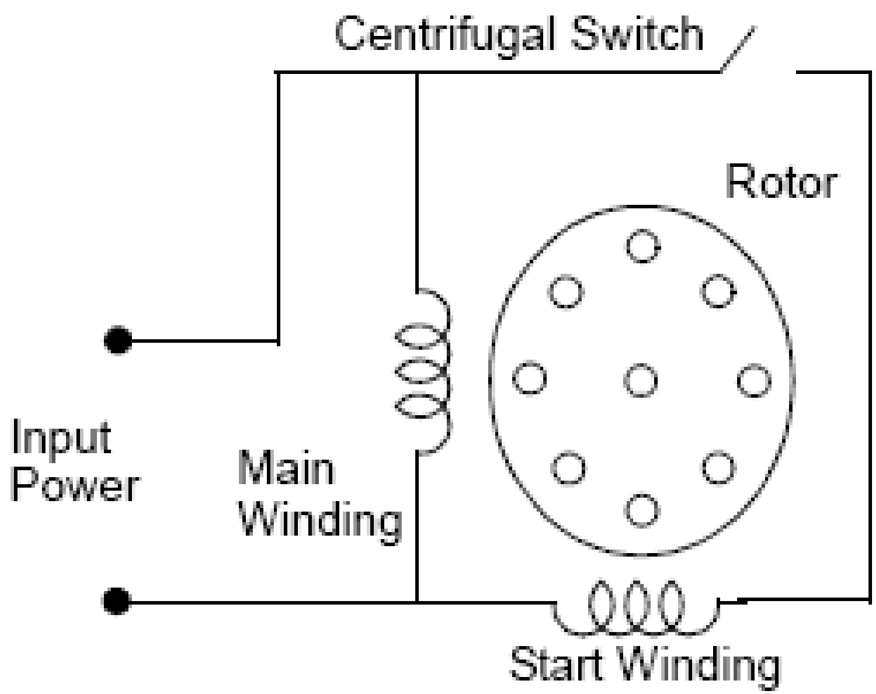
$$I_p = \frac{V_p}{\frac{R_r}{2s} + j\frac{X_{lr}}{2}} \qquad I_n = \frac{V_n}{\frac{R_r}{2(2-s)} + j\frac{X_{lr}}{2}}$$

Starting of single phase induction motors

- As noted previously, although a basic single phase induction motor produces net torque once it is running up in one direction, it produces no starting torque
- Various mechanisms are employed in practical induction motors to ensure reliable starting – they are all based on introducing a phase shifted component of field on the d-axis, usually but no exclusively by fitting a second coil on the stator and supplying it with a phase shifted current
- They all involve some degree of compromise and do not generally produce very high levels of starting torque compared to the rated torque.

Split-phase motor

- Two stator winding (main + auxiliary starting) -displaced by 90^o in space
- Auxiliary has higher resistance to reactance ratio – hence current has different phase to main winding
- Resulting rotating field produces starting torque but inefficient – auxiliary winding is usually switched out by a centrifugal switch

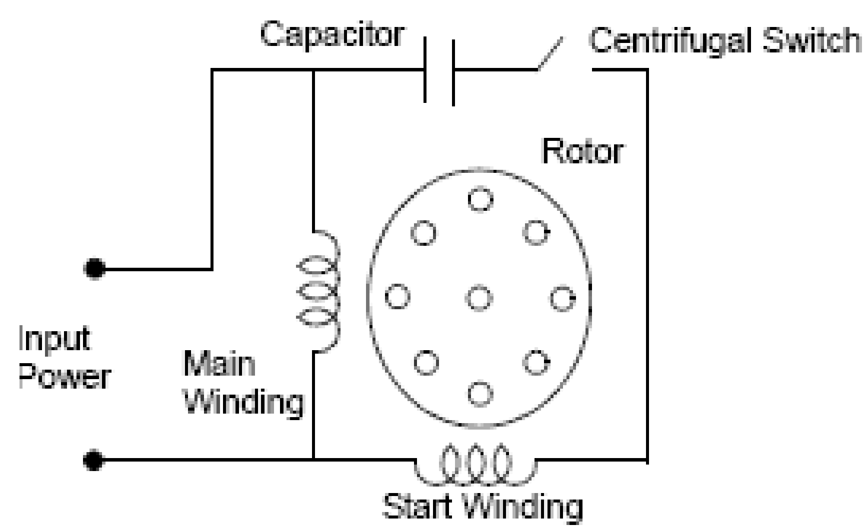


Single-phase induction motors with starting capacitors

- All variants use an auxiliary starting winding
- Use capacitor in series with auxiliary starting winding to produce a large phase shift in current and hence a phase-shifted field
- Higher efficiency and higher starting torques than split-phase machines
- Used where reasonably high starting torques required compared to rated torque
- Several different configurations used depending on applications requirements and cost / performance constraints

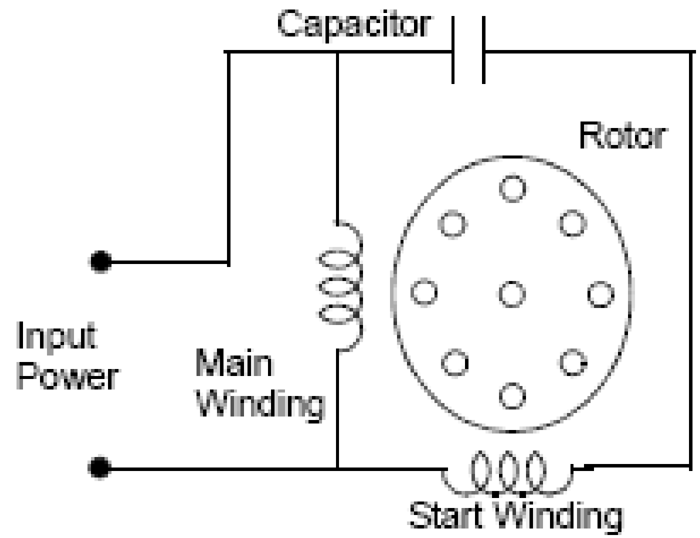
<u>Capacitor – start motor</u>

Capacitor only used for starting – switched out by centrifugal switch



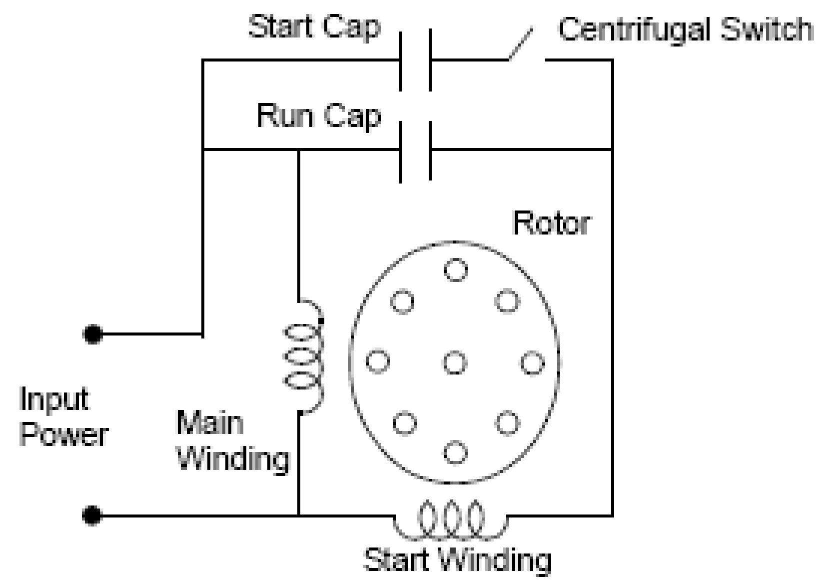
Permanent split capacitor (PSC)

Capacitor left in circuit
Has some advantages in terms of normal running power factor and suitability for variable speed operation from power electronic inverter



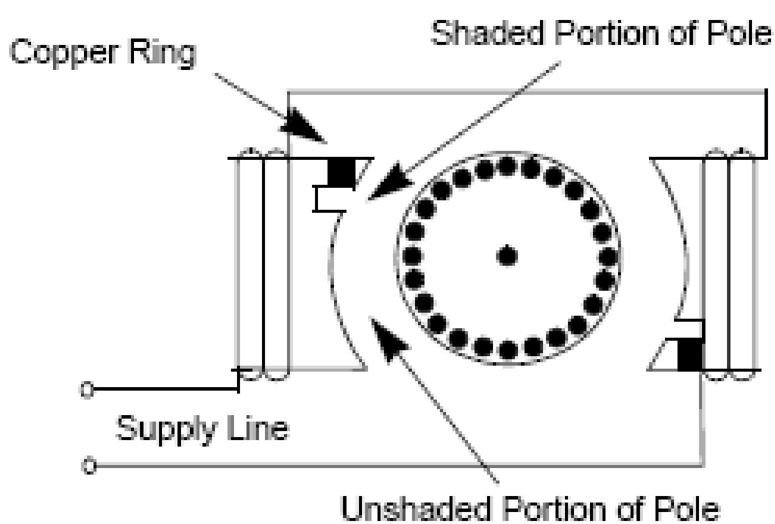
Capacitor start – capacitor run

(sometimes called two value capacitor motor)
Combination of capacitor start /PSC motors
Most complex but best performance as capacitor values can be optimised for start and run seperately

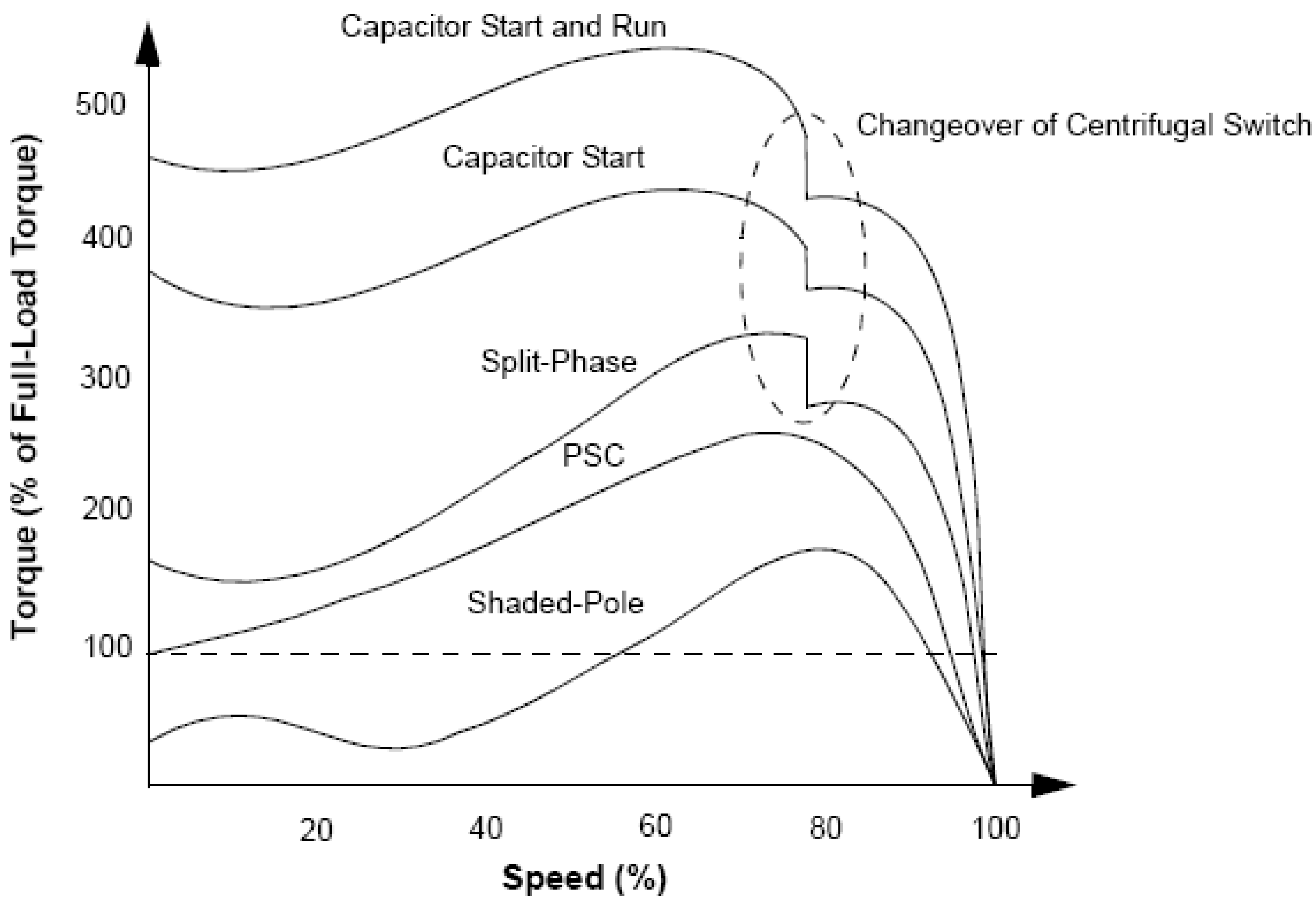


Shaded-pole motor

- Retains single stator coil
- Short-circuited copper ring placed around section of stator pole
- Induced currents flow in the ring (which oppose incident field) – results in a phase shifted flux variation under the ‘shaded’ region of pole
- Produces low starting torque and inefficient during running
- Only used in low cost / low power applications with predictable starting loads (e.g. cooling fans, fan heaters)



Typical torque-speed curves



Further useful information on single-phase induction machine starting at:

http://ww1.microchip.com/downloads/en/AppNotes/00887a.pdf