EE3014 POWER ELECTRONICS FOR RENEWABLE ENERGY SYSTEMS

UNIT II

ELECTRICAL MACHINES FOR WIND ENERGY CONVERSION

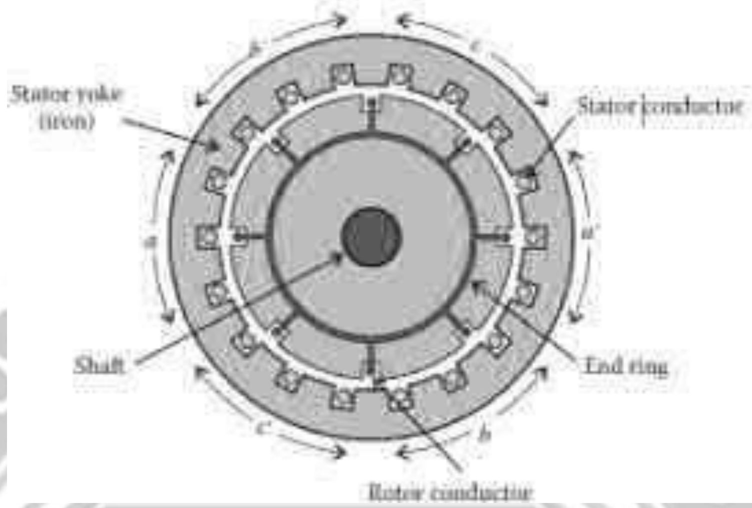
2.4- SCIG

SQUIRREL CAGE INDUCTION GENERATORS (SCIG)

Constructional features

Asynchronous Induction generators are widely used in wind mills due to the several advantages, such as robustness, mechanical simplicity and low price. Induction machines operate in the generating and motoring modes fundamentally in the same manner except for the reversal power flow. Therefore, the equivalent circuit and the associated performance are valid for different slip. If the rotor is driven by a prime mover above the synchronous speed, the mechanical power of the prime mover is converted into electrical power to the utility grid via stator winding. The SCIG is a self-excited induction generator where a three-phase capacitor bank is connected across the stator terminals to supply the reactive power requirement of a load. When such an induction machine is driven by an external mechanical power source, the residual magnetism in the rotor produces an Electromotive Force (EMF) in the stator windings. This

EMF is applied to the capacitor bank causing current flow in the stator winding and establishinga magnetizing flux in the machine.



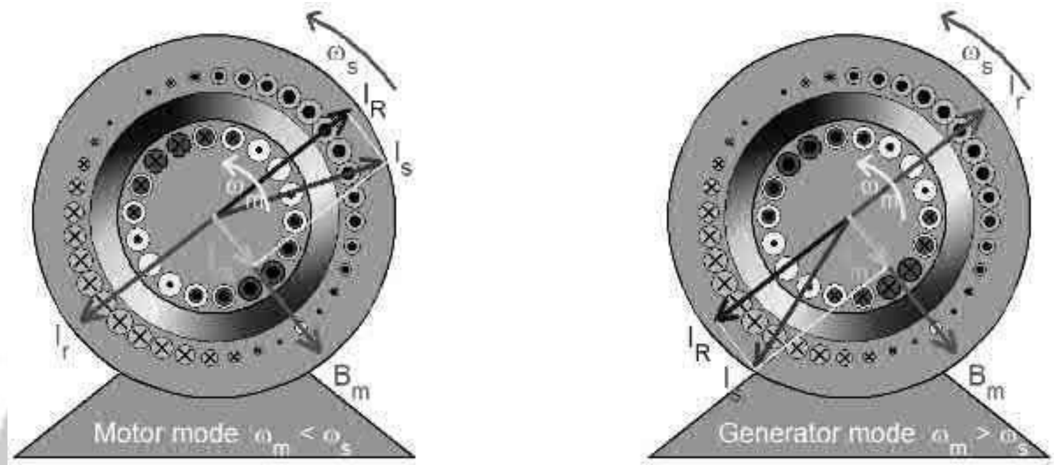
An induction generator connected and excited in this manner is capable of acting as a standalone generator supplying real and reactive power to a load. SCIG have a steep torque speed characteristic and therefore fluctuations in wind power are transmitted directly to the grid. SCIG feed only through the stator and generally operate at low negative slip, approximately 1 to 2

percent. The slip, and hence the rotor speed of a SCIG varies with the amount of power generated. The generator will always draw the reactive power from the grid. Reactive power consumption is partly or fully compensated by capacitors in order to achieve a power factor close to unity and make the induction machine to self-excite. The speed varies over a very small range above synchronous speed as it is coupled with the grid, hence commonly known as a fixed-speed generator. SCIG drives have bulky construction, low efficiency, low reliability and need of maintenance, also the existing of slip ring, brush and three-stage gearbox increases the system mass and cost, also electrical and mechanical loss. Recently, squirrel-cage induction generators are dropping in this application.

Principle of operation

Initially, the induction machine is connected in motoring command such that it generateselectromagnetic torque in the same direction as the wind torque. In steady-state, the rotationalspeed exceeds the synchronous speed and the electromagnetic torque is negative. Thiscorresponds to the squirrel-cage induction machine operation in generation mode. As it isdirectly connected to the grid, the SCIG works on its natural mechanical characteristic having anaccentuated slope (corresponding to a small slip) given by the rotor resistance. Therefore, the SCIG rotational speed is very close to the synchronous speed imposed by the grid frequency.

Furthermore, the wind velocity variations will induce only small variations in the generatorspeed.



As the power varies proportionally with the wind speed cubed, the associated electromagnetic variations are important. SCIG are preferred because they are mechanically simple, have high efficiency and low maintenance cost. Furthermore, they are very robust and stable. The rotating magnetizing field represented by the space vector $\mathbf{B_m}$ (or, equivalently by the magnetizing current $\mathbf{I_m}$) moves at the synchronous speed ω_s with respect to a stator (or stationary) observer and at the slip speed $\omega_{sl} = \omega_s - \omega_m$ with respect to a rotor observer. In the motor mode of operation where $\omega_m < \omega_s$, the rotor effectively moves backwards (clockwise) with respect to the field, inducing in each bar a voltage having the polarity indicated and a magnitude proportional to slip velocity u and to the field strength acting on the bar (in accordance with the flux-cutting rule $\mathbf{v = Blu}$). Since the magnetic field is sinusoidally distributed in space, so will the induced voltages in the rotor bars. Ignoring the effects of rotor leakage, the resulting rotor currents are in phase with the induced voltages and are thus sinusoidally distributed in space varying sinusoidally in time at slip frequency; they may then be represented by the space vector $\mathbf{I_r}$ which rotate at the slip speed ω_{sl} with respect to the rotor andat synchronous speed ω_s with respect to the stator. Because $\mathbf{B_m}$ cannot change with a fixed stator input voltage (in accordance with Faraday's law), a stator space vector $\mathbf{I_R}$ is created in order to compensate for the rotor effects so that the resultant stator current becomes $\mathbf{I_s = I_R + I_m}$.

The electromagnetic force exerted on rotor bar acting in the positive or anticlockwisedirection (same as rotor speed) in the present case of a motor. The resultant torque developed onthe rotor also acts in the same direction. Follow the path taken by one rotor bar as it travelsaround, observing the polarity and magnitude (described by the size) of the bar current. In thecase of a generator where $\omega_m > \omega_s$, all polarities and directions are reversed as can be observed in the right figure (except for the magnetizing component).

Modelling of Squirrel Cage Induction Generator (SCIG)

A three-phase voltage system may be expressed, with obvious meaning of the notation,as follows

$$V_a(t) = V\cos(\omega t + \varphi)$$

$$V_b(t) = V\cos\left(\omega t + \varphi - \left(\frac{2}{3}\right)\pi\right)$$

$$V_c(t) = V\cos\left(\omega t + \varphi - \left(\frac{4}{3}\right)\pi\right) \qquad (1)$$

The corresponding space-vector is calculated in (2). Notice that the amplitude of the defined voltage space-vector is equal to the peak amplitude of the instantaneous voltage:

$$V_s(t) = \frac{2}{3}(v_a(t) + av_b(t) + a^2v_c(t)) = ve^{j\varphi}e^{j\omega t} \qquad (2)$$

where

$a = e^{j(2/3)\pi}$

$a^2 = e^{-j(2/3)\pi}$

$V = Ve^{j\omega}$

The phasor V is defined in such a way that its magnitude is equal to the peak-value of the voltage. The first part of (2) is valid also if the three-phase quantities do not form a balanced system. In this case, the space vector becomes:

$$V_s(t) = V_1e^{j\varphi 1}e^{j\omega t} + V_2ve^{-j\varphi 2}e^{-j\omega t} = V_1e^{j\omega t} + V_2e^{-j\omega t} \qquad (3)$$

Similar expressions can be obtained for currents and fluxes. The zero-sequence is not considered here, since commonly an induction generator is not grounded and therefore no zero- sequence current can flow. If no zero-sequence component is present, the instantaneous valuesof the currents in the three phases can be obtained from the corresponding space-vector as:

$$i_a(t) = Re(i_s)$$

$$i_b(t) = Re(a^2 i_s)$$

$$i_c(t) = Re(a i_s) \quad (4)$$

Using the introduced space-vector notation and using a stationary reference frame, the equations describing the electrical dynamics of a squirrel-cage induction machine are given by :

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$$v_s = R_s i_s + \frac{d\psi_s}{dt}$$

$$0 = R_r i_r + \frac{d\psi_r}{dt} - j\psi_r\psi_r \qquad (5)$$

$$\psi_s = L_s I_s + L_m I_r$$

$$\psi_r = L_m I_s + L_r I_r \qquad (6)$$

where

$L_s = L_{sl} + L_m$ and $L_r + L_{rl} + L_m$