5.1 Output equation of AC motor

Output equation is the mathematical expression which gives the relation between the various physical and electrical parameters of the electrical machine.

In an AC motor the output equation can be obtained as follows Consider an 'm' phase machine, with usual notations

Output Q in kW = Input x efficiency

Input to motor = $mV_{ph}\ I_{ph} \cos \Phi \times 10\text{-}3\ k_W$

For a 3 Φ machine m = 3 ,

Input to motor = $3V_{ph}\ I_{ph} \cos \Phi \times 10\text{-}3\ k_W$ Assuming

$V_{ph} = E_{ph}$, $V_{ph} = E_{ph} = 4.44\ f\ \Phi\ T_{ph}K_w$

$= 2.22\ f\ \Phi Z_{ph}K_w$

$f = PN_S/120 = Pn_s/2$,

Output = $3 \times 2.22 \times Pns/2 \times \Phi Z_{ph}K_w\ I_{ph}\ \eta \cos \Phi \times 10\text{-}3\ k_W$

Output = $1.11 \times P\Phi \times 3I_{ph}\ Z_{ph} \times ns\ Kw\ \eta \cos \Phi \times 10\text{-}3k_W$,

$P\Phi = Bav\pi DL$, and $3I_{ph}\ Z_{ph}/\ \pi D = q$

Output to motor = $1.11 \times Bav\pi DL \times \pi Dq \times ns\ Kw\ \eta \cos \Phi \times 10\text{-}3$ kW

$Q = (1.11\ \pi 2\ Bav\ q\ Kw\ \eta \cos \Phi \times 10\text{-}3)\ D^2L\ ns$ kW

$Q = (11\ Bav\ q\ K_w\ \eta \cos \Phi \times 10\text{-}3)\ D^2L\ ns\ k_W$

Therefore,

Output $\boxed{Q = Co\ D^2L\ n_s \text{ kW}}$

where Co = $(11\ Bav\ q\ Kw\ \eta \cos \Phi \times 10\text{-}3)$

V_{ph} = phase voltage;

I_{ph} = phase current

Z_{ph} = no of conductors/phase

T_{ph} = no of turns/phase

Ns = Synchronous speed in rpm

ns = synchronous speed in rps

p = no of poles,

q = Specific electric loading

Φ = air gap flux/pole;

B_{av} = Average flux density

kw = winding factor.

η = efficiency

cosΦ = power factor

D = Diameter of the stator,

L = Gross core length

Co = Output coefficient

From the output equation of the machine it can be seen that the volume of the machine is directly proportional to the output of the machine and inversely proportional to the speed of the machine. The machines having higher speed will have reduced size and cost. Larger values of specific loadings smaller will be the size of the machine.

Separation of D and L:

Inner diameter and gross length of the stator can be calculated from D^2L product obtained from the output equation. To separate suitable relations are assumed between D and L depending upon the type of the generator. Salient pole machines: In case of salient pole machines either round or rectangular pole construction is employed. In these types of machines, the diameter of the machine will be quite larger than the axial length.

Round Poles:

The ratio of pole arc to pole pitch may be assumed varying between 0.6 to 0.7 and pole arc may be taken as approximately equal to axial length of the stator core. Hence Axial length of the core/ pole pitch = L/ p = 0.6 to 0.7

Rectangular poles:

The ratio of axial length to pole pitch may be assumed varying between 0.8 to 3 and a suitable value may be assumed based on the design specifications. Axial length of the core/ pole pitch = L/ p = 0.8 to 3

Using the above relations D and L can be separated. However once these values are obtained diameter of the machine must satisfy the limiting value of peripheral speed so that the rotor can withstand centrifugal forces produced.

Limiting values of peripheral speeds are as follows:

- Bolted pole construction = 45 m/s
- Dove tail pole construction = 75 m/s
- Normal design = 30 m/s

Design of salient pole machines:

These type of machines have salient pole or projecting poles with concentrated field windings. This type of construction is for the machines which are driven by hydraulic turbines or Diesel engines.Rotor of water wheel generator consists of salient poles. Poles are built with thin silicon steel laminations of 0.5mm to 0.8 mm thickness to reduce eddy current laminations. The laminations are clamped by heavy end plates and secured by studs or rivets. For low speed rotors poles have the bolted on construction for the machines with little higher peripheral speed poles have dove tailed construction as shown in Figs. Generally rectangular or round pole constructions are used for such type of alternators. However the round poles have the advantages over rectangular poles.

In case of salient pole machines either round or rectangular pole construction is employed. In these types of machines the diameter of the machine will be quite larger than the axial length.

Round Poles:

The ratio of pole arc to pole pitch may be assumed varying between 0.6 to 0.7 and pole arc may be taken as approximately equal to axial length of the stator core. Hence

Axial length of the core/ pole pitch = $L/\tau p$ = 0.6 to 0.7

Rectangular poles:

The ratio of axial length to pole pitch may be assumed varying between 0.8 to 3 and a suitable value may be assumed based on the design specifications.

Axial length of the core/ pole pitch = $L/\tau p$ = 0.8 to 3

Using the above relations D and L can be separated. However once these values are obtained diameter of the machine must satisfy the limiting value of peripheral speed so that the rotor can withstand centrifugal forces produced.

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Design of turbo alternators

Turbo alternators: These alternators will have larger speed of the order of 3000 rpm. Hence the diameter of the machine will be smaller than the axial length. As such the diameter of the rotor is limited from the consideration of permissible peripheral speed limit. Hence the internal diameter of the stator is normally calculated based on peripheral speed. The peripheral speed in case of turbo alternators is much higher than the salient pole machines. Peripheral speed for these alternators must be below 175 m/s.