7. The polyphase synchronous machine

The polyphase synchronous machine can be classified as either a cylindrical rotor or a salient pole machine according to its form of construction. Most turbine-driven synchronous generators are high speed sets with a 2-pole construction and are highly suited to the cylindrical rotor, rotating field type of construction. Hydroelectric power generators are generally low speed multipolar machines of the salient pole type. The synchronous motor can be of either form of construction, although the majority of motors will be of the salient pole type.

In the case of the cylindrical rotor machines, it is assumed that the air-gap between the stator and rotor is constant, so that the reluctance of the mutual magnetic circuits does not depend on the angular position of the rotor. In the case of a salient pole machine, however, there are two definite axes of symmetry and the reluctance will then be a function of the angular position of the rotor. In these circumstances, the techniques used for the derivation of equivalent circuits and performance characteristics of the two types of machine are different.

7.1. Basis of operation of cylindrical rotor machines

The basic principles underlying the operation of polyphase synchronous machines have been discussed in chapter 1 where the important concept of load angle has been introduced.

In the basic analysis, it will be assumed that saturation can be neglected and that the m.m.f. set up by the d.c. excitation is sinusoidally distributed in space, so that all alternating voltages and currents are sinusoids. The machine will be considered as a symmetrical polyphase machine and equivalent circuits and phasor diagrams will be drawn on a ‘per-phase’ basis.

Consider the operation of a 3-phase, rotating field machine connected to a constant voltage, 3-phase system with the machine excitation set to produce an open-circuit voltage equal to the system voltage \( V \). Under these conditions, the machine is said to be ‘floating’ on the system and the corresponding phasor diagram is shown in Fig. 7.1(a) which shows the separate time and space varying quantities. The m.m.f., \( F \), produced by the d.c. excitation is equal to the resultant m.m.f., \( F_r \) (which sets up the resultant flux \( \Phi_r \)), since
the armature current, $I_a$, and hence the armature reaction m.m.f., $F_{ar}$, are zero. The internal e.m.f., $E_r$, shown in Fig. 7.1(a) is set up by the flux produced by the d.c. excitation acting alone and is known as the excitation e.m.f. In the first stage of analysis, the leakage impedance of the armature will be neglected so that the resultant e.m.f., $E_r$, set up by the resultant flux $\Phi_r$ will equal the system voltage, $V$, and will be constant.

When the power applied to the shaft of the machine is increased, with constant excitation, the rotor speed will increase as the machine enters the generating mode. During this transient period, the axis of the field m.m.f. is

$$V = E_r$$

![Phasor Diagrams](image)

**Fig. 7.1. Simplified phasor diagrams:**
(a) 'Floating'. (b) Generating. (c) Motoring.

... driven ahead, in the direction of rotation, of the axis of the resultant m.m.f. and this condition will continue until the electrical power output from the machine balances the increase in applied shaft power. The axis of the field m.m.f. will then have moved through the necessary load angle $\delta_g$ and the final steady state condition is shown in Fig. 7.1(b).

If, from the floating condition, mechanical output power is taken from the shaft, with constant excitation, the rotor speed must decrease as the machine enters the motoring mode. The axis of the field m.m.f. will then lag behind, in the direction of rotation, the axis of the resultant m.m.f. and the transient condition will continue until the electrical input power equals the required value of load power on the shaft. The axis of the field m.m.f. will then have moved through the necessary load angle $\delta_m$ and the final steady state condition is shown in Fig. 7.1(c).

In both the above cases, it follows from the phasor diagrams of Fig. 7.1(b) and (c) that

$$F \sin \delta = F_{ar} \cos \phi.$$  \hspace{1cm} (7.1)

The armature reaction m.m.f., $F_{ar}$, is directly proportional to the armature current, $I_a$, so that, at constant terminal voltage, the quantity $F_{ar} \cos \phi$ is a