7 Three-phase Alternator

One of the most important electric machines is the **three-phase alternator**. It is a synchronous (cf. Chapter 7.2) machine and can be employed both as generator and as motor.

One main field of application is generator operation for energy production in power stations. The three-phase alternator, at this point, transforms mechanical energy into electrical energy that usually is fed to three-phase systems (cf. Chapter 6). While doing so, it both provides active and reactive energy for the three-phase system and its connected consumers, e. g. transformers (cf. Chapter 8) and three-phase asynchronous motors (cf. Chapter 9). The three-phase alternator, therefore, shall be the starting point of describing electric machines and drives.

The three-phase synchronous machine is also employed as motor transforming electric energy into mechanical energy. The three-phase synchronous motor has the advantage of constant speed at variable load. Therefore, it, for example, is employed for clocks but also for slowly running drives of high power (some MW), e. g. in cement mills or blast furnace blowing engines.

Compared with the three-phase asynchronous motor and direct-current motor, the three-phase synchronous motor plays but a role of secondary importance in industrial drive engineering. That’s why we shall only focus on generator operation in the following.

7.1 Three-phase Alternator Construction

Considering its construction a three-phase alternator is a rotating machine. It consists of a stationary **stator** and a rotating **rotor**. Stator and rotor are separated by an air gap from each other (approx. 50 mm on small, and approx. 10 cm on large machines). The rotor of a three-phase alternator is designed either as **non-salient-pole rotor** (also termed as drum-type rotor, round rotor or cylindrical rotor, **Figure 7.1 a**) or as **salient-pole rotor** (**Figure 7.1 b**).

This is based on predetermined driving engine’s speed (e. g. steam or hydraulic turbine) and mechanical stress caused by that. In an **internal-pole version**, rotors have distinct salient poles for generating a magnetic unidirectional field and are also termed as rotating magnetic poles. The stator, in this case, carries a three-phase winding. The rotor winding can be accessed through slip rings and contact brushes from outside, and is passed through by direct current.

There are also **external-pole generators** where the rotor carries the three-phase winding (accessible through slip rings and contact brushes), and the stator the direct current carrying salient poles.

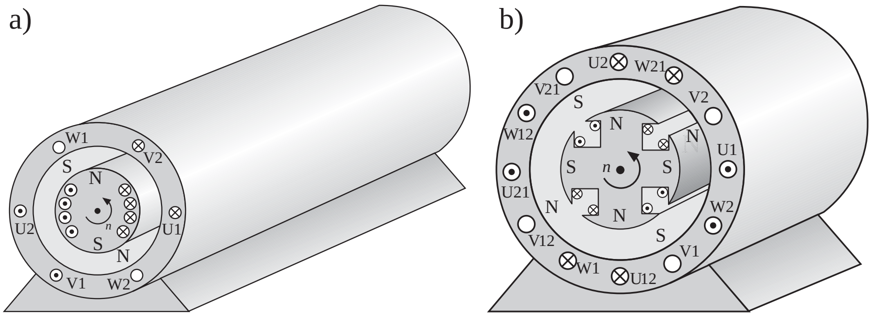

Figure 7.1 Principle of alternator with a) non-salient-pole rotor and b) salient-pole rotor

Non-salient-pole rotors rotate quickly, and are driven by steam turbines at speeds of round about 1500 min^{-1} to 3000 min^{-1}. They are built from solid iron as a rule, and their largest units have diameters of approx. 1.2 m and an axial length of approx. 8 m. The outer rotor periphery has milled slots to take up the rotor winding. This winding is passed through by direct current generating a constant magnetic field that rotates with the externally driven rotor. Usually non-salient-pole rotors have one north pole and one south pole or two north poles and two south poles that alternate on the rotor circumference. As poles on magnetic fields always would appear in pairs we, too, mark their number by **pole pair number** *p*. For instance $p = 1$ for non-salient-pole rotor in Figure 7.1 a, and $p = 2$ for salient-pole rotor in Figure 7.1 b.

Salient-pole rotors rotate slowly and are driven by hydraulic turbines (or diesel engines in standby power systems) at speeds of approx. 75 min^{-1} up to 1500 min^{-1}. Usually salient-pole rotors have a large diameter (up to approx. 15 m) at small axial overall length (up to approx. 3 m). The rotor poles are usually screwed to an iron rotor body. The smaller rotor speed the more north and south poles are alternately distributed among rotor circumference (e. g. $p = 40$ at $n = 75$ min^{-1}). The non-salient-pole rotor, too, carries a direct current carrying rotor winding (Figure 7.1 b).

The **stator** (on inner-pole or revolving-field machines) consists of a core assembly with longitudinal slots into which a three-phase copper stator winding is inserted. In this case the windings with three phase windings U, V and W with connection points U1–U2, V1–V2 and W1–W2 are distributed evenly among circumference, and they are passed through by phase currents i_1, i_2 and i_3. Figures 7.1 a and 7.1 b show the principles for a two-pole winding and a four-pole winding.

It will be important for the functioning of a three-phase alternator that the stator and rotor number of pole pairs match. To have this condition met the stator winding conductors need to be distributed appropriately among stator circumference, and phase currents must flow through the conductors in certain directions.

In Figure 7.1 a for instance, the stator field north and south pole position is illustrated with a pole pair number of $p = 1$ for an instant in which current i_3 through phase winding W (W1–W2) is zero right then. In this moment, currents i_1 and i_2 through phase windings U (U1–U2) and V (V1–V2) are equal and have opposite direction (cf. **Figure 7.2**, instant ①).

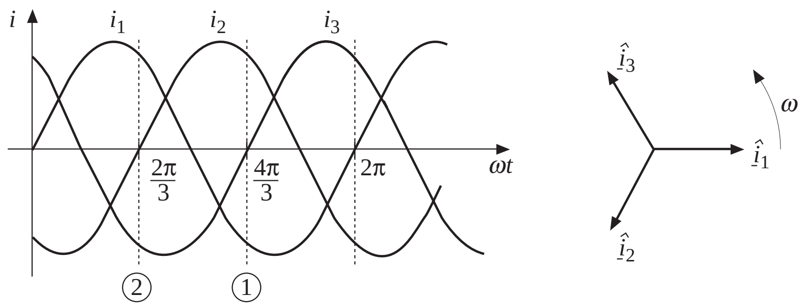

Figure 7.2 Stator currents

On a three-phase winding passed through by three-phase current a magnetic rotating field with pole pair number $p = 1$ results if the three phase windings of the winding are spatially twisted by 120° (cf. Chapter 9.2.2). You can realize a larger number of pole pairs by correspondingly partitioning the winding. Figure 7.1 b represents the north and south pole positions of a rotary stator field with pole pair number $p = 2$ for a certain point in time. Current i_2 through phase winding V (V1–V12–V21–V2) is zero right then while currents i_1 and i_3 through phase windings U (U1–U12–U21–U2) and W (W1–W12–W21–W2) are equal and have opposite direction (Figure 7.2, instant ②).

The phase winding connection points are run to the terminal box (**Figure 7.3**).

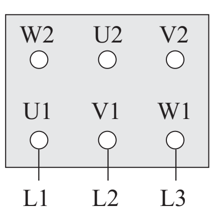

Figure 7.3 Terminal box