19.5. Interconnection of Three Phases

If the three armature coils of the 3-phase alternator (Fig. 19.8) are not interconnected but are kept separate, as shown in Fig. 19.9, then each phase or circuit would need two conductors, the total number of conductors, in that case, being six. It means that each transmission cable would contain six conductors which will make the whole system complicated and expensive. Hence, the three phases are generally interconnected which results in substantial saving of copper. The general methods of interconnection are

(*a*) Star or Wye (Y) connection and

(*b*) Mesh or Delta (Δ) connection.

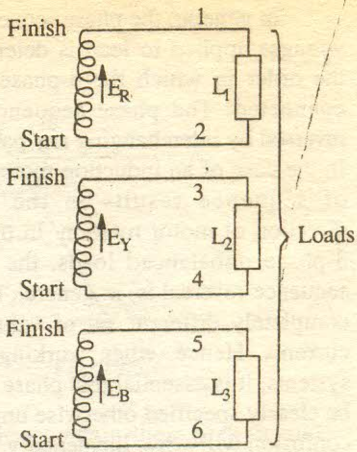

Fig. 19.9

19.6. Star or Wye (Y) Connection

In this method of interconnection, the *similar** ends say, 'star' ends of three coils (it could be 'finishing' ends also) are joined together at point *N* as shown in Fig. 19.10 (*a*).

The point *N* is known as *star point* or *neutral point.* The three conductors meeting at point *N* are replaced by a single conductor known as *neutral conductor* as shown in Fig. 19.10 (*b*). Such an interconnected system is known as four-wire, 3-phase system and is diagrammatically shown in Fig. 19.10 (*b*). If this three-phase voltage system is applied across a balanced symmetrical load, the neutral wire will be carrying three currents which are exactly equal in magnitude but are 120° out of phase with each other. Hence, their vector sum is zero.

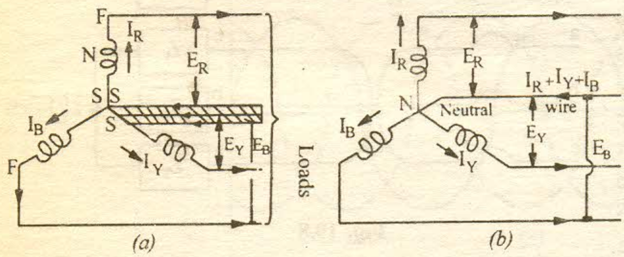

Fig. 19.10

i.e. $$\mathbf{I}_R + \mathbf{I}_Y + \mathbf{I}_B = 0 \quad \text{... vectorially}$$

The neutral wire, in that case, may be omitted although its retention is useful for supplying lighting loads at low voltages (Ex. 19.22). The p.d. between any terminal (or line) and neutral (or star) point gives the *phase* or *star* voltage. But the p.d. between any two lines gives the line-to-line voltage or simply line voltage.

19.7. Values of Phase Currents

When considering the distribution of current in a 3-phase system, it is extremely important to bear in mind that :

(*i*) the arrow placed alongside the currents I_R I_Y and I_B flowing in the three phases [Fig. 19.10 (*b*)] indicate the directions of currents when they are assumed to be *positive* and not the directions at a particular instant. It should be clearly understood *that at no instant will all the three currents flow in the same direction either outwards or inwards.* The three arrows indicate that first the current flows outwards in phase *R*, then after a phase-time of 120°, it will flow outwards from phase *Y* and after a further 120°, outwards from phase *B*.

(*ii*) the current flowing outwards in one or two conductors is always equal to that flowing inwards in the remaining conductor or conductors. In other words, *each conductor in turn, provides a return path for the currents of the other conductors.*

* As an aid to memory, remember that first letter *S* of Similar is the same as that of Star.

In Fig. 19.11 are shown the three phase currents, having the same peak value of 20 A but displaced from each other by 120°. At instant '*a*', the currents in phases *R* and *B* are each + 10 A (*i.e.* flowing outwards) whereas the current in phase *Y* is – 20A (*i.e.* flowing inwards). In other words, at the instant '*a*', phase *Y* is acting as return path for the currents in phases *R* and *B*. At instant *b*, $I_R = +15$ A and $I_Y = +5$ A but $I_B = -20$A which means that now phase *B* is providing the return path.

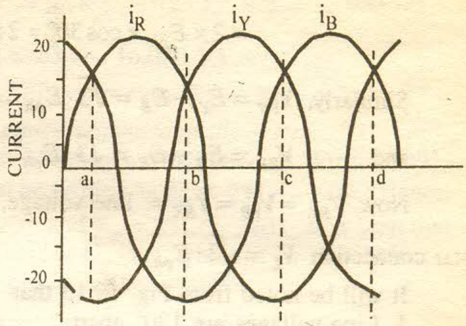

Fig. 19.11

At instant *c*, $I_Y = +15$ *A* and $I_B = +5$A and $I_R = -20$A.

Hence, now phase *R* carries current inwards whereas *Y* and *B* carry current outwards. Similarly at point *d*, $I_R = 0$, $I_B = 17.3$ A and $I_Y = -17.3$ A. In other words, current is flowing outwards from phase *B* and returning via phase *Y*.

In addition, it may be noted that although the distribution of currents between the three lines is continuously changing, yet at any instant the algebraic sum of the *instantaneous* values of the three currents is zero *i.e.* $i_R + i_Y + i_B = 0$ – algebraically.

19.8. Voltages and Currents in Y-Connection

The voltage induced in each winding is called the *phase* voltage and current in each winding is likewise known as *phase* current. However, the voltage available between any pair of terminals (or outers) is called *line* voltage (V_L) and the current flowing in each *line* is called *line* current (I_L).

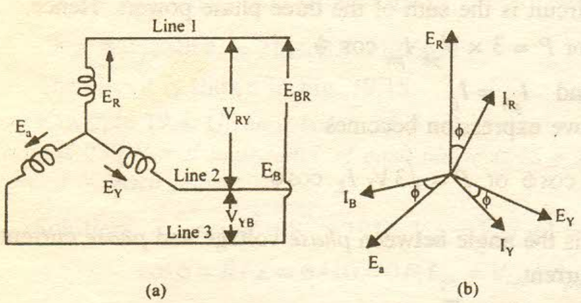

Fig. 19.12

As seen from Fig. 19.12 (*a*), in this form of interconnection, there are two phase windings between each pair of terminals but since their *similar* ends have been joined together, they are in opposition. Obviously, the *instantaneous* value of p.d. between any two terminals is the *arithmetic difference* of the two phase e.m.fs. concerned. However, the r.m.s. value of this p.d. is given by the *vector difference* of the two phase e.m.fs.

The vector diagram for phase voltages and currents in a star connection is shown in Fig. 19.12 (*b*) where a balanced system has been assumed.* It means that $E_R = E_Y = E_{ph}$ (phase e.m.f.).

Line voltage V_{RY} between line 1 and line 2 is the vector difference of E_R and E_Y.

Line voltage V_{YB} between line 2 and line 3 is the vector difference of E_Y and E_B.

Line voltage V_{BR} between line 3 and line 1 is the vector difference of E_B and E_R.

(*a*) Line Voltages and Phase Voltages

The p.d. between line 1 and 2 is $V_{RY} = E_R - E_Y$ ... vector difference.

Hence, V_{RY} is found by compounding E_R and E_Y reversed and its value is given by the diagonal of the parallelogram of Fig. 19.13. Obviously, the angle between E_R and E_Y reversed is 60°. Hence if $E_R = E_Y = E_B$ = say, E_{ph} – the phase e.m.f., then

* A balanced system is one in which (*i*) the voltages in all phases are equal in magnitude and offer in phase from one another by equal angles, in this case, the angle = 360/3 = 120°, (*ii*) the currents in the three phases are equal in magnitude and also differ in phase from one another by equal angles.

A 3-phase balanced load is that in which the loads connected across three phases are identical.