employed in each branch, but with two-phase three-wire supply, two- phase transformers must be supplied.

*Phase Transformers* are arrangements of static or rotary trans- formers intended to transform single-phase alternating currents into polyphase currents. An important system of phase transformation has been described by C. F. Scott.@@1 It is known that if two alternating electromotive forces differing in phase are connected in series, the resulting electromotive force will in general differ in phase and value from either of the components. Thus, if two alternating electromotive forces differing 90° in phase, and having magnitudes in the ratio of 1 : √3, are connected in series, the resulting electro­motive force will have a magnitude represented by 2, and the three can be represented by the sides of a triangle which is half an equilateral triangle. If then a two-phase alternator, D (fig. 9), provides two-phase currents, and if the two circuits are connected, as shown, to a pair of single-phase trans- formers, T1 and T2, we can obtain three-phase alternating currents from the arrangement. The primaries of both transformers are the same. The secondary circuit of one transformer, T2, has, say, 100 turns, and a connexion is made to its middle point O, and this is connected to the secondary of the other transformer which has 87 ( = 50 √3) turns. From the points A, B, C we can then tap off three-phase alternating cur­rents. The advantages of the Scott system are that we can transform two-phase alternating currents into three-phase for transmission, and then by a similar arrangement retransform back again into two-phase for use. In this manner an economy of 25% in copper is effected, for instead of four transmission lines we have only three. The system adapts itself for the transmission of currents both for power in driving three-phase motors and for working incandescent lamps. A somewhat similar system has been designed by C. P. Steinmetz for producing three- phase currents from single-phase (see *Electrician,* xliii. 236). When a number, of alternating electromotive forces are maintained in a closed circuit, the sum of all must be zero, and may be represented by the sides of a closed polygon. The fundamental principle of Mr Steinmetz’s invention consists in so choosing the number of these electromotive forces that the polygon must remain stable. Thus, if three single-phase alternators are driven independently at constant speed and excitation, and if they are joined in series, then three wires led away from the junction points will provide three-phase currents to a system from which lamps and motors may be worked.

Reference must be made to the continuous current transformer. The conversion of a continuous current supplied, say, at 100 volts, into one having an electromotive, force of 10 volts, can of course be achieved by coupling together on the same bedplate a suitable electric motor and a dynamo. The combination is called a *motor-dynamo set,* and each machine preserves its own identity and peculiarity. The same result may, however, be accomplished by winding two separate armature circuits on one iron core, and furnishing each with its own commutator. The two circuits are interlaced or wound on together. An arrangement of this kind constitutes a *rotatory* or *rotary transformed* or continuous current transformer. It has the advantage of greater cheapness and efficiency, because one field magnet serves for both armature windings, and there is only one armature core and one pair of bearings ; moreover, no shift or lead of the brushes is required at various loads. The armature reactions of the two circuits annul each other. Machines of this description are self-starting, and can be constructed to take in primary current at high pressures, say 1000 to 2000 volts, and yield another larger current of much lower voltage, say 100 or 150 volts, for use with electric lamps. They are used in connexion with public electric supply by continuous current in many places.

Another important class of rotatory transformer is that also called a *rotatory converters* by means of which continuous current is translated into alternating current of one-, two- or three-phase, or vice versa. The action of such an appliance may best be under­stood by considering the simple case of a Gramme ring armature

(see Dynamo) having, in addition to its commutator, a pair of in­sulated rings on its shaft connected with opposite ends of the arma- ture winding (fig. 10). If such a ring is placed in a bipole field magnet, and if a pair of brushes make contact with the commutator C and another pair with the two rings called slip rings, S1 S2, and if continuous current at a constant voltage is supplied to the com­mutator side, then the armature will begin to revolve in the field, and from the brushes in contact with the slip rings we can draw off an alternating current. This reaches its maximum value when the points of contact of the rings with the armature circuit pass the axis of commutation, or line at right angles to the direction of the magnetic field, for it has at this moment a value which is double the steady value of the continuous current being poured into the armature. The maximum value of the electromotive force creating this alternating current is nearly equal to the electro- motive force on the continuous current side. Hence if A is the maximum value of the continuous current put into the armature and V is the value of the brush potential difference on the continuous current side, then 2A is the maximum value of the out- coming alternating current and V is the maximum value of its voltage. Hence. 2 A V/2 =AV is the maximum value of the out- coming alternating current power, and if we neglect the loss in the armature for the moment, the power given out is equal to the power put in. Hence, assuming a simple harmonic law of variation, the effective value of the alternating current voltage is V/√2, and that of the alternating current is 2A√2. This conclusion follows at once from the fact that the mean value of the square of a sine function is half its maximum value, and hence the R.M.S. value is 1/√2 times the maximum value. The outcoming alternating current has its zero value at the instant when the ends of the diameter of the axis to which the rings are connected are in the direction of the magnetic field of the transformer. Hence the power output on the alternating current side varies from a maximum value AV to zero. The rotatory transformer thus absorbs continuous current power and emits it in a periodic form; accordingly, there is a continual storage and emission of energy by the armature, and therefore its kinetic energy is periodically varying during the phase. The armature is also creating a back-electromotive force which acts at some instants against the voltage driving the current into the armature and at others is creating an electromotive force that assists the external impressed voltage in driving a current through the alternating current side. If we put on another pair of insulated rings and connect them to points of the insulated diameter at right angles to the points of connexion of the first pair of rings, we can draw off another alternating current, the phase of which differs 9o0 from that of the first. Similarly, if we provide three rings connected to points removed 120° apart on the armature circuit, we can tap off a three-phase alternating current.

Returning to the case of the single-phase rotatory transformer, we may notice that at the instant when the outcoming alternating current is zero the armature is wholly engaged in absorbing power and is acting entirely as a motor. When the alternating current is a maximum, the armature on the other hand is acting as a generator and adds current to the current put into it. The ratio between the potential difference of the brushes on the continuous current side and the root-mean-square or effective value of the voltage between any pair of rings on the alternating current side is called the transformation ratio of the converter.

The following table, taken from a paper upon rotatory converters by S. P. Thompson *(Proc. Inst. Elec. Eng.,* November 1898), gives the voltage ratio or conversion ratio in the case of various forms of rotatory transformer:—

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Number of slip rings. | Angle between points of connexions to armatures. | Type of current generated. | Voltage  ratio. | Effective voltage on alternating current sine as percentage of voltage on continuous current side. |
| 2 | 180° | Single-phase | √2 :1 | 70∙71 |
| 3 | 120° | Three-phase | 2√2:√3 | 61∙23 |
| 4 | 90° | Two-phase | √2 :1 | 70·71 |
| 4 | 90° | Four-phase | 2:1 | 50 |
| 6 | 60° | Three-phase | 3√3:√3 | 61∙23 |
| 6 | 60° | Six-phase | 2√2:1 | 35∙35 |

*@@@1 Proceedings of the National Electric Light Association* (Washington, U.S.A., 1894); also *Electrician* (1894), xxxii. 640.