Sept. 26, 1944. K. L. HANSEN 2,358,926

COMMUTATION MEANS AND METHODS OF COMMUTATION

Filed Dec. 24, 1941 4 Sheets-Sheet 1

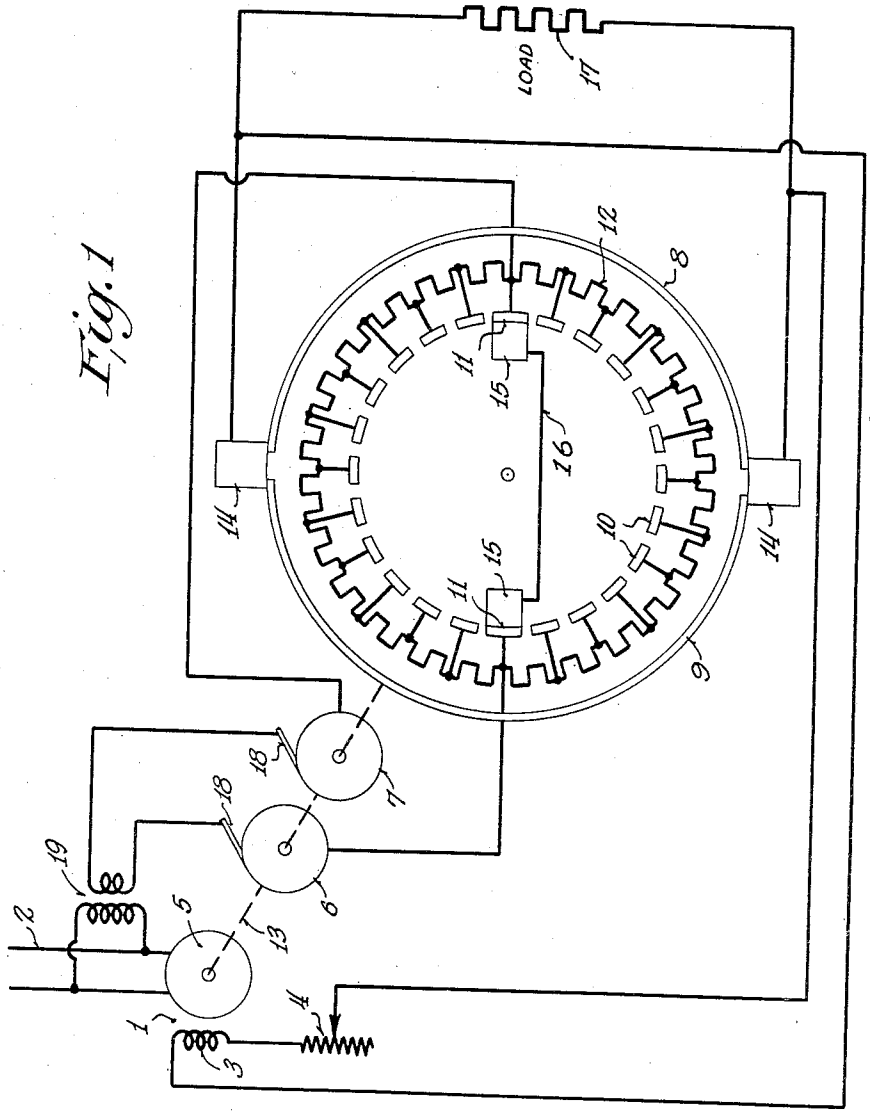


Fig. 1

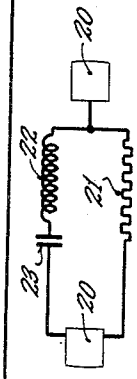


Fig. 3

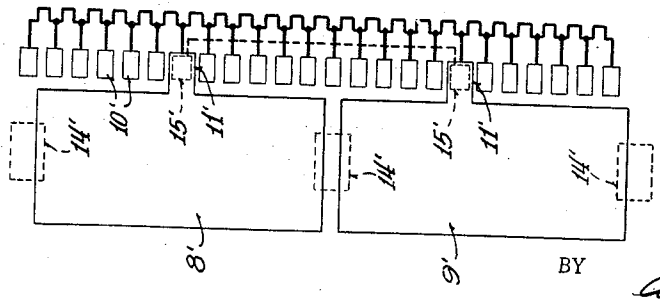


Fig. 2

INVENTOR.
KLAUS L. HANSEN

BY

Arthur R. Woolpert

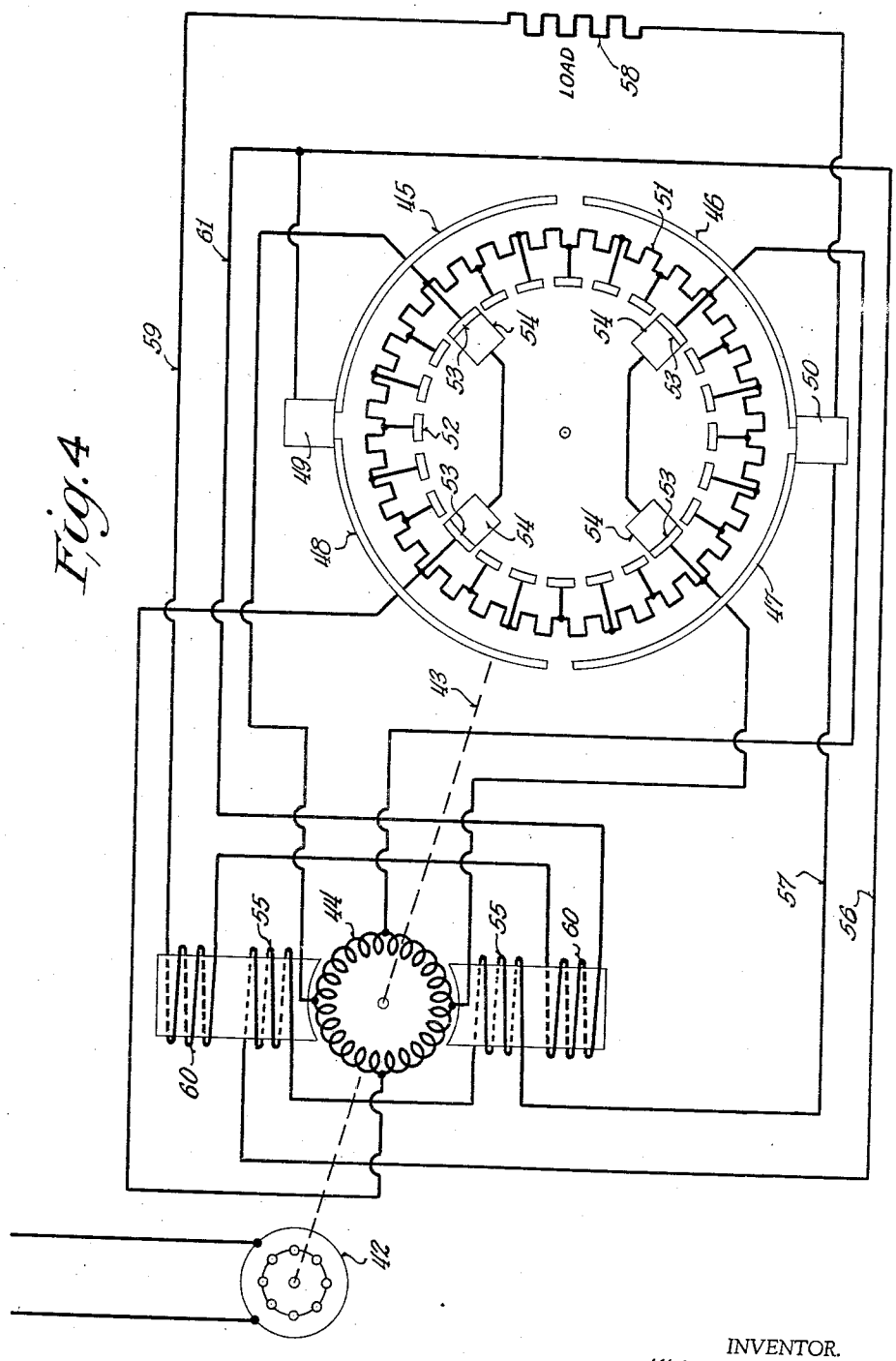
ATTORNEY.

Sept. 26, 1944. K. L. HANSEN 2,358,926

COMMUTATION MEANS AND METHODS OF COMMUTATION

Filed Dec. 24, 1941 4 Sheets-Sheet 2

Fig. 4



INVENTOR.
KLAUS L. HANSEN

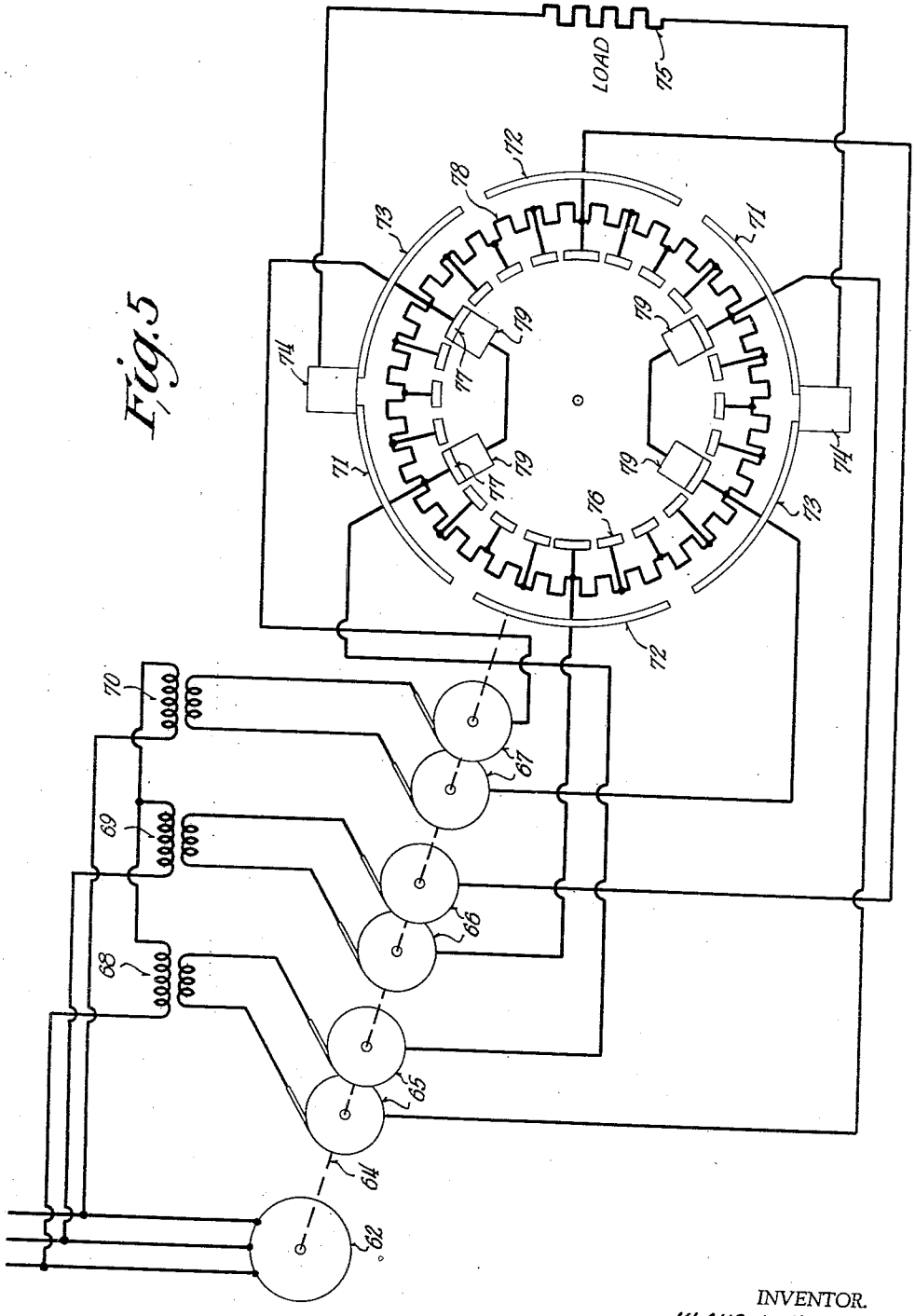
BY Arthur R. Woolfolk
ATTORNEY.

Sept. 26, 1944. K. L. HANSEN 2,358,926

COMMUTATION MEANS AND METHODS OF COMMUTATION

Filed Dec. 24, 1941 4 Sheets-Sheet 3

Fig. 5



INVENTOR.
KLAUS L. HANSEN

BY

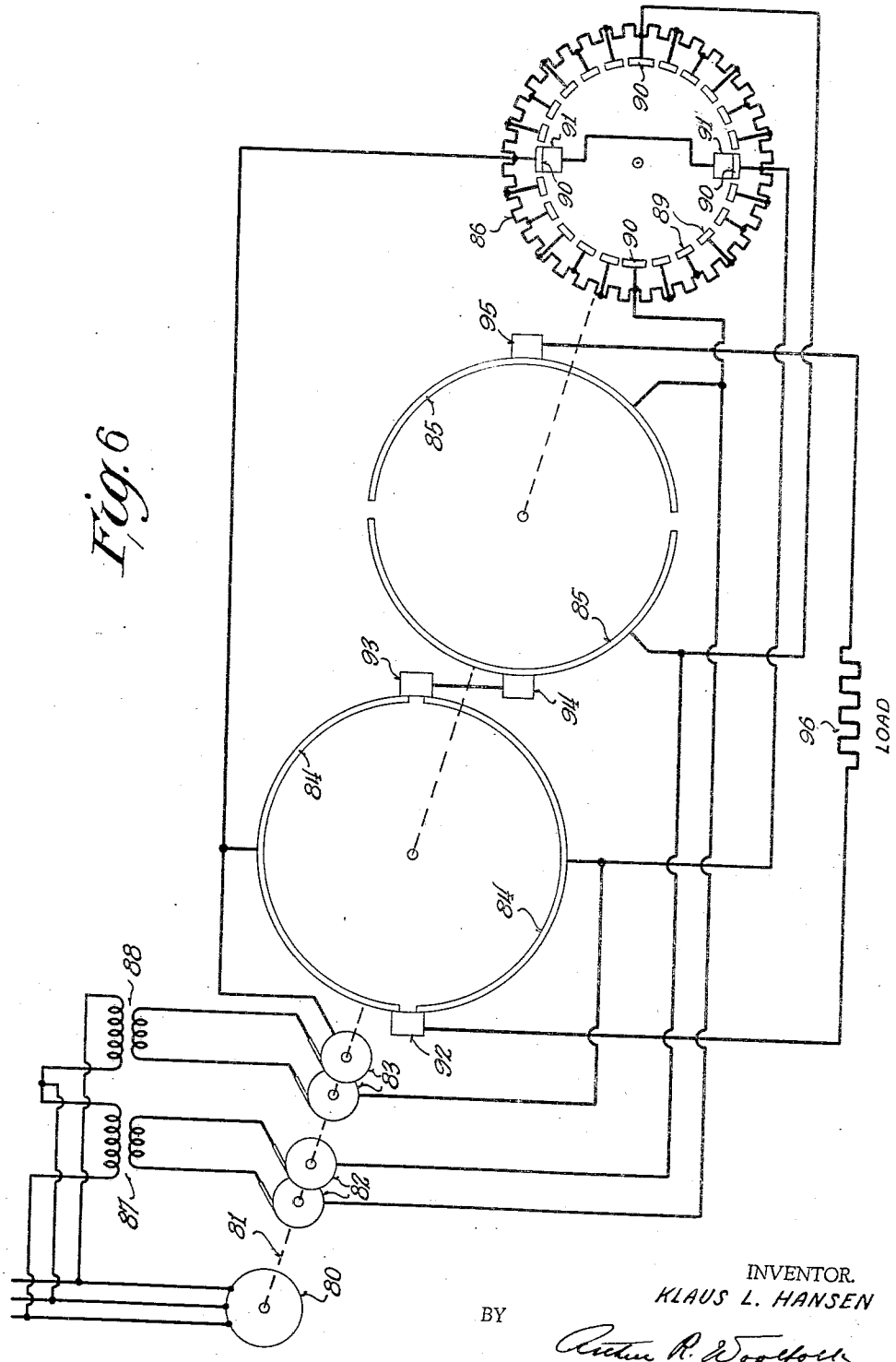
Andrew R. Woolfolk
ATTORNEY.

Sept. 26, 1944. K. L. HANSEN 2,358,926

COMMUTATION MEANS AND METHODS OF COMMUTATION

Filed Dec. 24, 1941 4 Sheets-Sheet 4

Fig. 6



INVENTOR.
KLAUS L. HANSEN

BY

ATTORNEY.

Patented Sept. 26, 1944

2,358,926

UNITED STATES PATENT OFFICE

2,358,926

COMMUTATION MEANS AND A METHOD OF COMMUTATION

Klaus L. Hansen, Milwaukee, Wis.

Application December 24, 1941, Serial No. 424,272

21 Claims. (Cl. 175—364)

This invention relates to commutation means and a method of commutation.

In order to indicate the position of this invention in the field of commutation, one example, namely, rectification by commutation, will be discussed, though it is to be distinctly understood, as will apear hereinafter, that this invention is not limited to rectification solely.

A special form of commutator is the mechanical rectifier which in its simplest form consists of two semi-cylindrical metal segments which are connected to a source of alternating current with two brushes arranged to bear on the commutator at diametrically opposite points, such brushes being connected to a load circuit. The rectifier segments are caused to rotate in synchronism with the alternating current supply and the brushes are adjusted so as to be at the gaps between the segments at the instant the alternating current voltage passes through zero. When the brushes are wide enough to span the openings between segments, it is called short-circuit rectification and, on the other hand, when the brushes are not wide enough to span the gap between segments, it is called open circuit rectification. In the former arrangement the load circuit is never broken and in the latter arrangement the load circuit is broken.

A rectifier constructed in either of the above ways is subject to severe sparking which is more emphasized for all loads other than small resistance loads. Various methods have been employed to lessen the sparking, one of which is to connect a resistance from segment to segment. If this resistance has a high value, it is not effective in preventing sparking and when it is too low, a great deal of current flows through the resistance and thus markedly lowers the efficiency of the apparatus.

Another method which has been used to a limited extent is to divide the segments into several small sub-segments near the points at which commutation takes place and provide resistances between the main segments and the several sub-segments. A modification of this is to gradually change the material of the segments so as to effect an increase in resistance towards the ends of the segments. The purpose of the increased resistance is to limit the circulating current in the brushes at the instant of commutation for short-circuit rectification. This is accomplished to a limited extent but nevertheless by this arrangement resistance is introduced in the main load circuit. Additionally, the number of segments must be relatively small or the time of direct contact between the alternating current supply source and the direct current load circuit is shortened to such an extent that the efficiency is seriously impaired.

If a few segments only are employed, it is necessary to use a high resistance between them in order to effectively limit the circulating current.

Thus in the prior devices there is the choice between good commutation and low efficiency or high efficiency and poor commutation.

This invention is designed to overcome the above noted defects and objects of this invention are to provide novel commutating means and a method of commutation which is very efficient, which avoids sparking to a marked degree, and which can be operated to commutate the alternating current in synchronism or out of synchronism without excessive or detrimental sparking under either condition.

In greater detail, objects of this invention are to provide a parallel path between the main segments which has interposed therein a variable resistance that periodically and automatically fluctuates between maximum and minimum having minimum value at the instant of commutation and having maximum value between the periods of commutation, thereby securing all of the advantages of a bridging resistance between segments while avoiding loss in efficiency.

Further objects are to provide commutating means and a method of commutation which may be operated in synchronism with the alternating current for rectification and which may be operated out of synchronism with the alternating current for frequency conversion and which may be employed in power factor correction and speed control, or which may be used to convert direct current into alternating current if such should be desired.

Further objects are to provide a construction in which relatively wide brushes may bear on the main segments, thereby enabling the shortening of the axial length of the segments although a relatively high current is handled by the device, the invention being designed to provide proper commutation whether short-circuit rectification or open circuit rectification is employed, the bridging circuit coming into play to either directly or partially short-circuit the segments by providing the bridging path at the instant a main brush leaves a segment, engages an approaching segment, or bridges successive segments.

A few of the many embodiments that the invention may take are shown in the accompanying drawings, though it is to be understood that

the forms shown are merely for the purpose of illustration and are not intended as limiting the invention.

In the drawings, Figure 1 is a view showing a synchronous rectifier.

Figure 2 is a development of the main and auxiliary commutators.

Figure 3 is a view showing a possible arrangement of the bridging circuit.

Figure 4 is a view of a rectifier in which polyphase current is fed from the rotor of a driven generator and converted into uni-directional current.

Figure 5 shows the invention as applied to a rectifier for converting three-phase alternating current to uni-directional current.

Figure 6 shows the invention as applied to a rectifier for converting two-phase alternating current to uni-directional current.

Referring to Figure 1, it will be seen that a synchronous motor indicated generally at 1 has been provided and is supplied from the single phase alternating current mains 2. It may be provided with a direct current field 3 connected to a source of direct current hereinafter described and whose excitation may be varied by means of a rheostat 4 if desired. The rotor 5 of the synchronous motor is operatively connected to a pair of slip rings 6 and 7 and with a main commutator having segments 8 and 9 and with an auxiliary commutator having a plurality of segments 10 certain of which may be made larger than others as indicated at 11.

The auxiliary commutator is provided with a continuous resistor 12 which at regular intervals is connected to the segments 10 and 11. The main and auxiliary commutator are carried by suitable insulating supporting means, not shown, in any conventional manner.

The rotor 5 may be directly connected to the slip rings 6 and 7 and to the main and auxiliary commutators by means of the shaft 13 or may be connected by gearing not shown. In the event that the speed of the main and auxiliary commutators is not the same as that of the synchronous motor, suitable gearing would be interposed so as to have one segment of the main commutator pass under a brush for one-half cycle of the alternating current. The showing for Figure 1 is that for a two-pole synchronous motor and for a two-segment main commutator.

A pair of main brushes 14 are arranged at diametrically opposite points and bear on the segments 8 and 9 of the main commutator. A pair of auxiliary brushes 15 are arranged at diametrically opposite points electrically at right angles to the position of the brushes 14 and are arranged to bear against the segments of the auxiliary commutator. It is to be noted that the resistor 12 is connected at diametrically opposite points to the segments 8 and 9 and it is to be noted also that the auxiliary brushes 15 are connected by the conductor 16 so that the brushes 15 are directly connected to each other. The circuit 16 will hereinafter be referred to as a bridging circuit. It may have resistance if so desired, or may have a combination of resistance, inductance, or capacity, as will be described hereinafter. The main brushes 14 are connected to the load 17 and supply uni-directional current to the load, as will appear hereinafter. The slip ring 7 is connected to the segment 8 of the main commutator and the slip ring 6 is connected to the segment 9 of the main commutator.

Brushes 18 bear on the slip rings 6 and 7 and are connected to opposite sides of the secondary of a transformer 19 supplied from the mains 2. It is to be understood that all of the figures in the drawings are merely diagrammatic figures and no attempt has been made to show the mechanical details as these may take any of the well known forms.

If desired, the auxiliary commutator may be a separate and distinct member from the main commutator, or if desired, the main commutator segments, as shown in Figure 2 and indicated at 8' and 9', may be provided with projecting portions 11' which correspond to the segments 11 which together with the segments 10' of Figure 2 constitute the different segments of the auxiliary commutator. The auxiliary brushes are indicated in dotted lines in Figure 2 and the main brushes 14' are also indicated by dotted lines. For the sake of clearness the upper and lower main brushes 14' are supposed to indicate one and the same brush in the developed form of Figure 2.

Either of the constructions, namely, a separate auxiliary commutator wholly distinct from the main commutator may be employed or one in which projections from the main commutator form certain segments of the auxiliary commutator, may be employed as shown in Figure 2.

The operation of the rectifier shown in Figure 1 is as follows: Assume that the motor indicated generally at 1 is running in synchronism with the alternating current in the mains 2 and alternating current is supplied to the segments 8 and 9 of the main commutator. The main commutator and the auxiliary commutator rotate in synchronism with the alternating current and consequently at successive half cycles the segments 8 and 9 are alternately connected to the upper and lower main brushes 14 and therefore direct current or uni-directional current flows through the load circuit 17. However, it is to be noted that at the instant commutation takes place, the segments 8 and 9 are short-circuited by the bridge circuit 16 through the medium of the auxiliary brushes 15 and the segments 11.

The segments 11 and the brushes 15 are so made that prior to the time a main brush leaves one of the segments of the main commutator, a bridge circuit is established between the segments 11 of the auxiliary commutator which are directly connected to the segments 8 and 9 of the main commutator. Thus when the main brushes 14 bridge the gap between the commutator segments of the main commutator, a bridging path or parallel path is formed by the bridging circuit 16 and there is, therefore, no circulating current in the main brushes 14. Consequently substantially sparkless commutation will take place.

As the main and auxiliary commutators rotate synchronously to a different position where the main brushes are spaced from the gap between the segments of the main commutator, a part of the resistance 12 is interposed in the bridging circuit and the amount of resistance so interposed increases substantially uniformly upon rotation of the main and auxiliary commutators arriving at a maximum when the main brushes are centrally located with respect to the segments 8 and 9 of the main commutator. Thereafter this interposed resistance decreases to a minimum which, in the form shown in Figure 1, is substantially zero resistance, namely, merely the resistance of the bridging circuit just prior to the instant that the main brushes bridge the gap be-

tween the segments of the main commutator and thus short-circuited condition persists until after the main brushes have left the receding edge of the corresponding segment of the main commutator.

It will be seen, therefore, that at the instant commutation takes place, the segments of the main commutator are short-circuited and that thereafter resistance is interposed in the bridge circuit which gradually increases in value and thereafter decreases, the increase and decrease being periodic as hereinabove described. Thus it will be seen that substantially sparkless commutation takes place not only at the main brushes but also at the auxiliary brushes, for if the zero point of both the voltage and current does not occur at the instant of commutation, nevertheless the auxiliary circuit is not suddenly broken but instead resistance is gradually interposed in this auxiliary circuit which resistance increases to a maximum and thereafter decreases as hereinabove described. Thus substantially sparkless commutation also takes place at the auxiliary brushes as well as at the main brushes. It is obvious that when the main brushes bridge the segments of the main commutator, any difference in potential that would tend to exist under adverse conditions as hereinabove set forth between the segments of the main commutator is neutralized by the bridging circuit.

It is to be noted particularly that this arrangement will take care of very adverse conditions even when there is considerable phase displacement between the current and voltage curves. The auxiliary brushes cooperating with the auxiliary commutator and the resistance **12** automatically produces a zero potential or neutral zone in that part of the cycle where the main brushes bridge the segments of the main commutator, regardless of the conditions of the load circuit. Of course, where there is considerable phase displacement between the current and voltage, there necessarily will be a larger current in the bridge circuit **16** than where the current and voltage are in phase.

The resistance **12** is so chosen that a relatively small current flows between the segments of the main commutator when the main brushes are approximately centrally located on the segments of the main commutator and that at the instant of commutation substantially short-circuit condition exists due to the bridging circuit **16**. Thus a relatively high efficiency is produced, as there is a very small amount of waste energy, while still maintaining substantially sparkless commutation.

It is to be noted that the synchronous motor **1** may be relatively small as it does not transmit the power load of the load circuit **17** but merely serves to rotate the several rotary parts in synchronism with the alternating current.

It is to be noted further that the main brushes may be made circumferentially as wide as desired and that the gap between the segments of the main commutator may also be made as wide as desired. This permits increasing the circumferential width of the main brushes and correspondingly reduces the axial length of the commutator for the same current density. In other words, the axial length of the main current carrying segments may be materially shortened.

It is to be noted that in the description and showing of this form of the invention and in all other forms of the invention short-circuit commutation has been illustrated and described, but it is to be distinctly understood that open circuit commutation could be employed if so desired. In this case before a main brush left a main commutator segment, the short-circuit bridge path would be established and also this short-circuit bridge path would be maintained until after a main brush arrived at the succeeding commutator segment, or at all events would be reestablished when a main brush arrived at a succeeding commutator segment.

For short-circuit commutation as shown, the bridge circuit is so arranged as described hereinabove that the main segments are short-circuited prior to the time a main brush contacts an approaching segment and is maintained until after the main brush leaves a receding segment.

It is apparent that the bridge circuit **16** need not be a pure dead short-circuit path but may, if desired, have resistance and inductance and capacity therein, as indicated in Figure 3, in which the auxiliary brushes are indicated at **20**, the resistance at **21**, the inductance at **22**, and the capacity at **23**. The inductance and capacity may form a tuned circuit which may resonate at either the main frequency or at any of the harmonic frequencies or at some other frequency, depending upon the result it is desired to obtain. For instance, if for a given set of conditions certain harmonics are generated at the instant of commutation at the main commutator, it may be found desirable to tune this portion of the auxiliary circuit, namely, that including the condenser **23** and inductance **22**, to such harmonics, thus providing a substantially short-circuit condition for such harmonics. In addition to this, if it is desired, the bridge circuit **16** of Figure 1 may have resistance in it if such is required.

While Figure 3 has been shown as especially applicable to the device shown in Figure 1, it is to be understood that capacity, inductance, and resistance can be used in the bridge circuits in any form of the invention.

It is to be understood that in the form of the invention shown in Figure 1, and in all other forms of the invention as well, the main and auxiliary brushes may be arranged to be simultaneously and equally shifted as desired so that all of the brushes may be shifted as a unit. The purpose of this is to make it possible to adjust all of the brushes as a unitary structure to their most desirable position depending on the conditions to be met.

It is obvious that if the rectifier ran at half synchronous speed, there would be four main segments and four points of connection between the circular resistance and the main segments and there would be four auxiliary brushes connected together.

Figure 4 shows how this novel form of commutation may be applied to the rectification of two-phase current so that each phase is employed in supplying the direct current or uni-directional current to the load circuit. In Figure 5 any suitable motor indicated at **42** is connected by means of the shaft **43** with the armature of a generator and with the rectifier. The generator is designed to produce two-phase current and at equally spaced points around the armature winding **44** connections lead to the segments of the main commutator indicated at **45**, **46**, **47** and **48**.

A pair of main brushes **49** and **50** bear upon the main commutator at diametrically opposite points. The continuous resistor is indicated at **51** and it is connected at four equally spaced points to the four segments **45**, **46**, **47** and **48**. It is also

connected at regular intervals to the segments of the auxiliary commutator. It is to be noted that four of the segments of the auxiliary commutator indicated at 53 are larger than the remaining segments 52 for the purpose hereinbefore described. Four auxiliary brushes indicated at 54 are located at equally spaced points and bear on the auxiliary commutator. It is to be noted that the brushes 54 are spaced forty-five electrical degrees from the brushes 49. The auxiliary brushes 54 are connected in pairs by bridging circuits as shown, so that the two brushes which are forty-five electrical degrees on opposite sides of the main brush 49 are connected together and the two brushes which are forty-five electrical degrees on opposite sides of the main brush 50 are connected together. As previously described, all of the brushes are shiftable as a unit.

The generator is provided with shunt windings 55 which are connected directly across the main brushes 49 and 50 by means of the conductors 56 and 57. The load is indicated at 58 and has one side connected directly to the main brush 50. The other side of the load is connected by means of the conductor 59 to one side of the series winding 60 of the generator and the other side of the series winding is connected by means of the conductor 61 to the other main brush 49.

It is to be noted that the generator is arranged to develop two-phase current and one phase is connected to diametrically opposed segments 45 and 47 of the main commutator and the other phase is connected directly to the opposed segments 46 and 48 of the main commutator.

It is apparent that the rectified current is more nearly a uniform direct current than in the case of the rectifier illustrated in Figure 1, where a single phase arrangement is employed.

It is also apparent that instead of having the generator supply the two-phase current to the respective pairs of main segments 45, 47 and 46, 48, these segments could be connected to the secondaries of transformers supplied from a two-phase supply system.

In either arrangement for two-phase rectification it will be seen that the induced voltage impressed on the main segments produces zero voltage between the segments when the segments are bridged by the main brushes.

The novel form of commutation may be applied to rectification for a three-phase system. Figure 5 shows such an arrangement. In this figure, a three-phase synchronous motor is indicated by the reference character 62 which is connected by means of a shaft 64 with the rectifier and with three pairs of slip rings indicated respectively at 65, 66 and 67. Brushes bearing on these slip rings are supplied with current from the secondaries of three transformers indicated generally at 68, 69 and 70. The primaries of the transformers are connected in any conventional manner to the same three-phase mains which supplies the motor 62. The pair of slip rings 65 are connected to the diametrically opposed segments 71 of the main commutator. The slip rings 66 are connected to the diametrically opposed segments 72 of the main commutator and the slip rings 67 are connected to the diametrically opposed segments 73 of the main commutator. A pair of main brushes 74 are provided which bear on the main commutator and which are located at diametrically opposed points. These main brushes are connected to the load indicated at 75.

One of the phases is reversed so as to produce a 60° displacement between the voltage applied to the segments.

The auxiliary commutator is provided with a plurality of segments 76 and with six regularly spaced segments 77. The segments 77 are made larger than the segments 76 for the purpose hereinbefore described. The segments 77 are connected to the segments of the main commutator and all of the segments of the auxiliary commutator are connected at regularly spaced points to the continuous resistance 78. Four auxiliary brushes indicated at 79 are positioned thirty electrical degrees on each side of the main brushes 74 and are connected in pairs as shown in Figure 5 to provide bridging circuits. It is to be noted that the two auxiliary brushes 79 which are spaced respectively thirty electrical degrees on opposite sides of a main brush 74 are connected together and the other two auxiliary brushes 79 which are respectively spaced thirty electrical degrees on opposite sides of the other main brush 74 are connected together.

It will be noted that this form of the invention provides for the rectification of three-phase current for supplying a single load circuit and is so arranged that the rectified current very closely approaches a uniform direct current.

In two-phase rectification the invention may be applied so that each of the secondaries are in series with the load circuit all of the time. Figure 6 shows this arrangement. In Figure 6 a synchronous motor is indicated by the reference character 80 and the shaft 81 thereof carries two pairs of slip rings 82 and 83, two pairs of main commutator segments 84 and 85, and the auxiliary commutator and its continuous resistor 86. A pair of brushes are connected to the secondary of one of the transformers 87 and bear upon the slip rings 82 and similarly a pair of brushes are connected to the secondary of the other transformer 88 and bear upon the slip rings 83. These transformers as well as the motor are supplied with two-phase current from the same mains. The slip rings 82 are connected to the segments 85 and the slip rings 83 are connected to the segments 84. In addition to this, the segments 84 are connected to diametrically opposite points on the continuous resistance 86 of the auxiliary commutator and the segments 85 are connected to diametrically opposite points on the continuous resistor 86, the points of connection being spaced a quarter way around such resistance. The auxiliary commutator is provided with a plurality of segments 89 and with four relatively larger segments 90 for the purpose hereinabove described. Auxiliary brushes 91 bear on the auxiliary commutator and are connected by a bridging circuit. A pair of main brushes 92 and 93 bear on the segments 84 of the main commutator and a pair of main brushes 94 and 95 bear on the segments 85 of the other portion of the main commutator. The main brushes 93 and 94 are connected together and the brushes 92 and 95 are connected to opposite ends of the load 96.

It is apparent that when two-phase current is supplied the apparatus, each of the secondaries are always in the load circuit and commutation for one secondary occurs at ninety mechanical degrees from commutation for the other secondary due to the arrangement of the segments 84 and 85 of the main commutator. It is to be noted that a single continuous resistor 86 is used for both pairs of the segments of the main commutator. This form of the invention has the advantage that commutation for any pair of segments always

takes place at the zero point. Also it is to be noted that for a given direct current load voltage, less voltage difference need exist between each pair of segments of the main commutator than in the form of the invention shown in Figure 4.

It is to be noted also that the time required to dissipate the current which existed in the auxiliary circuit at the time of commutation with respect to one pair of segments of the main commutator has been extended to a half period instead of a quarter period for the form of the invention shown in Figure 4.

It can readily be seen that the principle shown in Figure 6 can be followed for a greater number of phases than two if so desired.

It will be seen that this novel method of commutation may be used in many different types of devices and for many different services.

It will be seen further that substantially sparkless commutation results and that many different devices can be constructed in which the method of commutation hereinabove described is employed. A few of the many devices have been illustrated and described. The invention provides a novel means and method of commutation which is applicable to widely different services or purposes. For instance, it may be followed for rectification as herein shown, or may be followed for frequency change, power factor correction and speed control as in my divisional United States Patent No. 2,341,095 of February 8, 1944. For rectification obviously the devices are operated in synchronism, whereas for frequency conversion such is not the case. Under all conditions, however, minimum sparking results as a bridging path of low resistance is established at the time of commutation whose resistance periodically and automatically varies between minimum and maximum to avoid needless losses while securing substantially sparkless commutation in the manner hereinabove set forth in detail.

It is to be noted that a load circuit is established in all forms of the invention and that this load circuit includes the main brushes and is unbroken at all times.

Wherever "auxiliary commutator" is referred to, it is intended to cover a construction whether the auxiliary commutator is wholly distinct and separate from the main commutator or whether it is made as a part of the main commutator.

Although this invention has been described in considerable detail, it is to be understood that such description is intended as illustrative rather than limiting, as the invention may be variously embodied and is to be interpreted as claimed.

I claim:

1. The method of commutating electric current comprising causing relative motion between main commutator segments and main brushes, and establishing a variable resistance bridging circuit between said main commutator segments independently of the main brushes and decreasing the resistance of said bridging circuit to a substantially short-circuit value at the instant the main brushes are leaving said main commutator segments.

2. The method of commutating electric current comprising causing relative motion between main commutator segments and main brushes, and establishing a variable resistance bridging circuit between said main commutator segments independently of the main brushes and decreasing the resistance of said bridging circuit to a substantially short-circuit value at the instant the main brushes are initially engaging said main commutator segments.

3. The method of commutating electric current comprising causing relative motion between main commutator segments and main brushes to cause said main brushes to periodically change-over with respect to said main commutator segments, and establishing a substantially short-circuiting bridging circuit between said main commutator segments independently of the main brushes during change-over at the instant the main brushes are initially engaging said main commutator segments and subsequently causing the resistance of the bridging path to sequentially increase to a maximum and during change-over decrease to a minimum.

4. The method of commutating electric current comprising causing relative motion between main commutator segments and main brushes to cause said main brushes to periodically change-over with respect to said main commutator segments, and establishing a substantially short-circuiting bridging circuit between said main commutator segments independently of the main brushes during change-over at the instant the main brushes are leaving said main commutator segments, and subsequently causing the resistance of the bridging path to sequentially increase to a maximum and during change-over decrease to a minimum.

5. The method of commutating electric current comprising causing relative motion between main commutator segments and main brushes to cause said main brushes to periodically change-over with respect to said main commutator segments, maintaining a bridging circuit between the said main commutator segments independently of the main brushes and periodically varying the resistance of the bridging circuit from maximum to minimum, the minimum value of the resistance of the bridging circuit occurring during change-over at the instant the main brushes are leaving said main commutator segments.

6. The method of commutating electric current comprising causing relative motion between main commutator segments and main brushes to cause said main brushes to periodically change-over with respect to said main commutator segments, maintaining a bridging circuit between the said main commutator segments independently of the main brushes and periodically varying the resistance of the bridging circuit from maximum to minimum, the minimum value of the resistance of the bridging circuit occurring during change-over at the instant the main brushes are initially engaging said main commutator segments.

7. The method of commutating electric current comprising causing relative motion between main commutator segments and main brushes, maintaining a bridging circuit between the said main commutator segments independently of the main brushes and periodically varying the resistance of the bridging circuit from maximum to minimum, the minimum value of the resistance of the bridging circuit occurring at the instant the main brushes are bridging said main commutator segments.

8. The method of commutating alternating current comprising causing relative motion between main commutator segments and main brushes, leading alternating current to the commutator segments, maintaining a bridging circuit between said main segments independently

of said main brushes, and causing the resistance of the bridging circuit to periodically vary from a minimum at the instant of commutation to a maximum between periods of commutation.

9. The method of rectifying alternating current comprising causing relative motion between main commutator segments and main brushes, leading alternating current to the said main commutator segments, maintaining said relative motion in synchronism with the alternating current so that a predetermined number of said main segments pass a main brush for each cycle, maintaining a bridging circuit between said segments independently of said main brushes, and causing the resistance of the bridging circuit to periodically vary from a minimum at the instant of commutation to a maximum between periods of commutation.

10. A device for commutating electric current comprising a main and an auxiliary commutator each provided with segments, main and auxiliary brushes bearing on said main and auxiliary commutators respectively, means for causing relative rotation between said commutators and their respective brushes, means for leading current to the segments of said main commutator, a resistor connected at spaced points to the segments of said auxiliary commutator, certain segments of said auxiliary commutator being connected to the segments of said main commutator, and a bridge circuit joining the brushes of said auxiliary commutator.

11. A device for commutating electric current comprising a main and an auxiliary commutator each provided with segments, main and auxiliary brushes bearing on said main and auxiliary commutators respectively, means for causing relative rotation between said commutators and their respective brushes, means for leading current to the segments of said main commutator, a continuous closed resistor connected at spaced points to the segments of said auxiliary commutator, certain segments of said auxiliary commutator being connected to the segments of said main commutator, and a bridge circuit joining the brushes of said auxiliary commutator.

12. A device for commutating electric current comprising a revolubly mounted unit including main and auxiliary commutators each provided with segments, said unit including a resistance, means for rotating said unit, said auxiliary commutator having its segments connected to spaced points of said resistance and having spaced segments connected to the segments of said main commutator, main and auxiliary brushes bearing on said main and auxiliary commutators respectively, and a bridging circuit connecting said auxiliary brushes.

13. In a device for rectifying alternating current, a source of alternating current, a synchronous motor connected to said source, a main commutator having its segments supplied from said alternating current source, an auxiliary commutator having a plurality of segments, said main and auxiliary commutators being driven from said synchronous motor, equally spaced segments of said auxiliary commutator being connected to the segments of said main commutator, a closed resistor having spaced points connected to the segments of said auxiliary commutator, auxiliary brushes bearing on said auxiliary commutator and electrically connected by a bridging circuit, a load circuit, and main brushes bearing on said main commutator and connected to said load circuit.

14. In a device for rectifying alternating current, a source of alternating current, a synchronous motor connected to said source, a transformer having its primary connected to said source, a main commutator having its segments supplied from the secondary of said transformer, an auxiliary commutator having a plurality of segments, said main and auxiliary commutators being driven from said synchronous motor, equally spaced segments of said auxiliary commutator being connected to the segments of said main commutator, a closed resistor having spaced points connected to the segments of said auxiliary commutator, auxiliary brushes bearing on said auxiliary commutator and electrically connected by a bridging circuit, a load circuit, and main brushes bearing on said main commutator and connected to said load circuit.

15. A rectifier comprising a main commutator having a plurality of segments, a source of polyphase alternating current connected to the segments of said main commutator, a load circuit, a pair of main brushes bearing on said main commutator and connected to the load circuit, an auxiliary commutator having a plurality of segments, regularly spaced segments of said auxiliary commutator being connected to the segments of said main commutator, a resistor connected at spaced points to the segments of said auxiliary commutator, auxiliary brushes connected by bridging circuit means and bearing upon said auxiliary commutator, and motor means for driving said main and auxiliary commutators in synchronism with said source of polyphase alternating current.

16. A rectifier comprising a main commutator having a plurality of segments, a source of two-phase alternating current connected to the segments of said main commutator, a load circuit, a pair of main brushes bearing on said main commutator and connected to the load circuit, an auxiliary commutator having a plurality of segments, regularly spaced segments of said auxiliary commutator being connected to the segments of said main commutator, a resistor connected at spaced points to the segments of said auxiliary commutator, two pairs of auxiliary brushes connected by bridging circuits and bearing upon said auxiliary commutator, and synchronous motor means for driving said main and auxiliary commutators.

17. A rectifier comprising a main commutator having at least three pairs of segments, a source of three-phase alternating current connected to the segments of said main commutator, a load circuit, a pair of main brushes bearing on said main commutator and connected to the load circuit, an auxiliary commutator having a plurality of segments, regularly spaced segments being connected to the segments of said main commutator, a resistor connected at spaced points to the segments of said auxiliary commutator, two pairs of auxiliary brushes connected by bridging circuits and bearing upon said auxiliary commutator, and a three-phase synchronous motor supplied from said source of three-phase alternating current for driving said main and auxiliary commutators.

18. A rectifier comprising at least two main commutators, each having a pair of segments, a source of polyphase alternating current connected to the segments of said two main commutators, a load circuit, a pair of main brushes bearing on each main commutator, all of said main brushes being connected in series with said

load circuit, an auxiliary commutator having a plurality of segments, regularly spaced segments of said auxiliary commutator being connected to the segments of said main commutators, a resistor connected at spaced points to the segments of said auxiliary commutator, a pair of auxiliary brushes connected by a bridging circuit and bearing upon said auxiliary commutator, and synchronous motor means driven from the source of polyphase current and driving said main and auxiliary commutators.

19. The method of commutating electric current comprising causing relative motion between main commutator segments and main brushes to cause said main brushes to periodically change-over with respect to said main commutator segments, establishing a substantially short-circuiting bridging circuit between said main commutator segments independently of said main brushes during change-over at the instant said main brushes are leaving said main commutator segments, establishing a load circuit including said main brushes, and maintaining said load circuit unbroken at all times.

20. The method of commutating electric current comprising causing relative motion between main commutator segments and main brushes to cause said main brushes to periodically change-over with respect to said main commutator segments, establishing a substantially short-circuiting bridging circuit between said main commutator segments independently of said main brushes during change-over at the instant said main brushes are initially engaging said main commutator segments, establishing a load circuit including said main brushes, and maintaining said load circuit unbroken at all times.

21. The method of commutating electric current comprising causing relative motion between main commutator segments and main brushes to cause said main brushes to periodically change-over with respect to said main commutator segments, establishing a substantially short-circuiting bridging circuit between said main commutator segments independently of said main brushes during change-over, establishing a load circuit including said main brushes, and maintaining said load circuit unbroken at all times.

KLAUS L. HANSEN.