No. 857,561. PATENTED JUNE 18, 1907.

M. LEBLANC.

APPARATUS FOR GENERATING HIGH FREQUENCY ALTERNATING CURRENTS.

APPLICATION FILED MAR. 14, 1906.

3 SHEETS—SHEET 1.

Fig. 1.

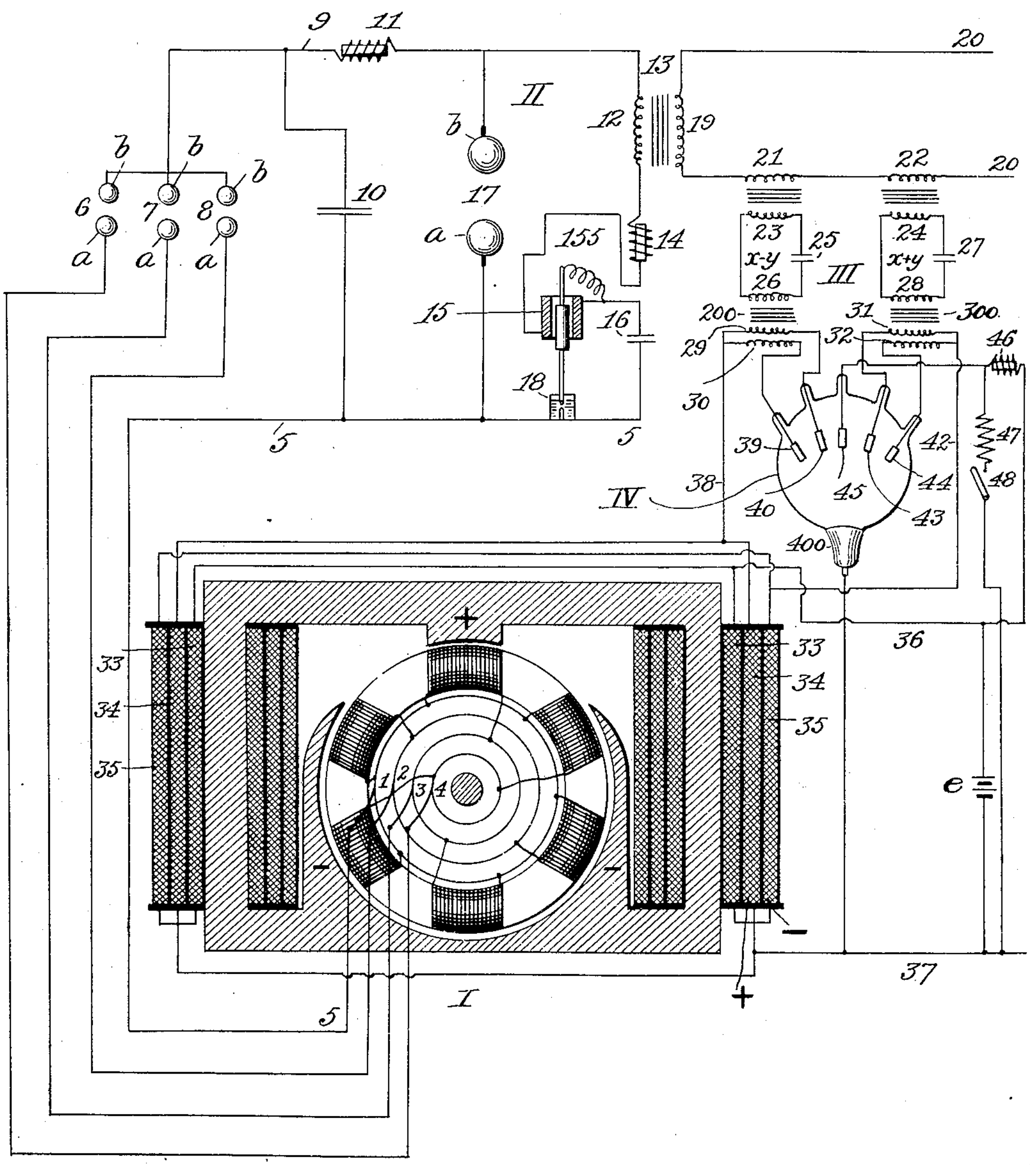

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Fig. 2.

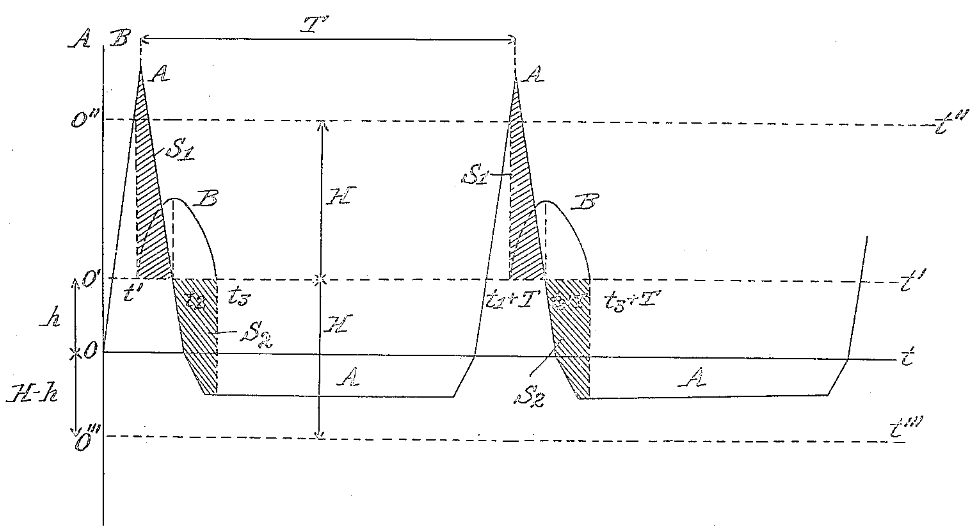
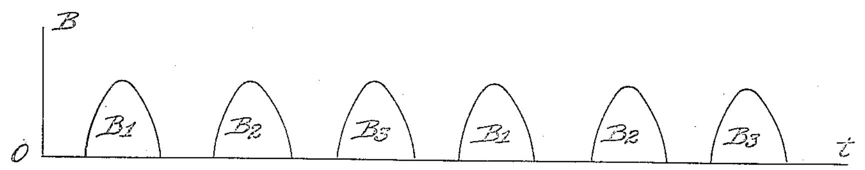


Fig. 3.



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3 SHEETS—SHEET 3.

Fig. 4.

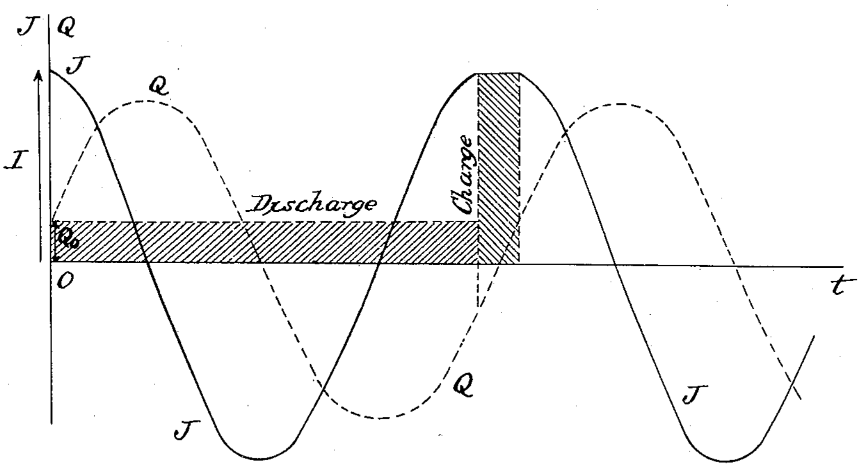


Fig. 5.

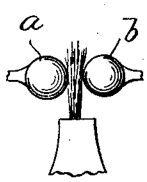


Fig. 6.

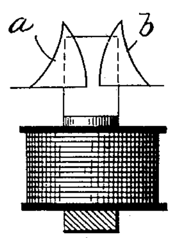


Fig. 7.

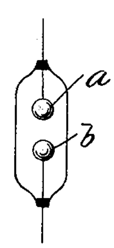
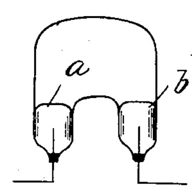


Fig. 8.



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UNITED STATES PATENT OFFICE.

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APPARATUS FOR GENERATING HIGH-FREQUENCY ALTERNATING CURRENTS.

No. 857,561. Specification of Letters Patent. Patented June 18, 1907.

Original application filed February 5, 1904, Serial No. 192,227. Divided and this application filed March 14, 1906. Serial No. 306,033.

To all whom it may concern:

Be it known that I, MAURICE LEBLANC, a citizen of the Republic of France, and a resident of Paris, France, have invented a new and useful Apparatus for Generating High-Frequency Alternating Currents, of which the following is a specification.

In an application No. 183,246, heretofore filed by me, on Nov. 30, 1903, I have described and claimed a means for producing unidirectional currents, which comprises a dynamo generating and alternating electromotive force having its maximum value of one sign greater than its maximum value of the opposite sign, and an electric exploder which is adjusted to establish an arc and to permit current to pass only with the electromotive-force of that sign which has the greater maximum value. The unidirectional current thus produced may be made continuous by means of a condenser in shunt of these parts.

In another application No. 183,247, heretofore filed by me, on Nov. 30, 1903, I have shown a means for changing the continuous currents thus produced into alternating currents traversing the primary coil of a transformer, which means consists, generally speaking, of a resonator connected to the line carrying the continuous currents and an electric exploder in shunt of the resonator, the parts being electrically proportioned so that the continuous current periodically charges the resonator when the exploder arc is not established and the resonator perodically discharges as an alternating current through the exploder when its arc is established, these alternating currents being led through the primary coil of the transformer. But in the application No. 183,247, the alternating current thus set up in the primary coil of the transformer is rectified into a continuous current in the working circuit which is connected to the transformer secondary.

Now in the present application, I may utilize the means for generating a continuous current above referred to and I may furthermore employ the means for converting this continuous current into an alternating current in the primary circuit of a transformer as above described. But the alternating currents generated in the secondary coil of this transformer, instead of being rectified, I now propose to supply as alternating currents of high frequency to the working circuits, and I furthermore propose to make both the effective intensity and the frequency of these high frequency currents as constant as those of currents furnished by alternators, so that one may utilize with them all the properties of electrical resonance. To this end I have devised an exciter for the dynamo or prime source of current, which exciter takes its energy from the working circuit and acts in such a manner, as will be more specifically pointed out later on, that any departure from the normal frequency of the alternating working currents brings about such a change in the excitation of the prime source of electrical energy as to restore this frequency to its normal value.

In the drawings,—Figure 1 shows a complete diagram of my system; Fig. 2 shows the electromotive-force and current curves of the prime source of electrical energy which I prefer to employ; Fig. 3 shows another set of current curves of this prime source; Fig. 4 shows the current curve of the apparatus which I prefer to use to transform the continuous currents into alternating currents; and Figs. 5, 6, 7 and 8, show types of electric exploders which I may employ.

In Fig. 1, I have indicated by I the prime source of electrical energy which I prefer to employ and which, taken with the electrical exploders shown as spark gaps 6, 7, 8, and the condenser 10, generates a continuous current of practically constant intensity. I have designated by II the electrical resonator and the exploder in shunt thereof, for transforming this continuous current into alternating currents. I have furthermore designated by III the frequency regulator which I have devised, by means of which any departure from the normal frequency of the alternating working currents produces such a change in the excitation of the prime generator as to restore this frequency to its normal value. The Roman numeral IV designates an electric valve or a symmetric device, used as a part of this exciter, which has for its function to permit only currents of a given sign to pass through it and to thereby rectify the alternating exciting currents, which are taken from the working circuit, into the continuous currents which are necessary to modify the excitation of the prime generator.

Coming now to a more specific description of the dynamo I which generates an alternating electromotive-force having its maximum value of one sign greater than its maximum value of the opposite sign, it will be found to consist of a pair of field poles having the circumferential extent of the positive pole, say, much less than that of its negative pole. The armature, in the case shown, consists of six coils connected in diametrically opposite pairs, and connected to the rings 1, 2, 3, 4, in such a manner that the brush which rests on the ring 1 acts as a common return for all the pairs of coils, and the brushes which rest on the rings 2, 3, 4, are each respectively connected to the other end of one of the three pairs of coils. The armature is supposed to turn at constant velocity and to be separately excited by means of field coils 33, 33, in a circuit with a source of continuous current, which impresses a constant difference of potential upon the terminals of the field coils.

It is manifest that instead of using two field poles, I may use a number of pairs of field poles; that instead of using three pairs of armature coils I may use any other number of such pairs; that I may use either a series or a parallel connection between the coils constituting a pair of coils; and that I may connect the armature coils in sets of three or more instead of in pairs.

Since the circumferential extent of the positive field pole of my prime generator is less than that of the negative field pole, it follows that the flux intensity is much greater under the narrow pole than under the broad pole. The armature being turned at a constant velocity within the magnetic field thus produced, it further follows that the electromotive-force developed in any conductor arranged on the surface of the armature parallel to the armature axis will vary as a function of the time according to a law something like that represented by the curve A of Fig. 2. That is to say, the maximum value of the positive electromotive-force will be much greater than the maximun value of the negative electromotive-force whereas the duration of the positive electromotive-force period will be much less than the duration of the negative electromotive-force period.

By referring to Fig. 1, it will be seen that the electrical exploders 6, 7, and 8, which each consist of a pair of separated balls *a*, *b*, are connected to the armature circuits of the prime generator I so that the balls *b*, *b*, *b*, are all connected through the condenser 10 to one side of the armature coils by means of the common return conductor 5, and that the balls *a*, *a*, *a*, by means of the brushes 2, 3 and 4, are each respectively connected to the other side of the armature coils. The condenser 10, in fact, is in shunt of the set of exploders 6, 7 and 8, and the armature circuits of the prime generator; and each armature circuit is in series with one exploder.

Since the electric exploder or spark gap *a*, *b*, may be of common form, I need only remark that in order to establish an arc between such exploders it is necessary to develop between them a voltage of a given magnitude; that the arc being once established, its resistance becomes quickly negligible, and that the arc is immediately extinguished when the intensity of the current which traverses it is zero or becomes inferior to a certain limit.

I designate by H the voltage necessary to establish or spring an arc in the exploders 6, 7, 8, and by h the voltage normally maintained between the plates of the condenser 10. It is to be observed that the magnitude of h is always less than the magnitude of H. I furthermore assume, to fix ideas, that the maximum positive value of the electromotive-force E supplied by any given armature circuits of the dynamo, is greater than the sum $H+h$, and that its maximum negative value is smaller than the difference $H-h$. I am, for the present, concerned merely with one armature circuit, say that connected with the exploder 6. Since now, during the period of positive electromotive-force, there is available, to establish the arc in the exploder, by reason of the presence of the condenser 10, a voltage of $E-h$, it will be clear that some time during the period in which the armature coil is the seat of positive electromotive-force, there will be available a voltage greater than $H+h-h$, that is to say H, to establish this arc in the exploder. It follows that the exploder arc will always be established some time during the period of positive electromotive-force in the armature coil.

Referring now to Fig. 2, in which I have traced a curve showing the variation of the electromotive-force E' developed between the balls of the exploder 6, I will assume that at the moment t_1, the voltage developed between the balls of the exploder is equal to H, that is that it is at this moment sufficient to establish the arc. Starting at this moment t_1, the armature circuit will be traversed by a current, the intensity of which will gradually increase, as is shown by the curve B in Fig. 2. If we neglect the energy lost in the circuits of the dynamo and in the exploder, that is to say if we suppose negligible the resistance of the armature circuits and of the exploder, when the latter is in action, the intensity of the current which traverses the exploder, once it is in action, will only be limited by the action of the self-induction of the armature circuit under consideration. This means, in effect, that the current B will lag 90 degrees behind the electromotive-force A, so that the intensity of this current B will be in maximum at the moment when the electromotive-force across the exploder, or the electromotive-force $E-h$, is zero. All this is well shown in Fig. 2 in which the axis of abscissa is $o\ t$. I have furthermore traced, in dots and dashes, a line $o'\ t'$ parallel to this axis and at a distance h above the same. The electromotive-force generated by the armature coil of the prime generator is to be measured positive and negative above and below the axis $o\ t$ along the curve A. The electromotive-force across the terminals of the exploder 6, by reason of the action of the condenser 10 having a normal voltage of h, is to be measured positive and negative above and below the line $o'\ t'$.

Since the maximum positive electromotive-force generated by the armature circuits is greater than $H+h$ as before assumed, the curve A will always have a part of its peak above the line in dashes $o''\ t''$ which is parallel to $o'\ t'$ and at a distance H therefrom. Therefore, during some portion of the period of positive electromotive-force, there will always be enough potential across the exploder 6 to establish an arc, as has been said before.

Since the maximum negative electromotive-force generated by the armature circuits of the prime generator is always less than $H-h$, it follows that the curve A will never reach the line $o'''\ t'''$ drawn at a distance of H below the axis $o'\ t'$. This, put in other words, means that the maximum negative electromotive-force across the terminals of the exploder 6, which is measured downward from the line $o'\ t'$, can never be equal to H, which means that it will always be insufficient to initially establish an arc across the exploder.

I have shown above that at an epoch of positive electromotive-force a t_1 current passes across the exploder which increases in intensity until the epoch t_2. Thereupon the intensity of this current diminishes and becomes zero at the epoch t_3 which epoch, according to the fundamental laws of current induction, is determined by the fact that the area S_2 shown in hachures is equal to the area S_1 shown in hachures. It can readily be shown that the distance $t_1\ t_3$ is always less than the distance T between two adjacent peaks of the curve A, which means that the current represented by the curve B will always become zero before the end of that complete period of electromotive-force in which the current was initially started. But when the current represented by the curve B, that is the current which traverses the exploder 6, becomes zero, the arc in this exploder will be immediately extinguished, and since, during the period of negative electromotive-force, this electromotive-force never reaches a value sufficient to initially establish the arc, as has been shown above, it follows that the exploder arc will not be re-established until the next positive period of electromotive-force A, that is at an epoth t_1+T. We see, therefore, that the action of the armature circuit of the prime generator which is connected to the exploder 6 is to send into the condenser 10 a series of positive current waves B_1, B_1, as shown in Fig. 3, and to send into this condenser no negative current waves. Similarly the action of that armature circuit which is connected with the exploder 7 is to send into the condenser 10 a series of positive current waves B_2, B_2. Finally the armature circuit which is connected with the exploder 8 sends into the condenser 10 a series of positive current waves B_3 B_3. By using a sufficiently large number of dephased armature circuits on the prime generator, it is manifest that the condenser 10 will receive what is practically an uninterrupted charge of continuous current. The apparatus will operate most efficiently if the voltage h, maintained across the condenser 10, is small with reference to the voltage H necessary to initially establish the exploder arc.

I now come to a description of the means II for transforming the continuous current, which is supplied by the devices above described, into an alternating current of high frequency in the primary circuit 12 of the transformer 13, such means consisting essentially of an electrical resonator of a specified electrical design with an electric exploder in shunt thereof to which an automatic circuit-breaker may be added for insuring the steadiness of the operation.

The primary circuit 12 of the transformer 13 passes through a self-induction coil 14 and a condenser 16 in series therewith. If the primary circuit 12 has sufficient self induction in itself, the coil 14 is unnecessary. Since the primary circuit 12, the self induction coil 14, and the condenser 16 constitute a circuit having both capacity and self induction, they will constitute an electric resonator in shunt of which, as is seen, is mounted an electric exploder 17 which may also be formed of two metallic balls a, b, separated by an air space.

The continuous current supplied by the line 9, in the manner already fully described passes into this resonator and charges the condenser 16 for a certain time, at the end of which an arc is established in the exploder 17. This arc once established, the resistance of the exploder becomes practically zero so that we have the well known phenomena of a charged condenser discharging through a small external resistance. This means that an oscillatory discharge will be set up giving rise to an alternating current. The electrical constants are so chosen that before the end of one complete oscillation of this discharge, that is shortly before the end of one complete period of the alternating current set up by the discharge, the arc in the exploder is disestablished. The condenser 16 is thereupon again charged by the continuous current supplied by the line 9 until matters are in the same state in which they were when the arc in the exploder was first established. But matters being in the same state in which they were at the moment when the exploder arc was established for the first time, it follows that the exploder arc will be again established, that there will be another oscillating discharge in the condenser and another alternating current comprising one complete positive and one complete negative period and so on. The alternating current, thus generated, will not gradually die down, as in the discharge of the ordinary Leyden jar, for the reason that the condenser is recharged from the main line at the end of each alternation.

I here remark that the self induction coil 11 helps to maintain constant the intensity I of the continuous current in the line despite the establishment of the exploder arc.

It is thus seen how, by the arrangement thus far described, a continuous current is transformed into an alternating current in the primary 12. The continuous current being of constant intensity, it can be shown that the alternating current into which it is transformed, is also of effective constant intensity.

It remains to briefly refer to the automatic circuit breaker 18. It will be noticed that, as shown, this automatic circuit breaker consists of a solenoid in series with the primary 12 and condenser 16, there being a branch circuit through the flexible conductor 155, the core of the solenoid and the mercury circuit breaker 18 which, when the solenoid is de-energized. shorts circuits the condenser 16 and practically short circuits the exploder 17. This automatic circuit breaker is designed to maintain its core raised and the short circuits broken throughout the normal operation of the apparatus. It does not go into and out of action at each oscillatory discharge of the exploder. But should, for any accidental reason, such as a surcharge on the working circuits, the arc in the exploder not disestablish itself at the proper time toward the end of any complete oscillation, the energy contained in the resonator will rapidly dissipate, so that the solenoid will permit its core to drop and short circuit the exploder arc 17. The exploder arc is therefore now extinguished as it should be. Thereupon the solenoid again raises its core to break the short circuits about the condenser 16 and the exploder 17 so that the system may renew its normal operation. The automatic circuit breaker has therefore the function of preventing a disarrangement of the normal operation of the system by reason of the failure of the exploder to disestablish its arc at the proper time.

I now briefly refer to the principles which are to be employed in the electrical design of the apparatus II, by reference to Fig. 4, in which the axis of abscissa denotes time and the axis of ordinates denotes current strength or charge.

So long as the resonator is short circuited by the exploder arc, it is the seat of a current of intensity J the variation of which may be represented by a curve resembling a sinusoid, such as the curve J shown by full lines in Fig. 4.

It is also manifest that the variation of the charge Q of the condenser 16 may be represented by a sinusoid such as the curve Q in dots and dashes, in Fig. 4, this curve being dephased by 90 degrees from the curve J.

Now it has been proposed, in the prior art, to convert a continuous current into an alternating current of high frequency by charging a resonator with the continuous current and then discharging the resonator through an exploder. But such apparatus has never been perfected to a point at which it can be commercially used and certainly not for the purposes requiring electrical resonance, for the reason that it was not known how to make the alternating currents of effective constant frequency, nor how to make them, practically speaking, sinusoidal in form. I have discovered how to do these two things. Without explaining, at length, how I have reached a knowledge of the requirements necessary to effect these two objects, I may say that if we designate by R the ohmic resistance of the resonator, by l the coefficient of its apparent self induction, by c the capacity of its condenser 16, and by E the quantity of electrical energy stored in the resonator at any instant of time t, then the rules are these: In order that the frequency of the alternating current shall be constant, it is necessary that R^2 shall be small with respect to $\frac{4l}{c}$. In order that the alternating current wave shall be sinusoidal, it is necessary that the quantity of energy E stored in the resonator shall be large with respect to that which is used up in the system between two consecutive explosions. In this connection I may say that if E_c and E_1 are the quantities of energy stored at the instant t in the condenser and self induction coil, respectively, and if x denotes the frequency we may write,

$$E_c = E \sin^2 2\pi \times t$$
$$E_2 = E \cos^2 2\pi \times t$$
$$E = E_c + E_2.$$

In order to transform the alternating currents of constant effective intensity in the primary circuit 12 into the alternating currents which are to be utilized on the working circuit, I use the secondary 19 of the transformer 13. The alternating currents in the primary circuit 12 are thus transformed into alternating currents in the secondary circuit 19 from which they are supplied to the working circuit 20. Since the effective intensity of the alternating current in the primary circuit 12 is constant, the effective intensity of the secondary currents in the secondary circuit 19 will ordinarily be constant, the transformer 13 being then of the constant current type and acting to transform an alternating current of constant effective intensity into another alternating current of constant effective intensity. If it be desired to transform the primary current of effective constant intensity into a secondary current of effective constant voltage, it is merely necessary to insert a condenser in series in the secondary circuit, of a capacity to render zero the co-efficient of apparent self induction of the secondary.

In the above description I have assumed the power factor of the working circuit to be constant so that if the prime generator is regulated to produce a continuous current of constant intensity, the frequency of the alternating currents will be constant. I now come to a description of my regulating exciter III which is intended to regulate the excitation of the prime generator I in such a manner that the frequency of the currents on the working circuits remains constant despite variations in the power factor. Now an increase in the excitation of the field of the prime generator acts to augment the intensity of the charging current of the resonator in diminishing the duration of this charge. Diminution of the duration of the charge will have for its effect the diminution of the interval of time which separates the initiation of two consecutive establishments of the arc in the exploder 17, thus augmenting the frequency x and vice versa. I have thus been led to rapidly augment the excitation of the generator if the frequency diminishes and to rapidly diminish this excitation if the frequency increases. In this way I bring about the result that the frequency on the working circuit does not vary except between limits as close together as I please.

Let us assume that the working circuit is the ordinary series circuit traversed by a current of effective constant intensity. Intercalate in series in this circuit, the primaries 21 and 22 of two transformers having secondary circuits 23 and 24. But if the working circuit 20 is of the multiple arc type, supplied with current at constant voltage, the primary circuits 21 and 22 will be mounted in multiple therein. But whether the working circuit is of the series or the multiple arc type, I mount a primary circuit 26 of a transformer 200 and a condenser 25 in series with the secondary circuit 23 and I furthermore mount the primary circuit 28 of another transformer 300 and a condenser 27 in series with the secondary circuit 24.

The secondary circuits 29 and 30 of the transformer 200 are wound in opposite directions so that each has the same co-efficient of self induction but so that the co-efficients of mutual induction with their primary circuit 26 are equal and of opposite signs. A similar remark applies to the secondary circuits 31 and 32 of the transformer 300.

I designate by y a frequency which is small with respect to the frequency x. I furthermore determine the capacity of the condenser 25 in such a manner that the apparent self induction of the circuit 23, 25, 26, is zero when it is traversed by currents of frequency $x-y$. I furthermore determine the capacity of the condenser 27 in such a manner that the apparent self induction of the circuit 24, 27, 28, is zero when it is traversed by a current of frequency $x+y$. From this it follows that the electromotive-force developed in the secondary circuits 29, 30 and 31, 32, will be equal when their frequency is x. When the frequency of the current in the working circuit diminishes and falls below x and thereby gets nearer to $x-y$ and farther from $x+y$, the electromotive-force developed in the circuits 29, 30, will increase, and the electromotive-force developed in the circuits 31, 32, will diminish. On the other hand, when the frequency of the alternating current in the working circuit increases above x, and gets nearer to $x+y$ and farther away from $x-y$, the electromotive-force in the secondaries 31, 32, will increase and that in the secondaries 29, 30, will decrease.

The prime generator I has exciting field coils 33, 33, interconnected in any suitable manner and traversed by a continuous current furnished by any local source of electrical energy, which maintains a constant difference of potential between the conductors 36 and 37. This is a common way of exciting the field magnets of a generator, and I need only say that I regulate the intensity of this local source of current in such a manner as to normally excite the prime generator to furnish to the working circuits currents of frequency x at mean load.

The coils 34, 34, which are connected to the secondaries 29, 30, are wound in such a way as to re-inforce the magnetizing effect of the field coils 33, 33. On the other hand the field coils 35, 35, which are connected to the secondaries 31, 32, are wound to counteract the magnetizing effect of the field coil 33, 33.

Not undertaking to explain, for the moment, the particular way of completing the connection of the secondaries 29, 30, with the field coils 34, and of the secondaries 31, 32, with the field coil 35, it will now at once be apparent that should, for any reason, the frequency of the alternating current on the working circuit 20 increase above the normal frequency x, the electromotive-force, in the secondaries of the transformer 300 will increase, which means that there will be more current in the field coils 35, subtracting from the effect of the exciting coil 33. At the same time the electromotive-force in the secondaries of the transformer 200 will decrease, so that there will be less current in the field coils 34, to re-inforce the normal field excitation of the coils 33. Both these actions, then, combine to decrease the excitation of the prime generator I, which means, as has before been explained, that the frequency of the alternating currents generated in the working circuit 20 will be decreased to restore the normal frequency. A corresponding remark applies if the frequency of the alternating working currents should, for any reason, fall below normal.

The connection between the secondaries of the transformer 200 and the field coils 34 as well as between the secondaries of the transformer 300 and the field coils 35, are completed through the electric valve or asymmetric device IV in a manner which will be apparent from a study of the drawing. One end of the secondary 29 is connected to the electrode 40. The corresponding end of the secondary 30 is connected to the electrode 39. One end of the secondary 31 is connected to the electrode 43 and the corresponding end of the secondary 32 is connected to the electrode 44. Opposite these electrodes just mentioned and co-operating with each of them is the electrode 400, which is connected to the wire 37 and thereby to one terminal of each of the field coils 34, 35. The other terminals of the field coils 34, 35, are connected, respectively, to the secondaries 29, 30, and 31, 32, by means of conductors 38 and 42. A circuit is thus established from the secondaries 29, 30, to the electrodes 39, 40, and across the vacuum to the common terminal 400, thence to the conductor 37, through the field coil 34, the wire 38, and back to the secondaries 29 and 30. A similar circuit may readily be traced connecting the secondaries 31, 32, through the electrode 43, 44, and the common terminal 400, with the field coil 35.

The electric valve IV which I have shown comprises terminals 39, 40, 43, 44, which are composed of bells of steel or iron, of one sign, located in a vacuum tube and a terminal 400, of opposite sign, composed of a drop of mercury. Such a construction has the remarkable property that once an arc is established in the vacuum tube, it will permit the current to pass from the steel bell to the mercury but will oppose a practically infinite resistance to the current passing in the opposite directions from the mercury to the steel bell. I may say immediately, however, that although this construction is very efficient for rectifying alternating currents, it is only here given by way of example. Explaining the action of this electric valve a little more fully, it is to be noted that an alternating current traversing the primary circuit 26 of the transformer 200 generates, say, a positive wave of electromotive-force in the secondary 29 and a simultaneous negative wave of electromotive-force in the secondary 30, this being due to the fact that these secondaries are oppositely wound. An arc being assumed as established in the electric valve, we will suppose that the connections are so fixed that the positive electromotive wave is allowed to generate a current passing from the electrode 40 to the electrode 400. At this time, the negative wave of electromotive-force in the secondary 30 produces no effect. But in the next half period of alternating current in the primary 26, there will be a negative wave of electromotive-force in the secondary 29, and a positive wave of electromotive-force in the secondary 30 so that a current now passes from the electrode 39 to the terminal 400, and no current passes from the terminal 40 to the terminal 400. This means that there will always be a current in a given direction circulating through the coil 34, passing in one half period from 39 to 400, and in the next half period from 40 to 400. The oppositely wound secondaries 29, 30, taken together with the terminals 39, 40, and the common terminal 400, of the electric valve have caused a rectified current to pass through the field coil 34, such rectified current being necessary for the proper differential excitations of the prime generator. A similar remark manifestly applies to the field coil 35, the secondaries 31, 32, the terminals 43, 44, and the co-operating terminal 400.

While it is true that, the arc once established in the electrical valve IV, the gap between the terminals 39, 40, 43, 44, and the co-operating terminal 400, offers a practical negligible resistance to currents flowing in a given direction and prevents the flow of currents in the opposite direction, it is yet necessary, in order to initially establish the arc, to impress a high voltage across the terminals. To this end I add a fifth electrode 45, of iron or steel, to the electric valve, and place it in circuit with the impedance coil 46 which is thereupon connected with the conductor 36. I also run a tap through the resistance 47 and the circuit breaker 48, to the conductor 37, in the manner shown. By closing the circuit breaker 48, a current is passed through the impedance coil 46. When the circuit breaker is opened, the impedance coil 46 gives off a high tension discharge in a circuit which contains the field coil 33, which jumps from the terminal 45 to the terminal 400 and initially establishes the arc in the electric valve. This arc is thereupon maintained by the action of the other terminals which are sufficiently close together for the purpose.

While I have described my regulator III for use with the prime generator I and its coöperating apparatuses, it is clearly manifest that it may be used in other relations. It is furthermore to be understood that I have merely described what may be called generic types of electric exploders and electric valves, and that I may use other types.

In order to insure the instantaneous extinction of the arc in such exploders when the current traversing them becomes zero, I may send a current of air between the balls *a*, *b*, as indicated in Fig. 5. Or I may replace the balls by two horn shaped parts *a*, *b*, situated between the polar extremities of an electro magnet, as indicated in Fig. 6. Again I may inclose the balls *a*, *b*, in a vacuum tube as shown in Fig. 7, such exploders going out of action instantaneously as soon as the intensity of the current traversing them sinks below a certain limit. One of the most effective forms of electric exploder which may be employed consists of an inverted U tube in which a vacuum is maintained, the terminals being constituted by globules of mercury in the inverted ends of the tube, all as shown in Fig. 7. The effective resistance of such tubes is very small, after the arc has once been established; they go out of action instantaneously and the surface of their electrodes is not injuriously effected.

This is a division of my application No. 192,227, filed Feb. 5, 1904, in which the process is claimed.

I have not claimed herein the automatic circuit breaker nor certain details of my electric valve since these are covered in my companion application filed Nov. 30, 1903, under Serial No. 183,247.

I claim,

1. A system for transforming unidirectional currents into alternating currents of constant frequency comprising a line carrying continuous currents, a resonator having R^2 small with respect to $\frac{4l}{c}$, an induction coil having its primary connected with the resonator, and an electric exploder in shunt of the resonator, substantially as described.

2. A system for transforming unidirectional currents into alternating currents which are sinusoidal in form, comprising a line carrying continuous currents, a resonator arranged to store an amount of energy which is large with respect to that consumed in an alternating period, an induction coil having its primary connected with the resonator, and an electric exploder in shunt of the resonator, substantially as described.

3. A system for transforming unidirectional currents into sinusoidal currents of constant frequency, comprising a line carrying continuous currents, a resonator having R^2 small with respect to $\frac{4l}{c}$ and arranged to store an amount of energy which is large with respect to that consumed in an alternating period, an induction coil having its primary connected with the resonator, and an electric exploder in shunt of the resonator, substantially as described.

4. A prime generator of unidirectional current and an exciter winding therefor, a circuit carrying alternating currents transformed from the unidirectional currents, and an electrically tuned circuit associated with this circuit and with the exciter winding to maintain the frequency of the alternating currents constant, substantially as described.

5. A prime generator of unidirectional currents, and an exciter winding therefor, a circuit carrying alternating currents transformed from the unidirectional currents, and an electrically tuned circuit and an electric valve or current rectifier, associated with the alternating current circuit and the exciter winding to maintain the frequency of the alternating current constant, substantially as described.

6. A prime generator of unidirectional currents and a pair of differential exciter windings therefor, a circuit carrying alternating currents of a normal frequency transformed from the undirectional currents, and circuits electrically tuned to a frequency respectively above and below normal associated, on the one hand, with the alternating current circuit, and, on the other hand, with the differential exciter windings respectively, substantially as described.

7. A prime generator of unidirectional currents and a pair of differential exciter windings therefor, a circuit carrying alternating currents of a normal frequency transformed from the unidirectional currents, circuits electrically tuned to a frequency respectively above and below normal, and electrical valves or current rectifiers each respectively connected to a tuned circuit and an exciter winding, substantially as described.

8. A prime generator of unidirectional current and an exciter winding therefor, an electric resonator and an exploder in shunt thereof for transforming the unidirectional current into alternating currents, and an electrically tuned circuit energized by these alternating currents and associated with the exciter winding to maintain the alternating currents of normal frequency, substantially as described.

9. A prime generator of unidirectional current and a pair of differential exciter windings therefor, an electric resonator and an exploder in shunt thereof for transforming the unidirectional current into alternating

currents, and a pair of circuits energized by these alternating currents, tuned to a frequency respectively above and below the normal frequency it is desired to maintain, and in turn energizing the exciter windings of the prime generator to maintain the normal frequency constant, substantially as described.

10. A prime generator of unidirectional current and a pair of differential exciter windings therefor, an electric resonator and an exploder in shunt thereof for transforming the unidirectional current into alternating currents, a pair of circuits energized by these alternating currents and tuned to a frequency respectively above and below the normal frequency it is desired to maintain, and electric valves or current rectifiers connected to a tuned circuit and an exciter winding respectively, substantially as described.

In testimony whereof I have signed my name to this specification in the presence of two subscribing witnesses.

MAURICE LEBLANC.

Witnesses:

PIERRE LAVAUX,

HANSON C. COXE.