Aug. 1, 1939. C. A. SABBAH ET AL 2,168,173

TRANSFORMING MEANS

Filed June 5, 1937 3 Sheets-Sheet 1

Fig. 1.

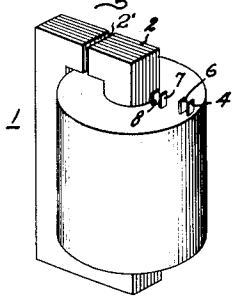


Fig. 2.

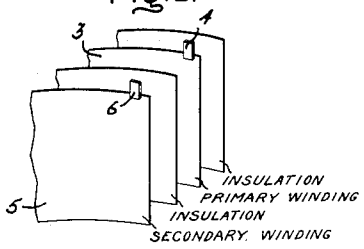


Fig. 3.

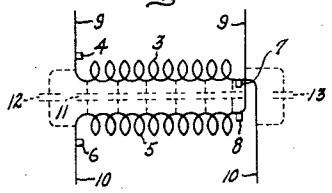


Fig. 4.

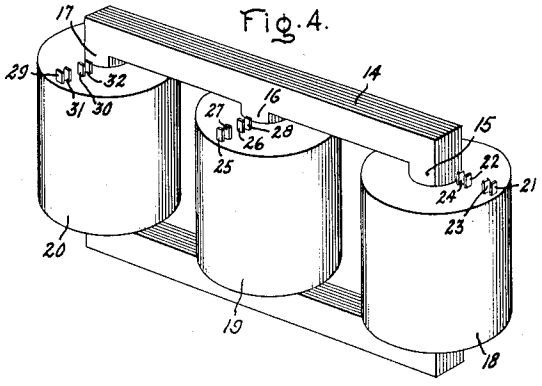
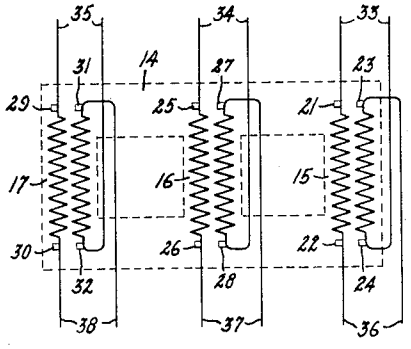


Fig. 5.



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TRANSFORMING MEANS

Filed June 5, 1937 3 Sheets-Sheet 2

Fig. 6.

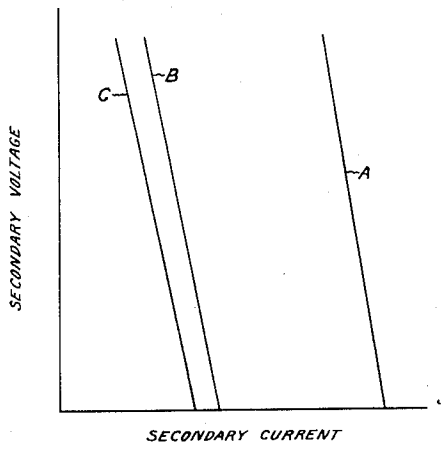


Fig. 7.

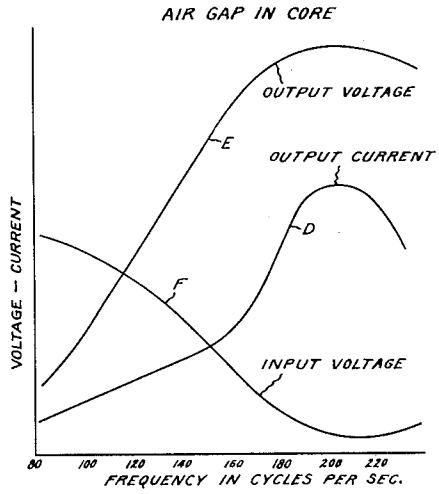


Fig. 7a.

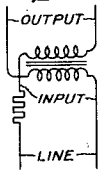


Fig. 8.

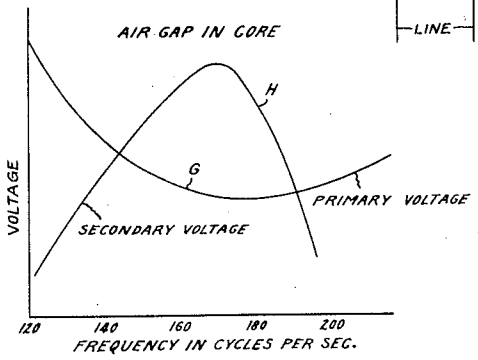
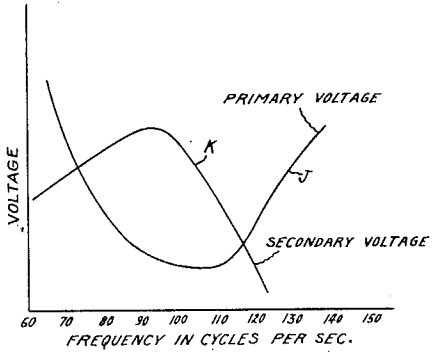


Fig. 9.



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TRANSFORMING MEANS

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Fig. 10.

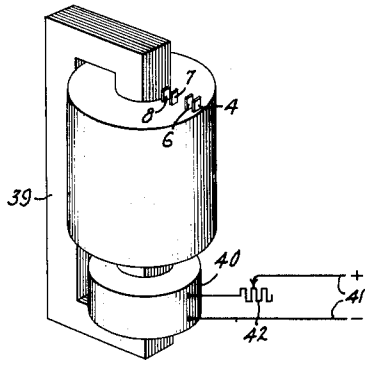
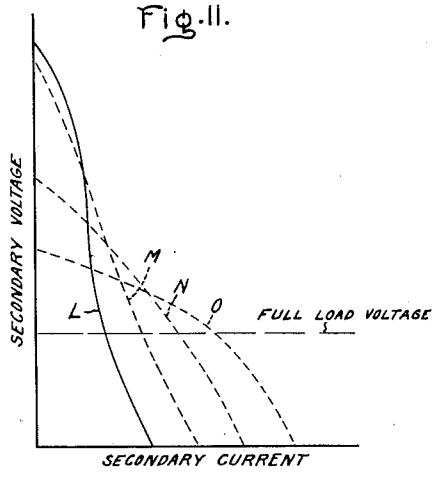


Fig. 11.



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Patented Aug. 1, 1939 2,168,173

UNITED STATES PATENT OFFICE

2,168,173

TRANSFORMING MEANS

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Application June 5, 1937, Serial No. 146,660

12 Claims. (Cl. 171—97)

The invention relates to electric translating apparatus and more particularly to electric translating apparatus for transmitting energy between constant voltage alternating current circuits and constant current alternating current circuits.

Heretofore there have been devised numerous arrangements for effecting the transfer of energy between constant voltage alternating current circuits and constant current alternating current circuits. Some of these arrangements have included devices having relatively movable parts for effecting this transformation and other arrangements have employed a plurality of reactances of opposite sign, such as inductances and capacitances, for effecting this transformation. In view of the recent advances in electric power transmission, there has been evidenced a decided need for transforming apparatus to facilitate the transformation of constant voltage alternating current to alternating current of constant value by apparatus having only stationary elements and by apparatus employing only a minimum number of parts, affording thereby an economical apparatus susceptible of a wide diversity of use and being of an inexpensive construction. For example, there has been evidenced a need for apparatus of this type for use in connection with the electric power transmission and distribution system disclosed and claimed in U. S. Letters Patent 1,990,758, granted to Charles W. Stone, February 12, 1935, and assigned to the assignee of the present application.

It is an object of the invention to provide a new and improved electric translating apparatus.

It is another object of the invention to provide a new and improved transforming apparatus for effecting the transfer of energy between constant voltage alternating current circuits and constant current alternating current circuits.

It is a further object of the invention to provide a new and improved transformer for effecting transfer of energy between constant voltage alternating current circuits and constant current alternating current circuits which is devoid of relatively movable parts and which is simple and reliable in construction and arrangement.

In accordance with the illustrated embodiments of the invention, there is provided a new and improved transforming device for effecting transfer of energy between constant voltage alternating current circuits and constant current alternating current circuits. The transforming device comprises a pair of spirally wound, electrically insulated windings preferably arranged to have a mutual inductance substantially equal to the self inductance of the windings and being proportioned so that there are provided mutually disposed surfaces in proximity to afford interwinding capacitance which together with the inductance constitutes a tuned circuit to effect the desired transformation. The windings are dimensioned so that the tuned circuit resonates to the frequency at which the device is intended to operate, or, in other words, the device is arranged to resonate to the frequency of the voltage or of the current of the associated circuits. The windings may be associated with a magnetic core structure and the magnetic core structure may be modified or dimensioned to control the output or the input characteristic of the device. For example, the core structure may be constructed to have an air gap to obtain the desired operating characteristics. In a modified embodiment of the invention an auxiliary coil, energized with direct current, is employed to control the saturation of the core member and to control thereby the value of the constant current output which is maintained.

For a better understanding of the invention, reference may be had to the following description taken in connection with the accompanying drawings, and its scope will be pointed out in the appended claims. Fig. 1 diagrammatically illustrates an embodiment of our invention as applied to an arrangement for effecting transfer of energy between a single phase constant voltage alternating current circuit and a single phase constant current alternating current circuit. Fig. 2 represents diagrammatically an arrangement of the windings and the insulation of the embodiment of the invention shown in Fig. 1. Fig. 3 represents the equivalent electric circuit of the arrangement shown in Fig. 1. Fig. 4 diagrammatically shows another embodiment of our invention as applied to an arrangement for effecting transfer of energy between a three phase constant voltage alternating current circuit and a three phase constant current alternating current circuit, and Fig. 5 represents the equivalent electric circuits and shows the manner in which the windings of Fig. 4 are to be connected to associated circuits. Figs. 6, 7, 8 and 9 represent certain operating characteristics of the arrangements shown in Figs. 1 and 4. Fig. 7*a* is an explanatory circuit diagram. Fig. 10 represents an embodiment of our invention in which the constant current to be maintained is controlled by controlling the saturation of the core struc-

ture, and Fig. 11 represents certain operating characteristics thereof.

Referring now to Fig. 1 of the accompanying drawings, the invention is diagrammatically shown as applied to a transforming device or a transformer 1 for effecting transfer of energy between a single phase constant voltage alternating current circuit and a single phase constant current alternating current circuit. The transformer 1 includes a pair of spirally wound windings which may be associated with a magnetic core member 2. The core member 2, if desired, may be constructed with a high reluctance portion, such as an air gap 2', to obtain a certain desired operating characteristic. The arrangement of the windings may be better understood by referring to the expanded view of Fig. 2. It is to be noted that the windings which have been termed primary winding and secondary winding are electrically separated from each other by the use of suitable insulation, and that a primary winding 3 is provided with a terminal 4 and that secondary winding 5 is provided with a terminal 6. The primary winding 3 and secondary winding 5 are dimensioned and disposed relative to each other so that there are provided sufficient areas thereof in proximity to establish a substantial inter-winding capacitance. Furthermore, the windings are arranged so that the mutual inductance thereof is substantially equal to the self inductances. The inductance of the windings 3 and 5 and the interwinding capacitance of these windings constitute in effect a monocyclic square. The primary winding 3 and the secondary winding 5 are also provided with terminals 7 and 8, respectively, which are connected to the other ends of the respective windings.

The equivalent electric circuit of the arrangement diagrammatically illustrated in Figs. 1 and 2 is shown in Fig. 3. The windings shown in Fig. 3 and the taps or terminal connections have been assigned reference numerals corresponding to the arrangements shown in Figs. 1 and 2. The transforming device of Fig. 3 is shown as being connected to effect transfer of energy between a constant voltage alternating current circuit 9 and a constant current alternating current circuit 10. Electrically opposite terminals of each of windings 3 and 5 are connected to different circuits. For example, terminal 4 of winding 3 is connected to circuit 9, while terminal 7 of winding 3 is connected to circuit 10; and terminal 6 of winding 5 is connected to circuit 10, while terminal 8 of winding 5 is connected to circuit 9. The capacitances 11 represent the distributed inter-winding capacitance of windings 3 and 5 and the capacitances 12 and 13 represent the resultant or effective inter-winding capacitance of these windings. The capacitances 12 and 13 may be considered as being effectively connected in series relation with the windings 3 and 5 and the associated circuits 9 and 10. The inductance of the windings 3 and 5 and the effective interwinding capacitance represented by the capacitances 12 and 13 constitute in effect a monocyclic square.

The operation of the embodiment of the invention diagrammatically shown in Fig. 1 may be best explained by considering the equivalent circuit shown in Fig. 3. Let it be assumed that it is desired to supply to the circuit 10 an alternating current of constant value from the constant voltage alternating current circuit 9. By virtue of the arrangement of the windings 3 and 5, the effective inter-winding capacitance as represented by capacitances 12 and 13 constitutes, together with the mutual inductance of windings 3 and 5, a tuned circuit of the series type which resonates to the frequency of the voltage of the alternating current circuit 9 to transform the constant voltage alternating current to alternating current of constant value. As the resistance of the load circuit connected to circuit 10 decreases, the voltage impressed on circuit 10 by the transforming device 1 will correspondingly decrease to maintain the output current at a substantially constant value; and, conversely, as the resistance of the load circuit increases, the voltage impressed thereon by the transforming device 1 will correspondingly increase to maintain the current constant.

The operation of the embodiment of the invention shown in Fig. 1 may be better understood by referring to the operating characteristics shown in Fig. 6. The curves A, B and C represent the secondary current, that is, the current in winding 5 under variable load conditions. Curve A represents the secondary current under varying load conditions with a certain value of applied primary voltage when the core member is provided with an air gap, and curve B represents the secondary current when the applied voltage is reduced to approximately one half that applied under the conditions represented by curve A. Curve C represents the secondary current under varying load conditions when the primary voltage applied is approximately that under the conditions represented by curve A and when the core member does not have an air gap.

The curves of Figs. 7, 8 and 9 will be of assistance in explaining the relationships between the elements of the inductive devices shown in Figs. 1 and 4. Although to effect transformation of constant voltage alternating current to alternating current of constant value by the use of applicants' invention the device is operated at a constant frequency, it is believed that the characteristics as shown in Figs. 7, 8 and 9 as functions of an applied voltage of variable frequency will be helpful in understanding the invention. Curves D, E and F represent the output current, output voltage and the input voltage as functions of the frequency of the line voltage for the circuit arrangement in Fig. 7a, where an impedance is connected in series relation with the line and serves as a protective means. Curves G and H of Fig. 8 represent the primary and secondary voltages, respectively, as functions of the frequency when an air gap is used in the core, and curves J and K of Fig. 9 represent the primary and secondary voltages, respectively, as functions of the frequency of the supply line when no air gap is employed.

Fig. 4 of the drawings represents diagrammatically an embodiment of the invention for effecting transfer of energy between three phase constant voltage alternating current circuits and constant current alternating current circuits. The transforming device includes a core structure 14 having three legs 15, 16 and 17 about which are wound coils 18, 19 and 20, respectively. Each of the coils 18, 19 and 20 comprises a pair of electrically insulated and spirally wound windings, such as windings 3 and 5 shown in Fig. 2. Each of the windings or conductors of coils 18, 19 and 20 is provided with two taps or terminals, one at the beginning and the other at the end of the winding. For example, the primary winding of coil 18 is provided with terminals 21 and 22 and the secondary winding is provided with terminals 23 and 24. In like manner, coils 19 and 20 are

provided with similarly connected terminals 25—28 and 29—32, respectively.

The circuit diagram of Fig. 5 represents the connections of the transforming device of Fig. 4 when it is desired to effect transfer of energy from constant voltage alternating current circuits 33, 34, and 35 and constant current alternating current circuits 36, 37 and 38. It, of course, will be well understood by those skilled in the art that the circuits 33—35 and 36—38 may be connected in the usual way to three phase alternating current circuits when it is desired to effect transfer of energy between three phase systems.

The embodiment of the invention shown in Figs. 1 and 4 operates to transform constant voltage alternating current into alternating current of constant value, or vice versa. One way in which the operation of the embodiment of our invention may be analyzed is as follows: The inductances of the windings 3 and 5 are assumed to have no individual leakage reactance. This assumption is justifiable whether the windings are on one core or on two cores, since the flux induced in each coil is identical. To facilitate the analysis of the operation of the arrangement, the elemental reactor currents or the currents transmitted through the elemental inductances of windings 3 and 5 may be represented by $a_1, a_2 \ldots a_{n-2}, a_{n-1}, a_n$, and the currents which flow by virtue of the elemental interwinding capacitances may be represented by $b_1, b_2 \ldots b_n$. The inductive reactance for the elemental portions of winding 3 will be represented as x_1, and the inductive reactance of the elemental portions of winding 5 will be represented by x_2. The voltage of the constant voltage alternating current circuit 9 may be represented as E, and the current of circuit 9 may be represented at a_0. Z may represent the impedance of load circuit 10, and b_0 may represent the current transmitted thereto. Kirchoff's equations may be written, referring to Fig. 3, assuming that there are n portions of the windings between the elementary interwinding capacitances. On this assumption, there are n reactors or inductances on each winding and $n+1$ capacitances. By multiplying the equations by $-j$ to simplify, and assuming n is an even number, the voltage equations may be written as:

$$jE = 2x_2b_1 - jZb_0 \tag{1}$$

$$jE = x_2b_1 - x_1(a_1 + a_2 + \ldots + a_n) \tag{2}$$

$$\left.\begin{aligned} x_2(b_2-b_1)+x_1(a_n-a_1)&=0\\ x_2(b_3-b_2)+x_1(a_n-a_2)&=0\\ \hline x_2\left(b_{\left(\frac{n}{2}+1\right)}-b_{\frac{n}{2}}\right)+x_1\left(a_{\left(\frac{n}{2}+1\right)}-a_{\frac{n}{2}}\right)&=0 \end{aligned}\right\} \tag{3}$$

$$\left.\begin{aligned} x_2(b_2-b_1)-2x_1\left(b_2+b_3+\ldots+b_{\frac{n}{2}}\right)-x_1b_{\left(\frac{n}{2}+1\right)}&=0\\ x_2(b_3-b_2)-2x_1\left(b_3+b_4+\ldots+b_{\frac{n}{2}}\right)-x_1b_{\left(\frac{n}{2}+1\right)}&=0\\ \hline x_2\left(b_{\frac{n}{2}}-b_{\left(\frac{n}{2}-1\right)}\right)-2x_1\left(b_{\frac{n}{2}}\right)-x_1b_{\left(\frac{n}{2}+1\right)}&=0\\ x_2\left(b_{\left(\frac{n}{2}+1\right)}-b_{\frac{n}{2}}\right)-x_1b_{\left(\frac{n}{2}+1\right)}&=\\ (x_2-x_1)b_{\left(\frac{n}{2}+1\right)}-x_2b_{\frac{n}{2}}&=0 \end{aligned}\right\} \tag{3a}$$

Solving for

$$b_{\left(\frac{n}{2}+1\right)}$$

in this last equation and substituting in those above yields a new set of equations from which

$$b_{\frac{n}{2}}$$

can be found and substituted. This operation is repeated until one Equation 2a remains. Letting

$$p=\frac{x_2}{x_1}$$

successive substitutions in Equation 2a yield:

$$\frac{jE}{x_1} = pb_1 - n\left(b_0+b_1+\ldots+b_{\frac{n}{2}}\right) - \frac{n}{2}\left(2+p\frac{1}{p-1}\right)b_{\frac{n}{2}} \tag{2b}$$

$$\frac{jE}{x_1} = pb_1 - n\left(b_0+b_1+\ldots+b_{\left(\frac{n}{2}-1\right)}\right) - \frac{n}{2}\left(2+p'\frac{2+\frac{p}{p-1}}{p-\left(2+\frac{p}{p-1}\right)}\right)b_{\left(\frac{n}{2}-1\right)} \tag{2c}$$

$$\frac{jE}{x_1} = pb_1 - n\left(b_{\left(\frac{n}{2}-\frac{n}{2}\right)}\right) - \frac{n}{2}f(p)b_{\left(\frac{n}{2}-\frac{n}{2}+1\right)} \tag{2n}$$

By substituting b_1 from Equation 1 in Equation 2n, produces finally:

$$\frac{jE}{2}\left(p+\frac{n}{2}f(p)\right) = \left(j\frac{Z}{2}\left(p-\frac{n}{2}f(p)\right)-nx_2\right)b_0 \tag{6}$$

The current equations may be written as:

$$\left.\begin{aligned} a_1&=a_2+b_2\\ a_2&=a_3+b_3\\ a_3&=a_4+b_4\\ \hline a_{\frac{n}{2}}&=a_{\left(\frac{n}{2}+1\right)}+b_{\left(\frac{n}{2}+1\right)} \end{aligned}\right\} \tag{4}$$

$$\left.\begin{aligned} a_{\left(\frac{n}{2}+1\right)}&=a_{\left(\frac{n}{2}+2\right)}+b_{\frac{n}{2}}\\ a_{\left(\frac{n}{2}+2\right)}&=a_{\left(\frac{n}{2}+3\right)}+b_{\left(\frac{n}{2}-1\right)}\\ a_{\left(\frac{n}{2}+3\right)}&=a_{\left(\frac{n}{2}+4\right)}+b_{\left(\frac{n}{2}-2\right)}\\ \hline a_{(n-1)}&=a_n+b_2\\ a_n&=b_0+b_1 \end{aligned}\right\} \tag{5}$$

Using the equations of Groups 4 and 5, the currents represented by the a quantities can be eliminated from Equation 2 and the groups of Equations 3, as follows:

$$jE = x_2b_1 - nx_1\left(b_0+b_1+\ldots+b_{\frac{n}{2}}\right) - \frac{n}{2}x_1b_{\left(\frac{n}{2}+1\right)} \tag{2a}$$

If b_0 is to be independent of Z:

$$p-\frac{n}{2}f(p)=0 \tag{7}$$

In order to advance the analysis from this point, it is necessary to study Equation 7, particularly the $f(p)$. The object, of course, is to let

n become infinite. For different values of n, $f(p)$ becomes:

$$n=2f(p)_1=2+\frac{p}{p-1}$$

$$n=4f(p)_2=2+p\frac{2+\frac{p}{p-1}}{p-\left(2+\frac{p}{p-1}\right)}$$

$$n=6f(p)_3=2+p\frac{f(p)_2}{p-f(p)_2}$$

$$n=nf(p)_{\frac{n}{2}}=2+p\frac{f(p)_{n-1}}{p-f(p)_{n-1}}$$

Let $p=\frac{1}{2}$:

$$f(p)_1=1,\ f(p)_2=1,\ \ldots\ f(p)_n=1$$

Obviously, Equation 7 will not be solved for this value. However, if p is made equal to $\frac{1}{2}+c$, upon solution of Equation 7 for successive values of n, it will be seen that as n approaches infinity, p approaches $\frac{1}{2}$.

Substituting from Equation 7 into the left-hand side of Equation 6 produces, noting that $nx_2=x_c$:

$$b_0=-\frac{jE}{2}\cdot\frac{2p}{x_c}=-\frac{jE}{2x_c}$$

The above analysis proves that the current transmitted to circuit **10** is independent of Z for the proper frequency, and further shows that each small element is and operates as a monocyclic square.

In Fig. 10 there is shown another embodiment of our invention in which a magnetic condition of the core structure is controlled to effect control of the value of the constant current which is maintained. The arrangement of Fig. 10 is similar in many respects to that of Fig. 1 and corresponding elements have been assigned like reference numerals. A core member **39** is also provided with an agency, such as a coil **40**, which controls the saturation of the core member **39** to establish the value of constant current which will be maintained by the device. The coil **40** may be energized from any suitable source of direct current **41** and a circuit controlling means, such as an adjustable resistance **42**, may be used to control the current supplied to coil **40**. It is to be understood that the resistance **42** may be manually or automatically operated.

The curves of Fig. 11 represent the output current of the arrangement of Fig. 10 under varying load conditions. Curve L represents the output current when there is no current in coil **40**, and curves M, N and O represent this characteristic with increasing values of direct current in coil **40**. The normal range of operation of the device will be within the region lying between the horizontal line entitled Full load voltage and the abscissae axis.

While the invention has been shown and described as applied to a particular system of connections and as embodying various devices diagrammatically shown, it will be obvious to those skilled in the art that changes and modifications may be made without departing from the invention, and it is therefore, the aim in the appended claims to cover all such changes and modifications as fall within the true spirit and scope of the invention.

What is claimed as new and desired to secure by Letters Patent of the United States is:

1. In combination, an alternating current supply circuit, a load circuit, and a device comprising a pair of electrically insulated windings being wound in mutual inductive relation and being disposed relative to each other to have sufficient inter-winding capacitance which together with said inductance constitutes a tuned circuit resonant to the freqency of said supply circuit for effecting transformation of constant voltage alternating current to alternating current of constant value.

2. In combination, an alternating current supply circuit, a load circuit, and a transformer comprising a magnetic core structure and a pair of electrically insulated windings wound about said core structure and arranged to have a substantial mutual inductance, said windings being wound to minimize flux leakage therebetween and having sufficient inter-winding capacitance which together with said inductance constitutes a tuned circuit resonant to the frequency of said supply circuit for effecting transformation of constant voltage alternating current to alternating current of constant value.

3. In combination, an alternating current supply circuit, a load circuit, and a device comprising a pair of electrically insulated windings wound to form an inductance and being positioned relative to each other to minimize flux leakage therebetween, said windings having mutually disposed surfaces of a magnitude sufficient to provide a capacitance which together with said inductance constitutes a tuned circuit resonant to the frequency of said supply circuit for transforming constant voltage alternating current to alternating current of constant value.

4. In combination, a constant voltage alternating current circuit, a second circuit, and a device interposed between said circuits for transmitting alternating current of constant value to said second circuit from said constant voltage alternating current circuit comprising a pair of electrically insulated windings being wound to have a substantial mutual inductance and having sufficient inter-winding capacitance to constitute a tuned circuit resonant to the frequency of said constant voltage circuit.

5. In combination, a constant voltage alternating current circuit, a second circuit, and a device for transmitting alternating current of constant value to said second circuit from said constant voltage alternating current circuit comprising a pair of electrically insulated windings each having a pair of terminal connections, electrically opposite terminals of each of said windings being connected to a different one of said circuits, said windings having a substantial mutual inductance and having sufficient inter-winding capacitance to constitute a tuned circuit resonant to the frequency of said constant voltage circuit.

6. In combination, a constant voltage alternating current circuit, a second circuit, and a device for supplying alternating current of constant value to said second circuit from said constant voltage alternating current circuit comprising a magnetic core structure and a pair of electrically insulated windings wound about said core structure and having a mutual inductance substantially equal to the self inductances thereof, electrically opposite terminals of each of said windings being connected to a different one of said circuits, said windings being dimensioned so that there are afforded mutually disposed surfaces to form sufficient inter-winding capacitance to constitute with said mutual inductance a tuned circuit resonant to the frequency of said constant voltage circuit.

7. A device for effecting the transfer of energy between a constant voltage alternating current circuit and a constant current alternating current circuit comprising a pair of electrically insulated windings being wound to have an appreciable mutual inductance and having surfaces in proximity to afford inter-winding capacitance which together with said inductance constitutes a tuned circuit resonant to the frequency of said constant voltage alternating current circuit to effect said transfer, said inter-winding capacitance being effective as a series capacitance relative to the flow of current through said windings.

8. A device for effecting the transfer of energy between a constant voltage alternating current circuit and a constant current alternating current circuit comprising a pair of electrically insulated windings each having electrically opposite terminals thereof connected to a different one of the circuits and being wound to have an appreciable mutual inductance, said windings being dimensioned to provide surfaces in proximity to afford inter-winding capacitance which together with said inductance constitutes a tuned circuit resonant to the frequency of said constant voltage circuit to effect said transfer, said inter-winding capacitance being effective as a series capacitance relative to the flow of current through said windings.

9. In combination, a constant voltage alternating current circuit, a constant current alternating current circuit, and a transformer for effecting transfer of energy between said circuits comprising a pair of electrically insulated windings and being wound to have a substantial mutual inductance and being disposed relative to each other to have an inter-winding capacitance which together with said inductance constitutes a tuned circuit for transforming constant voltage alternating current to alternating current of constant value, said windings being dimensioned to be resonant to the frequency of said first mentioned circuits.

10. In combination, an alternating current supply circuit, a load circuit, and a transformer comprising a pair of electrically insulated windings being wound to have a substantial mutual inductance and being disposed relative to each other to have sufficient inter-winding capacitance which together with said inductance constitutes a tuned circuit resonant to the frequency of said constant voltage circuit for effecting transformation of constant voltage alternating current to alternating current of constant value and means for controlling the magnitude of the constant current alternating current.

11. In a combination, an alternating current supply circuit, a load circuit, a transformer comprising a magnetic core member, a pair of electrically insulated windings associated with said core member and arranged to have a substantial mutual inductance, said windings having sufficient inter-winding capacitance which together with said inductance constitutes a tuned circuit resonant to the frequency of said supply circuit for effecting transformation of constant voltage alternating current to alternating current of constant value, and means for establishing in said core member a unidirectional magnetomotive force to control the value of constant current which is transmitted to said load circuit.

12. In combination, an alternating current supply circuit, a load circuit, a transformer comprising a magnetic core member, a pair of electrically insulated windings associated with said core member and arranged to have a substantial mutual inductance, said windings having sufficient inter-winding capacitance which together with said inductance constitutes a tuned circuit resonant to the frequency of said supply circuit for effecting transformation of constant voltage alternating current to alternating current of constant value, and means for saturating said core member to control the value of constant current which is transmitted to said load circuit.

WILLIAM A. DODGE,
Administrator of the Estate of Camil A. Sabbah, Deceased.

LYSLE W. MORTON.

Certificate of Correction

Patent No. 2,168,173. August 1, 1939.

WILLIAM A. DODGE, ADMINISTRATOR OF CAMIL A. SABBAH, DECEASED, ET AL.

It is hereby certified that errors appear in the printed specification of the above numbered patent requiring correction as follows: Page 3, first column, line 38, for "at" read *as;* line 60, before the equation beginning with

$$\text{"}x_2(b_2-b_1)-2x_1\left(b_2+b_3+\ \ldots\ +b_{\frac{n}{2}}\right)-\text{"}$$

insert the following—

The current equations may be written as:

$$\left.\begin{aligned} a_1&=a_2+b_2\\ a_2&=a_3+b_3\\ a_3&=a_4+b_4\\ &\cdots\cdots\cdots\\ a_{\frac{n}{2}}&=a_{\left(\frac{n}{2}+1\right)}+b_{\left(\frac{n}{2}+1\right)} \end{aligned}\right\} \qquad (4)$$

$$\left.\begin{aligned} a_{\left(\frac{n}{2}+1\right)}&=a_{\left(\frac{n}{2}+2\right)}+b_{\frac{n}{2}}\\ a_{\left(\frac{n}{2}+2\right)}&=a_{\left(\frac{n}{2}+3\right)}+b_{\left(\frac{n}{2}-1\right)}\\ a_{\left(\frac{n}{2}+3\right)}&=a_{\left(\frac{n}{2}+4\right)}+b_{\left(\frac{n}{2}-2\right)}\\ &\cdots\cdots\cdots\\ a_{(n-1)}&=a_n+b_2\\ a_n&=b_0+b_1 \end{aligned}\right\} \qquad (5)$$

Using the equations of Groups 4 and 5, the currents represented by the a quantities can be eliminated from Equation 2 and the groups of Equations 3, as follows:

$$jE=x_2b_1-nx_1\left(b_0+b_1+\ \ldots\ +b_{\frac{n}{2}}\right)-\frac{n}{2}x_1b_{\left(\frac{n}{2}+1\right)} \qquad (2a)$$

and second column, line 39, beginning with the words "The current equations" strike out all to and including the equation

$$\text{"}jE=x_2b_1-nx_1\left(b_0+b_1+\ \ldots\ +b_{\frac{n}{2}}\right)-\frac{n}{2}x_1b_{\left(\frac{n}{2}+1\right)} \qquad (2a)\text{"}$$

in lines 63 to 68 inclusive; and that the said Letters Patent should be read with these corrections therein that the same may conform to the record of the case in the Patent Office.

Signed and sealed this 26th day of September, A. D. 1939.

[SEAL]

HENRY VAN ARSDALE,
Acting Commissioner of Patents.