May 1, 1956 M. MORRISON 2,744,228

APPARATUS FOR REDUCTION OF AMPLITUDE VARIATION IN PULSATING VOLTAGES

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FIG. 1

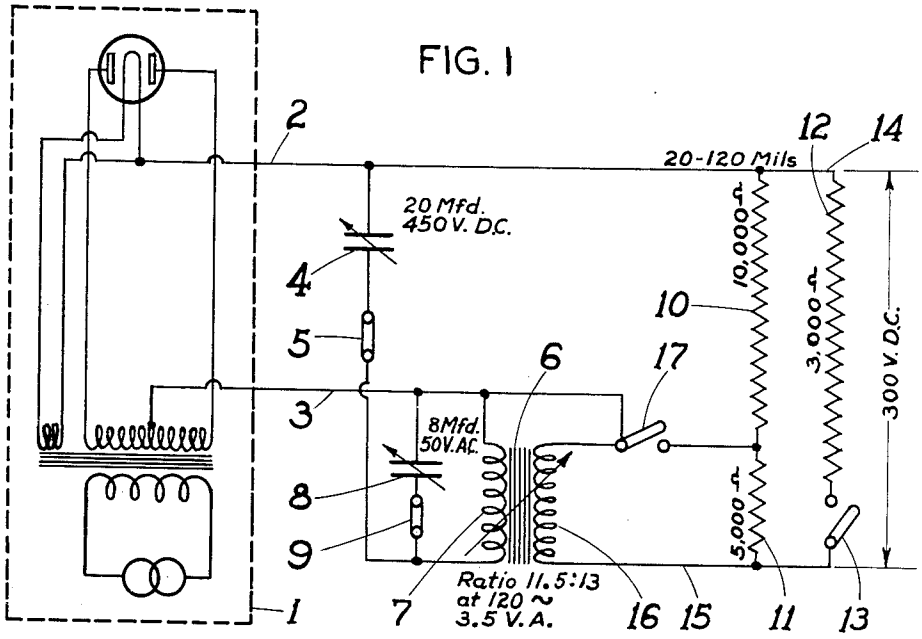


FIG. 2

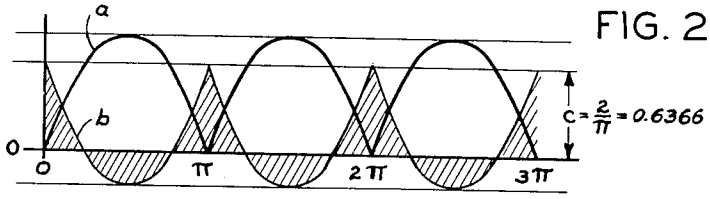


FIG. 3

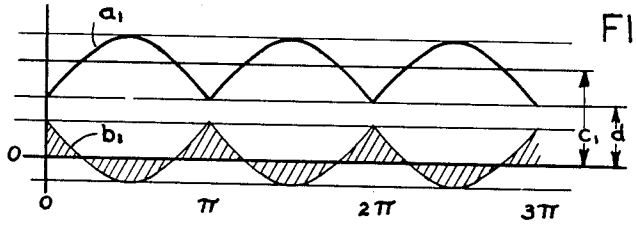
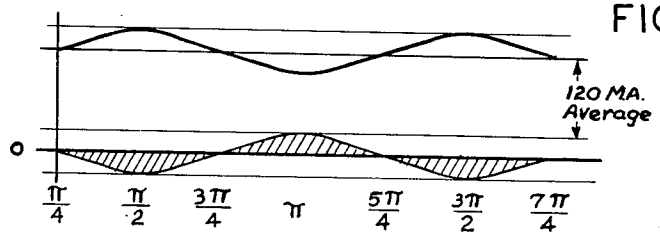


FIG. 4



INVENTOR.

Montford Morrison

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APPARATUS FOR REDUCTION OF AMPLITUDE VARIATION IN PULSATING VOLTAGES

Montford Morrison, Rochester, N. Y.

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6 Claims. (Cl. 321—10)

The present invention relates generally to systems and methods for reducing the harmonic content in periodic pulsating voltages, it relates more particularly to systems and methods for improving the constancy of output potentials in alternating current rectifier systems and more specifically to improvement in plate power supplies for electron discharge tubes.

Among the objects of this invention are; to provide a system and method which can entirely eliminate the harmonic content of periodic pulsating currents; to provide such a system and method which derives its corrective properties directly from the pattern of the wave form to be corrected; and to provide such a system and method that the correction is automatic with variation in load.

The present invention is not limited to any particular generator or rectifier system, nor is it limited to single phase application, but may be applied to any source of pulsating periodic current.

The nature of the invention resides in a system and method of wave-form correction, rather than one of specific generator or rectifier corrective.

In prior art systems, the reduction of the harmonic content of rectified alternating current has been accomplished by the employment of electric wave filters, which may be viewed as series networks interposed between the source of rectified potentials and the load.

Such wave filters are commonly known as low-pass filters and these always employ series impedance components. These series impedance components contribute directly to the increase in the loss of voltage due to increased loads.

The constancy of load voltage in such circuits depends upon the storage of energy at intermediate positions in the filter and the subsequent withdrawal of energy from these positions. The withdrawal of energy from these positions, which is necessarily periodic, results in a periodic variation in the stored energy and therefore inherently a periodic variation in the load voltage.

The period of this variation being the period of the pulsations in the rectified voltage (not the period of the supply voltage).

In the present invention the system has no necessity of series impedance interposed between the source of pulsating voltage and the load.

The pulsating voltage is divided near its source into two circuits. One of which is supplied directly to the load in the form of a pulsating voltage and the other divided circuit causes the phase of the pulsating voltage to be reversed and this reversed voltage, which may be of the exact form of the pulsating voltage applied to the load, has its alternating current component added algebraically in the load circuit to the first mentioned pulsating voltage, which may, if desirable, entirely eliminate the alternating current component of the original pulsating voltage, resulting in a pure continuous direct voltage of a magnitude equal to the average value of the first mentioned voltage.

Such a system inherently has some filtering characteristics and may automatically supply the correct amount for exact load voltage correction with variations in load.

The full meaning of these statements will become obvious upon reading the specifications in connection with the accompanying drawing, in which Fig. 1 shows in diagrammatic form, one embodiment of the invention and Figs. 2, 3, and 4, are diagrams useful in understanding its operation.

Fig. 1, the dotted area **1** represents any source of periodic pulsating voltage (it may employ a polyphase system if desired), **2** and **3** are output leads therefrom. These two output leads supply a periodic pulsating voltage. In the embodiment under illustration, this pulsating voltage, in the presence of only a pure resistive load, would be a full wave rectified single phase voltage such as shown in Fig. 2 by the curve *a*.

Capacitor **4** is connected to lead **2** and through switch **5** to one terminal of primary winding **7** of transformer **6**. The other terminal of primary winding **7**, is connected to lead **3**. Primary winding **7** may be shunted by capacitor **8**, selectively by closing or opening switch **9**. Thus the input of transformer is supplied by shunt connections to source of pulsating voltage **1**.

The output load of the system, which operates at substantially continuous potential, is represented by resistors **10**, **11** and **12**. Resistor **12** may be selectively cut into, or out of, circuit employment by switch **13**.

Lead **2** is connected to resistors **10** and **12** at location **14**. Resistor **12** is connected to lead **15** when switch **13** is closed. Resistor **10** is connected through resistor **11** to lead **15**. Lead **15** is connected to one terminal of secondary **16** of transformer **6**, the other terminal of secondary **16** is connected to lead **3** and switch **17**, which in turn is connected to the joined position of resistors **10** and **11**, when closed.

Although the elementary diagram of the embodiment illustrated in Fig. 1, seems very simple to view and very easy to understand by a described operation, hereinafter given, it is pointed out that an analytic treatment of the invention is necessarily very complex, if every possible variation of the circuit parameters is considered, and every possible result of such variation is pointed out with particularity.

While some reasonable amount of theoretical analysis will be given, it is believed that the most satisfactory way to teach one skilled in the art how to make and use this invention is to give a practical example of a useful embodiment, and from that a study of its operation under variation of the characteristics of the given components other and further results will be indicated.

In line with this procedure the operation of the embodiment shown in Fig. 1, will be first treated from the simplest, idealistic form of operation to understand and then proceed to treat a typical form of operation more commonly found in practical embodiments.

Referring to Fig. 1, source of periodic pulsating potential **1**, is selected to produce an output voltage such as shown in Fig. 2, curve *a*. The total load illustrated in the diagram of Fig. 1, is (by disregarding the numerical values associated with the circuit components shown in the figure) adjusted to preserve the character of voltage wave form shown by *a* in the figure. This adjustment is made with switch **9** open and switch **17** closed. Under these conditions the loading of transformer **6**, is taken to be substantially resistive. Capacitor **4** eliminates the direct voltage component of output voltage *a* Fig. 2, from the primary **7**, of transformer **6**, the applied voltage being purely alternating.

If the wave-form of voltage *a*, is taken as sinusoidal, and the capacity of capacitor **4**, is properly selected in view of the loading adjustment to preserve the wave form of *a* and its phase position, the zero position of the alternat-

ing voltage applied to resistor 11, is determined by the condition that

$$-\int_0^{\pi}(\sin\theta - c)\,d\theta = 0 \qquad (1)$$

from which

$$c = \frac{2}{\pi} = 0.6366$$

and which position is indicated in Fig. 2 by curve *b*.

The average value of curve *a* is

$$a_{avg} = \int_0^{\pi} \sin\phi\, d\theta = \frac{2}{\pi} = 0.6366$$

and without going into an elaborate mathematical demonstration, it is believed that it is plainly obvious upon inspection of Fig. 2, that the algebraic sum of curves *a* and *b*, is a straight line parallel to the axis of the abscissas of a value 0.6366.

Returning to Fig. 1, then the pulsating voltage represented by curve *a*, is applied across resistor 10, and the alternating voltage *b*, is applied across resistor 11. These two resistors being in series, the algebraic sum of these two voltages appears across lead 2 and 15 and hence the total load has a pure continuous voltage impressed upon it and by closing switch 13, this continuous voltage is impressed upon a single load circuit.

While this description serves well to teach the generalized nature of the invention, more useful adjustments of the circuit parameters are desirable.

It is believed, it will be plainly obvious to those skilled in the art, that the nature of the invention is not limited to the employment of sinusoidal wave-form, but importantly resides in deriving an alternating voltage from a pulsating voltage, and by combining the two voltages in a series connection with proper phase relation to reduce the amplitude of pulsations in a load circuit.

This system of operation differs very clearly from prior art systems employing low-pass filters, in which capacitors are charged during voltage peaks of the pulsating voltage, to be drained off at intervals between the peaks. Such a system requires some periodic reduction in these charges, to be subject to recharging, and therefore always some ripple in the load voltage.

While in the present system there is some inherent filtering in many practical embodiments, by capacitor 4 alone, and, or in conjunction with the windings of transformer 6, and can contribute materially to the desired end result, the final reduction of the variation in amplitude of the pulsating voltage, by the impressing of the alternating voltage into the load circuit by transformer 6. The importance of this statement can be quickly appreciated, by reversing the phase of the alternating voltage applied to the load circuit, when it will be observed that an alternating component is introduced into that circuit.

In the present system the alternating voltage which is used to reduce the amplitude of pulsations in the load voltage, is a continuously functioning means, derived from a shunt connection to the source of potential, and not a system direct current charging and discharging.

The feature of automatic compensation of the alternating component which is added to the pulsating voltage in the load, can be understood by reference to Fig. 3, in connection with Fig. 2. If the circuit shown in Fig. 1, has been operating in accordance with illustrated curves in Fig. 2, as described and the resistive load of the circuit is decreased, the conditions represented in Fig. 3 can occur. The resistive load being decreased, there appears a residual charge in capacitor 4, represented by the ordinate value of the line *d*, in Fig. 3. The voltage pulsations decrease in amplitude as shown by curve a_1, with the consequent proportional reduction in the amplitude of alternating potential component thereof, but since the required amplitude of alternating potential for compensation, is produced by the amplitude requiring compensation, the

effect of amplitude adjustment is automatic. That is, any curve b_1, added to any corresponding curve a_1, results in a straight line, theoretically, but the value of the resultant potential is raised to a higher value. This action may be termed automatic load ripple compensation.

In prior art systems employing low-pass filters, variations in load cause variations in the amplitude of the load ripple, and very markedly so for load variations having periods in the neighborhood of the pulsation frequency.

At this point it is well to look at the harmonic content of curve *a* Fig. 2, and examine the problem of harmonic reduction more closely. Taking curve *a* as being sinusoidal of an amplitude of 1 and having a period of 2π, the Fourier Series analysis of this curve yields:

$$a = \frac{2}{\pi} - \frac{4}{\pi}\sum_{n=2}^{n=\infty} \frac{\cos n\theta}{(n-1)(n+1)} \qquad (2)$$

where *n* is even only.

This equation shows that the curve is composed of a constant value (which is the first power average) plus a series of alternating current components which must have a first power average of zero.

There is nothing in the theory which limits the order of the harmonic components in the periodic pulsating voltage wave or the amplitudes thereof, so that we may have any form of pulsating voltage wave, so long as it is periodic, thus

$$\text{Any wave-form} = \text{average voltage} - \sum_{n=1}^{n=\infty}(V_n' \sin n\theta + V_n'' \cos n\theta) \qquad (3)$$

and since the second term is that which requires compensation, and since the voltage represented by this term generates its own wave form for compensation (phase reversed), the system as described, may be applied to any form of periodic pulsating voltage for amplitude of pulsation reduction.

In the foregoing teaching of this invention the wave-forms have been assumed to be purely sinusoidal for simplicity and ease of understanding, but in many practical embodiments of this invention the periodic pulsating voltage that appears between terminals 2 and 3 of Fig 1 is a wave-form widely different from that of a sine curve.

This wave-form distortion is caused by the circuit loading, the circuit filtering action of the imposed load, and the operating characteristics of the rectifier employed in the generator enclosed in the dotted area.

Generally speaking, in practical circuits the arrangement shown in Fig. 1 is slightly altered and the operation of a practical device having circuit components of the characteristics and magnitudes of those indicated on the drawing will be disclosed.

Switch 9 is closed as indicated on the diagram, and switch 17 is open as indicated on the diagram. Switch 13 may be opened or closed at will. The switch 13 is closed and the pulsating voltage output of the generator in dotted area 1, is adjusted to give 300 V. D. C. as indicated on the diagram.

The ratio of transformation of transformer 6 and capacity of capacitor 8 is adjusted until the ripple in the voltage across resistor 12 substantially disappears. The ratio of voltage transformation in transformer 6 was found with the particular type of transformer employed, to be 11.5:13 and the capacity of condenser 8 was found to be 8 mfd.

This operation, of course, requires that the voltage across secondary 16 is of the proper phase relation to cancel out the alternating-current content of the pulsating voltage that appears across terminals 2 and 3.

It is well known that the harmonic content of such pulsating waves as those with which we are dealing and which is represented by the second term in the right hand member of Equation 3 above, in terms of the alternating

current frequency in the generator before rectification, that the harmonic content represents a series starting with the 2nd and continuing with the 4th, 6th, 8th . . . etc., with rapidly decreasing amplitudes.

The filtering action of capacitor **4** and transformer **6**, of course, reduces the amplitudes of all these harmonics by tending to reduce the amplitudes of the higher harmonics more than that of the 2nd, so that the prime function of transformer **6** with its connected circuits, is to principally eliminate the second harmonic by not only producing the correct amplitude, but also the correct phase position for compensation.

Where the above-referred-to filtering action of capacitor **4**, is to be taken into account in the theory of operation of Fig. 1, the voltage that appears between the output terminals **2** and **3**, may assume the form shown in the upper curve of Fig. 4, instead of the form a_1 shown in Fig. 3. Likewise the reversed alternating voltage component derived from the upper curve of Fig. 4, will assume the form of the lower curve in Fig. 4, instead of the form b_1 in Fig. 3. Obviously, from this point on, the operation of Fig. 1 with the waveforms of Fig. 4, will parallel the theory of operation already described under consideration of the waveforms of Figs. 2 and 3. The curves in Fig. 4, are plotted with physically double length abscissas and with a

$$\frac{\pi}{4}$$

shift in phase position, for clearness in inspection.

Many other and further embodiments of the invention may be made by those skilled in the art of its application, which can best be learned by experimental study of the simple circuit given or some modification of it, with variation of parameters to suit the problem to be solved.

What is claimed is:

1. In an electrical system for the reduction of amplitude variation in the output voltages of alternating current rectifier organizations, an alternating current rectifier organization producing at its output pulsating voltage having a waveform of a predetermined alternating voltage content and a predetermined constant voltage component, a first load circuit connected to said output and having said voltage waveform impressed upon it, a circuit connected in shunt relation to said first load circuit and including electrical circuit means eliminating substantially only said constant voltage component of said pulsating voltage waveform, magnetic circuit means connected to said circuit connected in shunt reversing the phase of the alternating voltage content of said circuit connected in shunt, a second load circuit connected to said magnetic circuit means and having said reversed alternating voltage content impressed upon it, and said two load circuits connected in series forming a series circuit with the polarities of the alternating voltages of said load circuits opposing, whereby reduction of amplitude variation of said pulsating voltage is caused at the terminals of said series circuit.

2. In a system for the reduction of amplitude variation in the output voltages of alternating current rectifier organizations, an alternating current rectifier organization producing pulsating output voltage having a waveform of a predetermined alternating voltage content comprising a series of harmonic frequencies and a predetermined constant voltage component, a first load circuit connected to said output voltage and having electrical circuit means preserving said pulsating voltage in substantially its organization output waveform, a second circcuit connected to said output voltage in parallel with said first load circuit and having electrical circuit means therein eliminating said constant voltage component and preserving in substantially organization output waveform said alternating voltage content, magnetic circuit means in said second circuit reversing the electrical phase of said preserved alternating voltage content of said waveform of said pulsating voltage

and conducting said reversed phase voltage to a second load circuit, and said two load circuits connected in series forming a series circuit with said harmonic frequencies of the alternating voltage of one of said load circuits operating in reversed phase relation with the corresponding harmonic frequencies of the alternating voltage of the other of said load circuits, whereby polarity opposition in the flows of current of the harmonic frequencies in said two load circuits cause reduction of amplitude variation of load voltage at the terminals of said series circuit.

3. In a system for converting alternating current into substantially constant voltage in a load circuit of finite resistance, a source of alternating current, rectifying means converting said alternating current into unidirectional pulsating current, electrical circuit means converting said unidirectional pulsating current into alternating current and maintaining the characteristic waveform of said pulsating current, magnetic circuit means reversing the phase relation of the last said alternating current, a first load circuit of finite resistance being connected across the rectifying means, a second load circuit of finite resistance being connected across the output side of the magnetic circuit means, said first and said second load circuits being connected in series relation and forming a series circuit, and instantaneously opposing polarities of current flows in said load circuits causing substantially constant voltage at the terminals of said series circuit.

4. In an electrical system for the elimination of amplitude variation in the output voltages of alternating current rectifier organizations, an alternating current rectifier organization producing at its output pulsating voltage having a waveform of a predetermined constant voltage component and a predetermined alternating voltage content, a first load circuit connected to said output and having both said constant voltage component and said alternating voltage content impressed upon it, an intermediary circuit having an input and an output, the input of the intermediary circuit being connected in shunt with the output of the alternating current rectifier and producing only said alternating voltage content across its output, a second load circuit connected in series with said first load circuit and forming a series circuit therewith, said second load circuit being magnetically coupled to said intermediary circuit and having said produced alternating voltage content impressed upon it in a reversed polarity relation to the corresponding alternating voltage in first said circuit, whereby the opposing alternating voltages in the two load circuits in series are substantially cancelled out at the terminals of the series circuit and only the constant volage component is available at said terminals.

5. In a system for converting alternating current into substantially constant voltage in a load circuit of finite resistance, a source of alternating current, rectifying means converting said alternating current into unidirectional pulsating voltage, electrical circuit means conducting said pulsating voltage in preserved waveform to a first load circuit of finite resistance, a circuit parallel to said first load circuit having electrical circuit means converting said unidirectional pulsating voltage into alternating voltage and maintaining in said parallel circuit the characteristic waveform of said pulsating voltage, magnetic circuit means coupled with said parallel circuit reversing the phase relation of the voltage from said parallel circuit and maintaining its waveform, means conducting said alternating voltage in reversed phase relation to a second load circuit of finite resistance, said two load circuits being connected in series relation and forming a series circuit, and the difference in flow of currents due to said voltages in said two load circuits causing substantially constant voltage difference between the terminals of the series circuit.

6. In a system for converting alternating current into substantially constant voltage in a load circuit of finite resistance, a source of alternating current, rectifying

means converting said alternating current into unidirectional voltage of constant and alternating components, a first and a second load circuit connected in series and forming a series circuit receiving electrical energy from said unidirectonal voltage, means coupling the unidirectional voltage to said first load circuit in preserved waveform, electromagnetic means coupling the second load circuit to said first load circuit, and said electromagnetic coupling means eliminating said constant component and reversing the phase relation of said alternating voltage component in said second load circuit, whereby said alternating components in said series circuit are neutralized at the terminals thereof, causing substantially constant voltage at said terminals.

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