Aug. 30, 1955 J. A. KUECKEN 2,716,707

CONDENSER IMPULSE GENERATOR AND METHOD

Filed Jan. 16, 1951 3 Sheets-Sheet 1

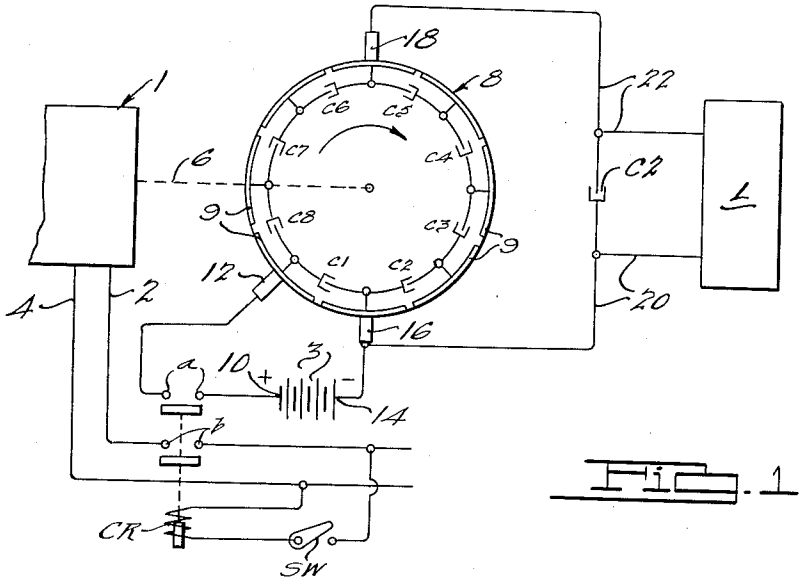


Fig. 1.

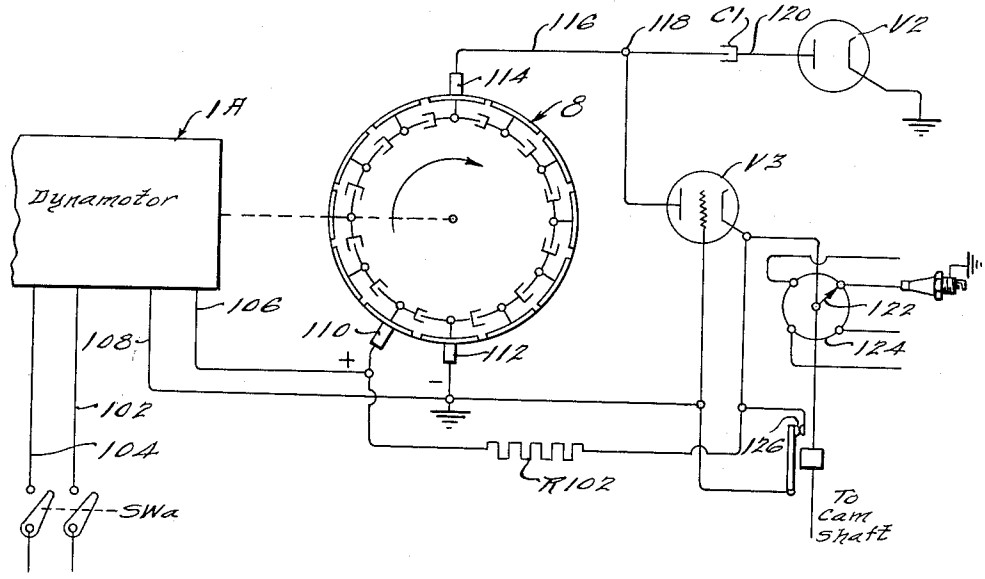


Fig. 2.

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CONDENSER IMPULSE GENERATOR AND METHOD

Filed Jan. 16, 1951 3 Sheets-Sheet 2

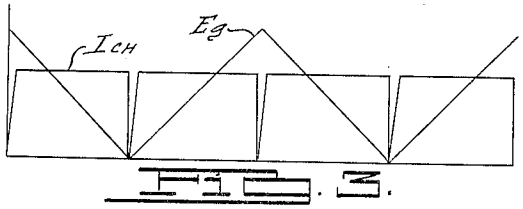


Fig. 3.

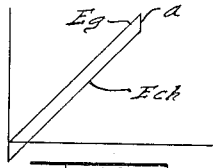


Fig. 4.

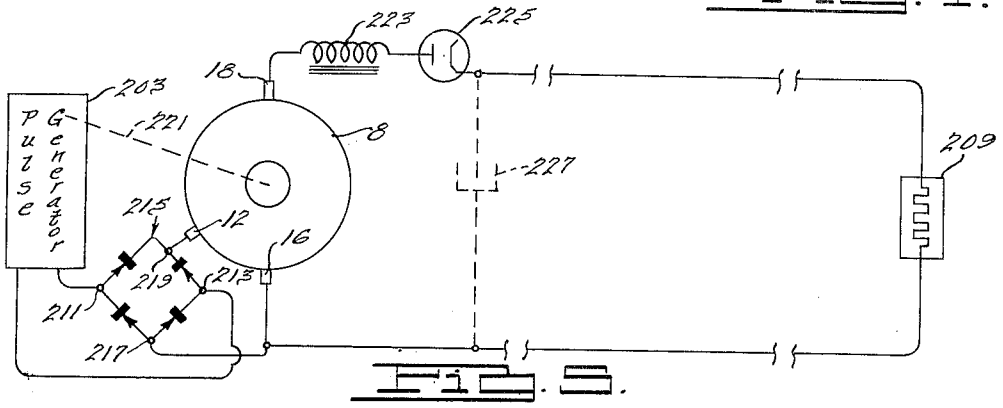


Fig. 5.

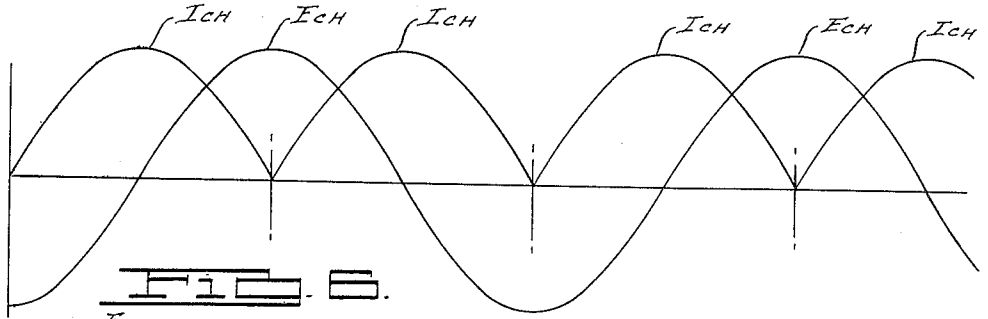


Fig. 6.

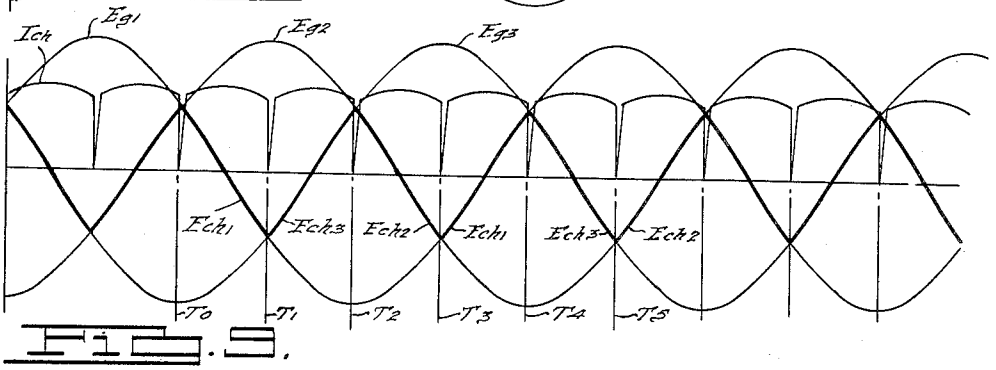


Fig. 9.

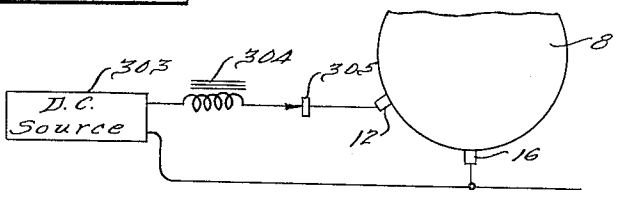


Fig. 7.

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Aug. 30, 1955 J. A. KUECKEN 2,716,707

CONDENSER IMPULSE GENERATOR AND METHOD

Filed Jan. 16, 1951 3 Sheets-Sheet 3

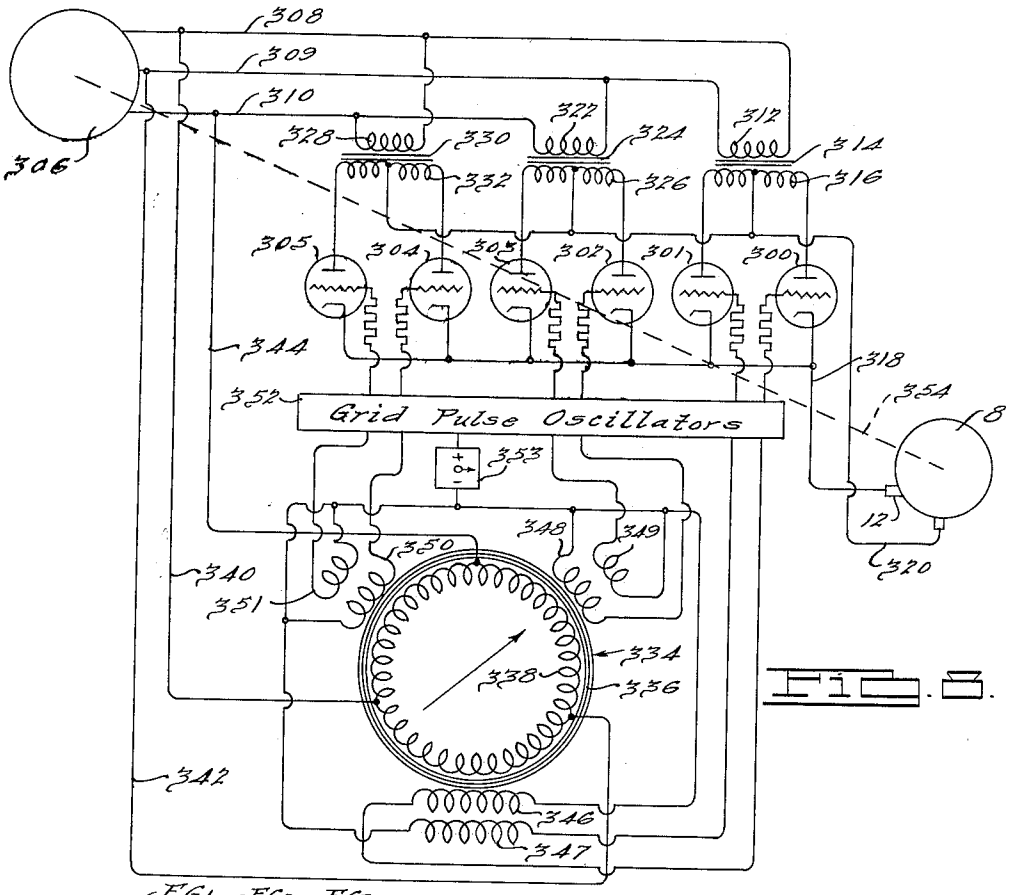


Fig. 9.

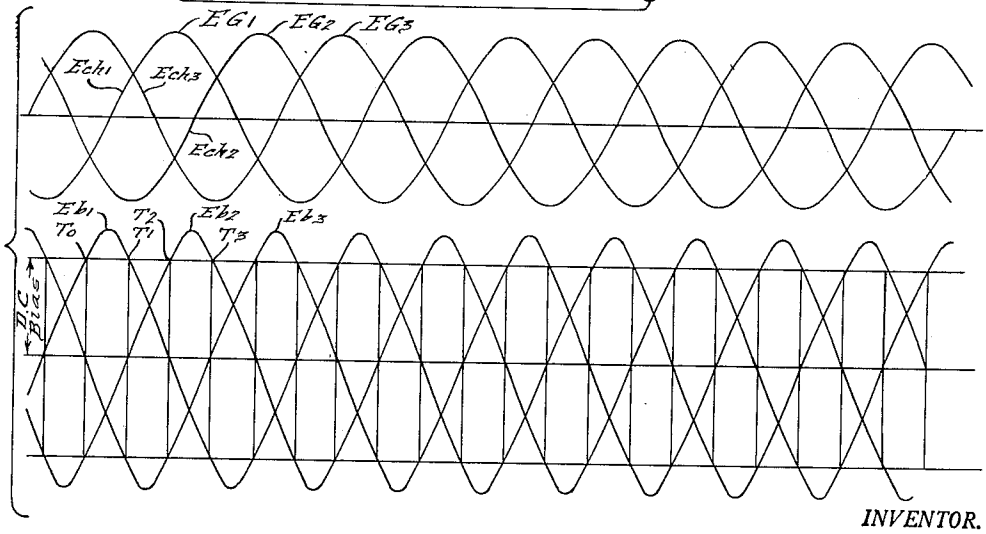


Fig. 10.

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United States Patent Office 2,716,707 Patented Aug. 30, 1955

2,716,707

CONDENSER IMPULSE GENERATOR AND METHOD

John A. Kuecken, Detroit, Mich.

Application January 16, 1951, Serial No. 206,217

39 Claims. (Cl. 307—110)

This application is a continuation in part of my co-pending, but since abandoned, application, Serial No. 148,231, filed March 4, 1950.

This invention relates generally to the generation of high unidirectional voltages from a low voltage source.

Generically the invention contemplates the arranging of a plurality of condensers in series relation with each other in the form of a closed loop and individually charging the condensers and discharging at least a portion of the condensers in series arrangement.

A primary object of this invention is to provide a new means for increasing the magnitude of unidirectional voltages.

Another object is to provide such a means which is simple and economical of manufacture and which may therefore be sold at a moderate price.

Another object is to provide such a means in which the low voltage supply will not "float" with respect to ground potential and therefore need be insulated only in accordance with its voltage and independently of the high voltage output.

A further object is to provide such a means in which the danger to personnel from the high voltage is a minimum.

Another object is to provide such a means which may be built in small as well as large units whereby it may be used in portable or mobile as well as fixed locations.

A further object is to provide a novel means for charging and discharging the capacitors with high efficiency.

A still further object is to provide for charging such a means from an alternating current supply.

A still further object is to provide for charging such a means from a polyphase alternating current supply.

A still further object is to provide an efficient method of discharging such a means.

Another object is to provide such a means which may be used in ignition systems of motor vehicles.

A still further object is to provide a new ignition system for internal combustion engines.

Other objects will be apparent from the specification, the appended claims and the drawings in which drawings:

Figure 1 is a schematic view of a high voltage generator embodying the invention and connected to supply a high voltage load;

Fig. 2 is a schematic view of a modified form of the invention;

Fig. 3 is a schematic view illustrating certain electrical characteristics of one form of the invention;

Fig. 4 is a schematic view illustrating certain other voltage characteristics of the invention;

Fig. 5 is a schematic view of a further form of the invention;

Fig. 6 is a schematic view illustrating certain electrical characteristics of another form of the invention when an alternating current supply is used;

Fig. 7 is a schematic view of a further modified form of the invention using a direct current source;

Fig. 8 is a schematic view of a still further modified

form of the invention using a polyphase alternating current source; and,

Figs. 9 and 10 are schematic views illustrating certain voltage characteristics of the form of the invention of Fig. 8.

Referring to the drawings by characters of reference, the numeral 1 indicates generally a suitable driving means such as an electric motor 1 connected by means of conductors 2 and 4 to a suitable source of electrical energy. The motor 1 has an output shaft 6 to which is connected a cylindrical drum 8 in which is mounted a plurality of condensers C1 to C8 inclusive arranged in continuous series circuit and of equal capacity. Eight capacitors C are shown but this number could be increased or decreased as desired. The common junction of each adjacent connection of the capacitors C is connected to a commutator-like segment 9 which lies along the peripheral surface of the drum 8. A battery B or other suitable source of direct current for individually charging the condensers C is provided. One terminal 10 is connected through the contacts *a* of a control relay CR to one brush 12. The other terminal 14 of the battery B is connected to a second brush 16. The brushes 12 and 16 are peripherally arranged around the drum 8 so that they will contact two adjacent segments 9 for individually charging the capacitor C which is connected therebetween. A third brush 18 is arranged on the periphery of the drum diametrically opposite from the brush 16. The brushes 16 and 18 constitute the high voltage output connections and may be connected by conductors 20 and 22 to a load L.

The control relay CR is provided with contacts *b* which are arranged in one of the conductors 2 or 4, they being in the conductor 2 in this instance so that upon energization of the control relay CR, the contacts *a* and *b* will close thereby completing the charging circuit of the battery B and energizing the motor 1. The control winding of the relay CR may be connected across the supply for the conductors 2 and 4 and may be controlled by means of the manually operable switch SW. Upon closure of the switch SW the relay CR is energized, closing its contacts *a* and *b*. Closure of the contacts *b* establishes an energizing circuit for the motor 1 whereby it is effective to rotate the drum 8. Closure of the contacts *a* completes a charging circuit through the battery B whereby the various capacitors C are individually charged as they are placed electrically between the brushes 12 and 16.

It is believed that the remainder of the construction may best be understood by a description of the operation thereof.

Assuming an initial state of the drum with all of the condensers discharged and C1 is connected between the brushes 12 and 16, closure of the contacts *a* of relay CR will cause the condenser C1 connected between the brushes 12 and 16 to be charged by the battery B whereby the voltage thereacross will be equal to that of the battery B. Since all of the condensers C1–C8 are series-connected in a closed loop the remainder of the condensers will as a unit assume a charge equal to, but opposite in sign, to that on C1. Since the total number of these condensers is one less than the number in the loop the charge on each will be *d* equal to

$$d=\frac{Ec}{N-1}$$

where Ec equals the change in voltage charge of the condenser and N equals the total number of condensers C of the loop.

Assuming for purposes of illustration a charging voltage of 300 and a loop of 8 condensers as shown, C1 will have a positive charge of 300 volts and each of the other condensers will have a negative charge of 42.9 volts.

Unless otherwise specified or connoted, a positive charge on a condenser is when the left terminal thereof is positive and a negative charge is when the left terminal is negative when the condensers are viewed from the center of revolution of drum **8**.

As the drum **8** is rotated (in this instance shown as clockwise but which could be in the other direction) the next capacitor **C2** with an opposite or negative charge of 42.9 volts, as expressed in the above equation, will be placed across the battery B whereby its charge will be reversed and increased in magnitude to the value E*ch* (300 volts). The remainder of the condensers **C1** and **C3–C8** must then assume a charge which is equal and opposite to the charge on the capacitor **C2**. Condenser **C2** had an original charge of 42.9 volts negative and after charging has a charge of 300 volts positive. The total change in charge of **C2** was 342.9 volts. This change is balanced by an equal change in the total charge on the condensers **C1** and **C3** through **C8** or seven other condensers. Each of these seven condensers therefore becomes more negatively charged to the extent of one seventh of the change in charge of 342.9 volts or roughly 49 volts. Since the loop now contains a condenser (**C1**) which has been charged by the battery B to positive 300 volts the condensers will have voltage charges as follows: **C1** +251; **C2** +300; and **C3** through **C8** −91.9.

As the drum **8** continues to present the condensers **C3** through **C8** in sequence the condensers being presented for charging by the battery B will be more and more negative requiring a greater and greater change in charging voltage. Starting from the original conditions of no charge on the condensers, the condensers are presented to the battery with voltages as follows: **C1**—0.00; **C2**—42.9; **C3**—91.9; **C4**—147.6; **C5**—211.8; **C6**—284.9; **C7**—368.5; and **C8**—464.0, assuming no output load is removed from the condensers.

At the time **C2** was presented, **C1** had a charge of 300 volts positive and therefore its voltage was reduced by 49.0 volts which is 1/7 of the 342.9 volt increase given **C2**. As the remainder of the condensers **C3–C8** are charged the voltage of capacitor **C1** is progressively reduced from the initial positive voltage of 300 until when it again is brought between the brushes **12** and **16** for recharging it has a negative charge of 230.2 volts. The change in voltage imparted to **C1** by the battery at its second trip to the battery in order to raise its charge to 300 volts positive is 530.2 volts.

During the next revolution of the drum, condensers **C2–C8** will arrive with negative charges of 257.0; 280.6; 299.6; 312.2; 316.1; 308.8; and 286.9 respectively which will cause a voltage increase in the negative direction on the condensers in the ring or loop, other than the condenser connected across the battery, of 75.8; 79.6; 82.9; 85.7; 87.5; 88.2; 87.0 and 83.9. In this manner condenser **C1** which had a charge of 300 volts positive as it left the brushes **12** and **16** will have a charge of 294.8 volts negative when it is placed for the third time between the brushes **12** and **16** for recharging to a value of 300 volts positive. The charge on the condensers **C2** through **C8** on their third charging may be shown to have the following approximate negative voltage charges; **C2**, 257.0; **C3**, 280.6; **C4**, 299.6; **C5**, 312.2; **C6**, 316.1; **C7**, 308.8; and **C8**, 286.9. On the next or fourth rotation of the drum the condensers may have the following approximate negative voltage charges: **C1**, 294.8; **C2**, 300.2; **C3**, 303.1; **C4**, 304.6; **C5**, 302.5; **C6**, 300.4; **C7**, 299.2; and **C8**, 300.9.

From the above, it will be seen that in the matter of a very few revolutions approximate equilibrium conditions are attained. It will further be observed that the average negative charge on the capacitors is approximately 300 volts. Since the condensers arrive with a negative voltage of 300 and leave with a positive voltage of 300 the total change in charge is 600 volts. This

will result in an average change in charge on the condensers not being charged of about 85.7 volts. As will be shown mathematically below, the maximum voltage appears between the brushes **16** and **18**. In this instance, the voltage can be found by assuming that equilibrium conditions have been reached and that at the selected instant condenser **C1** is connected between the brushes **12** and **16** and that the reference potential is the potential of brush **16**. The voltage across **C1** is 300; **C8** is 300–85.7; **C7** is 300–2 (85.7); and **C5** is 300–3 (85.7). The voltage across **C1** and **C5** is therefore the sum of the individual voltages or 685.8 volts for the example selected.

An analysis of the foregoing will show that under equilibrium conditions the difference in charge between any two adjacent capacitors other than between the one being charged and its following capacitor is a constant and the charges on the condensers are in arithmetic progression. The general formula for the sum of an arithmetic progression which may be found in any text on the subject and specifically in F. L. Griffin's Introduction to Mathematical Analysis, copyright 1921 by Frank L. Griffin, page 416, is:

$$S=\frac{n}{2}(a+l)$$

where

S equals the sum
n equals the number of terms
l is the last term
a is the first term

It will be realized that the sum of the voltages around the loop must be zero, the number of terms *n* will be the number of condensers in the ring, the first term *a* will be the charging voltage E*ch* and the last term *l* will be the voltage on the last condenser L. Therefore

$$0=\frac{N}{2}(Ech+L) \text{ or } Ech=-L$$

where

N equals number of condensers
Ech equals the charging voltage
L equals the voltage of the last condenser

The voltage of the last condenser will therefore be equal and opposite to the charging voltage at equilibrium conditions. This agrees with the step-by-step example given above.

It has been shown that the condenser which is being presented to the battery B has a charge equal to the battery voltage but of opposite sign. Therefore the change in voltage (*d*) imparted to each of the condensers other than that across the battery B is equal to

$$\frac{2Ech}{N-1}$$

Since the sign of *d* is negative and the total voltage around the loop of condensers is 0, there must be a point at which the sum of the voltages of a number (*nx*) of the condensers reaches a maximum after which it again decreases until when *nx* equals N the sum is zero. Using the basic formula

$$S=\frac{nx}{2}(Ech+l)$$

where *l* is the charge on the last condenser of the series, the voltage between brush **16** and any segment **9** may be calculated.

A second basic formula is

$$l=a+(n-1)d$$

where

a is the first term
n the number of terms
d is the difference

From the preceding it has been shown that under equilibrium conditions the change in charge imparted to the condenser by the battery is twice the potential of the battery or $Ec=2Ech$. Therefore rewriting a formula developed above and taking into account the algebraic sign

$$d=\frac{2Ech}{(N-1)}$$

Substituting in the formula for l

$$l=Ech+\frac{(nx-1)(-2Ech)}{N-1}$$

Substituting this in the formula for S

$$S=\frac{nx}{2}\left(Ech+Ech+\frac{(nx-1)(-2Ech)}{(N-1)}\right)$$

By simplifying and removing fractions

$$(N-1)(S)=NxEch(N-1)-(nx)^2Ech+NxEch$$

differentiating S with respect to nx and setting the differential equal to 0 to obtain the maximum value of S

$$0=Ech(N-1)-2NxEch+Ech$$

dividing by Ech and simplifying

$$(N-1)-2nx+=0$$

$$2nx=N \text{ or } nx=\frac{N}{2}$$

The maximum voltage produced is therefore between the brushes **16** and **18** where the number of condensers connected in series between the brushes is one-half of the total number. The magnitude of this voltage is calculated from the basic formula

$$S=\frac{n}{2}(a+1)$$

let

S equal the output voltage or Eo

n equal the number of condensers $\frac{N}{2}$

a equal the charging voltage Ech

l equal the voltage of the last condenser before brush 18, and

d equal the difference between voltage charges on the condensers

Since

$$l=a+(n-1)d$$

$$l=Ech+\left(\frac{N}{2}-1\right)\left(\frac{-2Ech}{N-1}\right)$$

$$l=Ech+(N-2)\left(\frac{-Ech}{N-1}\right)$$

Substituting in the S formula

$$S=Eo=\frac{N}{4}Ech\left(\frac{2(N-1)+(2-N)}{N-1}\right)$$

or

$$Eo=\frac{N}{4}Ech\left(\frac{N}{N-1}\right)$$

It has now been shown that under no load conditions the maximum voltage is between the brushes **16** and **18** and the value of this voltage may be calculated. The difference in voltage between each successive condenser except that between the one presented to the battery B and the one next behind it, opposite to the direction of the rotation of the drum, may be calculated. It has also been shown that the condenser just approaching the brush **18** has a positive charge and the condenser just leaving the brush **18** has a negative charge which is equal in magnitude to the following condenser but opposite in sign.

Under load conditions the maximum energy which may be drawn from the generator is that amount which will

reduce the energy charge on the condenser approaching the brush **18** to zero. The amount of this energy can be calculated from the well known condenser energy formula $Q=CV$ where

Q is the energy of the charge in coulombs
C is the capacity of the condenser in farads
V is the difference of potential in volts

It may thus be seen that for any given condenser charged to a predetermined voltage it will have a fixed number of ampere seconds (It) of energy. Therefore since the energy which may be taken is one-half the difference in charge between the condensers but it is taken from two condensers the rated energy output will be

$$Q=C\left(\frac{2Ech}{N-1}\right)$$

$$It=\frac{2CEch}{N-1}$$

As the drum rotates any single condenser will have its positive terminal connected to brush **18** $1/N$ of the time required per revolution of the drum **8** or the time of discharge of each condenser will be

$$\frac{1}{(N)(R)}$$

where

R is the number of revolutions each second
N is the number of condensers

Therefore substituting this relation for Q we get

$$(I)\frac{1}{(N)(R)}=\frac{2CEch}{N-1}$$

or

$$I=\frac{2(C)(Ech)(R)(N)}{N-1}$$

The rated output current will increase as a function of the speed at which the drum is driven, of the capacity of the condensers, of the capacitors as they are increased, and of the number of the capacitors. If desired a capacitor C2 may be connected across the conductors **20** and **22** to reduce the slight ripple in voltage which may occur due to the reduction in voltage of the condensers as they are reduced in charge.

It will now be apparent that this invention provides a means for generating a high direct current voltage which means is simply and economically manufactured and in which the charging voltage supply need be insulated only for the voltage which appears thereacross. The power required to drive the drum **8** is very low merely being that necessary to overcome the frictional and windage losses accompanying rotation of the drum **8** and is not dependent upon the power being removed from the high voltage generating drum.

In Fig. 2, there is shown a modified form of the invention in which the driving motor **1A** comprises a dynamotor supplied with energy through the conductors **102** and **104** and controlled by the switch SW*a*. The dynamotor has a direct current output which is carried by means of the conductors **106** and **108** to the brushes **110** and **112** which correspond respectively with the brushes **12** and **16**. Brush **114** which corresponds to brush **18** is connected by means of conductor **116** to one terminal **118** of a condenser C1. The other terminal **120** is connected to the anode of a triode valve V2. The cathode of the valve V2 is connected to ground as is the brush **112** whereby to complete the charging circuit for the capacitor C1. The valve V2 is continuously conductive and acts to continuously cause charging of the capacitor C1. The terminal **118** is also connected to the anode of a second valve V3 which is of the grid controlled triode type. The cathode of this valve V3 is connected to the distributing arm **122** of the distributor **124** which is driven by the

engine cam shaft. The valve V3 is normally held in a nonconductive condition to the bias voltage applied between the grid and cathode thereof which in this instance is shown as being derived from the dynamotor and including the resistor R102. The distributor contacts 126 of the distributor 124 are connected in shunt circuit between the grid and cathode of the valve V3 so that when they are in closed circuit position the grid is maintained at cathode potential and the valve V3 is permitted to conduct to supply ignition current and voltage to the distributor 124 for the various of the connected spark plugs. Conduction of the valve V3 permits current to not only flow from the generator 8 but also permits stored current to flow from the capacitor C1.

In the invention so far described, the question of efficiency of the transfer apparatus has not been discussed. I have found that the efficiency is widely variable and is dependent upon the manner in which the condensers are charged and discharged. By efficiency is meant the ratio of the energy output to the energy input of the apparatus. Since in general, the same relationships apply to charging and discharging and therefore for the sake of simplicity will be considered in the charging relationship. As will be apparent from the latter description, it may be desirable to use one form of the invention for charging and a second form of the invention for discharging.

Let us now examine the fundamental relationships involved in charging a capacitor. The general voltage formula for the conditions existing in a charging circuit are

$$Ech=iR+\frac{q}{C}$$

where E*ch* is as stated above the charging potential (volts) applied to the terminals of the condenser; *i* is the charging current (amps.) at any instant; R the internal resistance (ohms) of the condensers; *q* is the charge of the condenser (coulombs) at any instant; and C is the capacity of the condenser (farads). The power equation is

$$P=i^2R+\frac{t_2-t_0}{C}\int_{t_0}^{t_2}i^2dt$$

where P equals the power being delivered by the source.

The charging circuit is a series circuit and consequently the current in all portions thereof is the same. The solution of the voltage formula as found in standard texts in terms of *i* is

$$i=\frac{E}{R}e^{-\frac{t}{RC}}$$

When *i* is substituted in the power equation

$$P=R\frac{E^2}{R^2}e^{-\frac{2t}{RC}}+\frac{t_2-t_0}{C}\frac{E^2}{R^2}\int_{t_0}^{t_2}e^{-\frac{t}{RC}}$$

Since power multiplied by time equals energy supplied or W*h*

$$Wh=\frac{E^2}{R}\int_{t_0}^{t_2}e^{-\frac{2t}{RC}}dt+\frac{E^2(t_2-t_0)}{R^2C}\int_{t_0}^{t_2}e^{-\frac{2t}{RC}}dt$$

Integrating between

$$t_1=0 \text{ and } t_2=\infty$$

the following result is obtained

$$Wh=\frac{E^2C}{2}+\frac{tE^2}{R}$$

but

$$\frac{E^2}{R}=I^2R$$

Therefore

$$Wh=\frac{E^2C}{2}+(I^2R)t$$

It is known that the energy stored in a fully charged capacitor is

$$\frac{CE^2}{2}$$

and since

$$\text{Efficiency}=\frac{\text{energy stored in the capacitor}}{\text{energy to effect this storage}}$$

$$\text{Efficiency}=\frac{\frac{E^2C}{2}}{\frac{E^2C}{2}+(Ie^2R)t}=\frac{E^2C}{E^2C+2(Ie^2R)t} \quad (1)$$

Since

$$q=CE=iavt \text{ and } E=\frac{iavt}{C}$$

efficiency may also be expressed as

$$\text{Efficiency}=\frac{\frac{i^2at}{C}}{\frac{ia^2t}{C}+2(Ie^2R)}=\frac{ia^2t}{ia^2t+2CIe^2R} \quad (2)$$

In the instance of charging the capacitor with a constant voltage and using the formula for efficiency in terms of CE^2 to avoid solving for *ia* the efficiency may be calculated as follows:

By definition Ie=effective or root mean square current

$$Ie\sqrt{\int_0^T\frac{i^2dt}{T}} \text{ or } Ie^2=\frac{i}{T}\int_0^T i^2dt$$

substituting the formula for *i* and solving

$$i=\frac{E}{R}e^{-\frac{t}{RC}}$$

$$Ie^2=\frac{E^2C}{2RT}$$

where T is sufficiently long to fully charge the capacitor.

Substituting in the efficiency Formula 1

$$\text{Efficiency}=\frac{CE^2}{CE^2+\frac{2E^2C}{2RT}RT}=\frac{CE^2}{CE^2+CE^2}=50\%$$

A study of the formula for efficiency in terms of average and effective current indicates that the condenser charges in proportion to the average current while the charging losses are proportional to the effective (root mean square) current. To reduce the loss factor to a minimum value, the effective current value should be as low as possible. This can be attained only when the effective current is equal to the average current and which relationship by definition is known as current form factor. Ie can equal *ia* or a form factor of 1 can be had only by charging the condenser with a constant value of current and we shall therefore consider the efficiency under this charging condition.

In the general formula for efficiency developed above, a number of interrelated variables are present and it therefore becomes desirable to develop a formula for efficiency applicable to the specific case of constant current charging. Again we return to the basic formula

$$e=Ri+\frac{q}{C}$$

where

$$q=it$$

In this form *i* is a constant by definition. Therefore at full charge $EC=it_m$ where t_m equals the total or maximum time.

$$t_m=\frac{EC}{i}$$

and

$$i=\frac{EC}{t_m}$$

The losses are i^2Rt_m or

$$\frac{E^2C^2t_mR}{t^2_m}=\frac{E^2C^2R}{t_m}$$

if K=the number of natural time constants in t_m

$$t_m=KRC \text{ seconds}$$

and

$$\text{Losses}=\frac{E^2C}{K}=i^2Rt_m$$

Substituting this in the previously developed equation

$$\text{Efficiency}=\frac{CE^2}{CE^2+2(i^2R)t}$$

$$\text{Efficiency}=\frac{CE^2}{CE^2+2\frac{E^2C}{K}}$$

and by simplifying

$$\text{Efficiency}=\frac{1}{1+\frac{2}{K}}$$

As the value of K becomes larger the fraction

$$\frac{2}{K}$$

becomes smaller and if K were infinity the efficiency would reach 100%. The low values of K effect a more rapid change in the value of

$$\frac{2}{K}$$

and at relatively low values of K the quantity

$$\frac{2}{K}$$

becomes quite small. For example at values of K=40 for a condenser of a nominal 0.10 microfarad 600 volt rating the actual time required to charge the capacitor is in the vicinity of 0.000,0025 seconds which is indeed quite a short time and sufficiently short to be used in the drum **8**. The efficiency in such an instance would be approximately 95%.

Let us now determine what sort of a voltage-time relationship must be established to provide a constant value charging current. Referring to the basic formula

$$Ech=iR+\frac{q}{C}=iR+\frac{it}{C}$$

Our basic premise is that i remains a constant through the charging process. Therefore differentiating E*ch* with respect to time we have

$$\frac{dEch}{dt}=\frac{i}{C}$$

which will be recognized as a constant so that the rate of change of the voltage with respect to time is for constant current charging conditions. This voltage time relationship can be represented by a straight line and is diagrammatically shown in Fig. 3 where E*g* indicates the generated voltage and I*ch* indicates the constant charging current.

In Fig. 4 there is shown the voltage relationship of charging in which *a* indicates the resistance drop due to the internal resistance of the condenser, E*g* the generated voltage, and E*ch* the condenser charging voltage which, with a condenser of constant capacity, will also be a

measure of its charge in coulombs. The slope of the curves E*g* and E*ch* are

$$\frac{de}{dt}$$

The instantaneous voltage of $Ech=Bt-\phi$ where B is

$$\frac{d(Eg)}{dt}$$

and ϕ is the voltage drop due to the resistance of the condensers.

It will further be seen that the magnitude of charging voltage with constant current must be greater than the voltage to which the condenser is charged by a value equal to ϕ which is the product of the current and the internal resistance of the condenser.

In Fig. 5 there is diagrammatically shown an operating system in which the drum **8** acts to supply energy from a pulse generator **203** which has an output voltage wave equivalent to E*g* of Fig. 3 to a high voltage direct current transmission line **205—207** supplying a load **209**. The generator **203** is connected across input terminals **211** and **213** of a suitable full wave rectifying network diagrammatically shown at **215**. The direct current negative and positive output terminals **217** and **219** respectively are connected to the brushes **16** and **12** to provide a source of charging potential for the drum **8**. A suitable interconnection indicated by the dotted line **221** maintains the generator pulses in step with the rotating drum **8** so that a capacitor will be presented between the brushes **16** and **12** during a straight line voltage generation and will be removed from between the brushes **16** and **12** before there is a reversal of voltage direction. Preferably the condensers are presented adjacent one apex of the curve E*g* and removed adjacent the next apex.

Under conditions of full output of the drum **8**, the current may flow substantially as shown in Fig. 3 and the capacitors will be charged with a voltage E*ch* shown in Fig. 4 which differs from E*g* by the value ϕ. At lesser loads current will be supplied at the same rate but for a shorter time period and the approximately same ratio of E*g* and E*ch* will be had.

Fig. 5 also shows a network for charging the drum **8** with constant current and discharging the drum **8** into the load **209** by a sine wave of current. An inductance **223** is inserted in series between the brush **18** and the inductive line **205** so that the discharge of the drum or wheel **8** will be sinusoidal. A rectifier valve **225** is connected in series with the inductance **223** to permit the discharge current to flow only during the first half cycle of the normal damped sine wave of voltage which occurs when a capacitor is discharged through an inductance. Normally the line **205—207** will be quite long and have sufficient innate capacitance to absorb the discharge current from the condensers of the drum **8** as they are periodically placed between the brushes **16** and **18** so that a substantially uniform voltage and current are maintained at the load **209**. If the line **205—207** is not sufficiently capacitive, then a lumped capacitance in the form of a condenser **227** may be added in the manner shown.

Since the form factor is 1.111 for a sine wave and form factor *ff* equals *ia/ie*. The efficiency formula for a sinusoidal discharge may be readily calculated from the general efficiency formula

$$\text{Efficiency}=\frac{1a^2t}{1a^2t+2C1E^2R}$$

or

$$\text{Efficiency}=\frac{1}{1+\frac{2CRff^2}{t}}$$

but

$$t=KRC$$

therefore

$$\text{Efficiency}=\frac{1}{1+\frac{2.47}{K}}$$

By comparing this formula with that for a constant current discharge, it will be observed that the efficiency of a sinusoidal discharge of the drum 8 is nearly the same and since the factor

$$\frac{2.47}{K}$$

rapidly approaches an extremely small value at even relatively small values of K the use of a sine discharge in view of the economy of apparatus is commercially useful.

The calculation of the value of the inductance **223** which is to be used may be accomplished readily. The basic formula for the natural frequency of a circuit containing inductance, capacity and resistance is

$$f=\frac{1}{2\pi}\sqrt{\frac{1}{LC}-\frac{R^2}{4L^2}}$$

Such formula may be found in texts on the subject as for example in Alexander S. Landgsdorf's Principles of Direct Current Machinery, McGraw-Hill Book Co. (1940), page 224. Since the term $(R/2L)^2$ will be very small in comparison to $1/LC$ the formula may be simplified and expressed as

$$f=\frac{1}{2\pi}\sqrt{\frac{1}{LCx}}$$

Since

$$f=\frac{1}{T_0}$$

and the period of discharging is one half cycle

$$T=\text{time for } \tfrac{1}{2} \text{ cycle}=\frac{T_0}{2}=\frac{1}{2f}=\pi\sqrt{LCx}$$

where L=total inductance in circuit including the line **205—207**, Cx=total capacitance in circuit including line **205—207**, capacitor **227**, drum **8** etc. Since the drum **8** acts on discharge as two groups of series connected capacitors of value C connected in parallel to each other the capacity Cy thereof is

$$Cy=\frac{4C}{N}$$

The time T at which the discharge must occur as stated above is inversely proportional to the product of the R. P. S. (revolutions per second) of the drum 8 multiplied by the number of capacitors or

$$T=\frac{1}{WN}$$

which substituted in the above formula and solving for L results in

$$L=\frac{1}{W^2N^2\pi^2C}$$

At time T the current flowing through **225** will have become zero and therefore there is no arcing of the brushes **16** and **18**. Also due to the fact that the drum **8** is discharging into an already stressed capacitance line **205—207** the amount of current which will discharge from the drum will be a function of this difference in voltage between the drum and the line **205—207**. The difference in voltage is a function of the magnitude of load **209** and which at full load is that voltage which permits any one of the drum condensers to discharge an amount.

$$Q=\frac{CEch}{N-1}$$

In Fig. 6 there is diagrammatically shown the charging current and voltage which is obtained when the pulse generator is arranged to have a single phase sinusoidal alternating voltage output. When so used the form factor of the charging current is 1.111 and the efficiency of charging will be as indicated above

$$\text{Eff.}=\frac{1}{1+\frac{2.47}{K}}$$

which is not greatly different from the constant current efficiency and in many instances may be desirable since the pulse generator **203** in such a case can be a usual single phase alternator.

In Fig. 7 there is diagrammatically shown a circuit for providing a sinusoidal charging current from a constant voltage source **303** by means of an inductance **304** and a unidirectional current flow device diagrammatically shown as a rectifier **305**. In this form the value of the inductance **304** should be such that the time of the half wave length of the charging current is equal to T, the time any one condenser is connected between the brushes **12** and **16**. Neglecting resistance R which is small for the purposes of frequency determination this will be equal to

$$T=\pi\sqrt{LC}$$

where L and C are the inductance and capacitance of the charging circuit. If a small number of condensers are in the condenser ring of drum **8** it may be necessary to consider the effect of the $N-1$ condensers in parallel with the one being charged. However where $N-1$ is closely equal to N and greatly in excess of 1 it may be neglected. The efficiency will be of course

$$\text{Eff.}=\frac{1}{1+\frac{2.47}{K}}$$

The charge imparted by such a charging arrangement will be found to be

$$q=CE\left[1-C-\frac{Rt}{2L}\left(\cos\sqrt{\frac{1}{LC}}(t)+\frac{R}{\sqrt{44C}}\sin\sqrt{\frac{1}{LC}}(t)\right)\right]$$

where the R term has been dropped since it is relatively unimportant in the determination of time.

Since $T=\frac{1}{2}$ full wave of the charging frequency and

$$T=\pi\sqrt{LC}$$

$$q(\max)=CE\left[1+e^{-\left(\frac{R\pi^2}{2}\sqrt{\frac{C}{L}}\right)}\right]$$

Since R will normally be quite small the value of q can considerably exceed CE and the value of E*ch* will therefore considerably exeed E*g* or the value of the output voltage of the source **303**.

In Figs. 8, 9, 10 and 11 there is diagrammatically shown a charging system for the drum **8** which utilizes a polyphase alternating voltage source of any number of phases and which is shown as a conventional three phase alternating voltage and for simplicity will be so described but which could be of a different number of phases. According to this form the charging voltage is obtained only from limited portions of the voltage wave which most nearly approach straight lines and consequently provide a charging current which has a form factor closely approaching unity.

In Fig. 9 the curve E*g***1** represents the voltage of the first alternator phase, E*g***2** the voltage of the second alternator phase, and E*g*3 the voltage of the third alternator phase as presented to the valves **300—305**. At a point **T0**, the rectifier valve **300** of the network associated with this phase is rendered conductive to supply a charging voltage E*ch***1** for charging the wheel **8**. At the point **T1** this valve is rendered nonconductive in a manner to

be described hereinafter and the valve **305** of the rectifier associated with phase 3 is rendered effective to supply a charging voltage E*ch*3 to charge the drum **8**. Similarly at times T2, T3, T4, T5, etc. the various rectifiers **300**—**305** will be rendered conductive to supply the voltage portions E*ch*3, E*ch*2, E*ch*1, E*ch*3, E*ch*2 in that sequence. While these voltage portions E*ch* are not exactly straight line portions they closely approximate the same and considerably reduce the form factor of charging current which is obtained from the polyphase system of Fig. 8 over that of the sine wave charging system of Figs. 6 and 7.

It is desirable that the frequency of the polyphase alternator and average slope of the voltage portions E*ch*1, E*ch*2, and E*ch*3 be so related to the frequency at which the condensers of the wheel **8** are presented thereto that at the full load capacity of the wheel **8**, a condenser will be charged throughout substantially the full length of one of the E*ch* voltage portions. For example, a capacitor should be placed between the brushes **12** and **16** at a time just after T**0** and should be removed from the brushes **12** and **16** at a time just short of T**1**. At substantially the same time as the capacitor is placed between the brushes **12** and **16**, the corresponding rectifier valves for supplying voltage from the source in a proper polarity to the brushes **12** and **16** should be rendered conductive and these valves should be rendered nonconductive at substantially the same time as the capacitor is removed from between the brushes **12** and **16**. Theoretically this can be done at the time instants T**1**, T2, T3, etc. However if at any time more than one rectifier valve is rendered conductive strong circulating currents may be set up causing damage to the apparatus. Therefore, as a matter of safety, a practical arrangement is to render these valves conductive at a short time interval after T**0**, T**1**, T2, T3, etc. and to render them nonconductive at a short interval before the times T**0**, **1**, **2**, **3**, etc. The corresponding charging currents are shown as I*ch* in Fig. 9.

As stated above for purposes of illustration, a standard 60 cycle three-phase alternating voltage supply is shown. However, if a supply having a greater number of phases is used, the length of the sine wave of voltage which is used for charging will be somewhat reduced and will still further approximate a straight line. In such event it will be obvious that the frequency of the alternating current supply for charging each capacitor with one voltage wave portion would be somewhat reduced over the frequency of the three-phase supply since the time interval during which the capacitor is connected should remain constant.

This form of the invention in which the rectifier valves are rendered nonconductive prior to removing of the capacitor from the brushes **12** and **16** eliminates all arcing at the brushes, the rectifier networks acting to break any current flow.

In the foregoing discussion the following formulas were developed

$$Eo=\frac{N}{4}Ech\left(\frac{N}{N-1}\right) \text{ and } i=\frac{CEchWN}{N-1}$$

From these formulae the speed (W_2) of the drum or wheel **8**, the number of condensers (N), the capacity (C) thereof, and the voltage (E*ch*) to which the capacitors must be charged can be ascertained in accordance with the desired operating characteristics of the apparatus being designed.

The time of charging T will be

$$\frac{1}{WN}$$

Since, as will be apparent from an examination of Fig. 9, two charging voltage portions are used for each phase of the applied voltage for each complete cycle, the frequency of the generator will be equal to

$W_1=\frac{1}{2}$ (the number of generator phases multiplied by the number of condensers and divided by the speed of the drum)

$$W_1=\frac{1}{2(ph)\cdot\frac{N}{W_2}}$$

where $W_2=2\pi f$ or the angularly speed of the wheel in radians per second, N the number of capacitors on the wheel. $2\pi fN$ therefore equals the frequency of charging the condensers and if W_1 equals the electrical frequency of the generator

$$W_1=\frac{W_2N}{2(ph)}$$

The time T is the time interval between the times T**0** and T**1** or T**1** and T2, etc. and is such that the voltage wave passes through the neutral axis at a time which is substantially half of the time interval between the time T**0** and T**1**. At this point the voltage angle is either 0° or 180°. The sinusoidal formula for voltage is $e=E_m \sin wt$. Differentiating the instantaneous voltage with respect to time, we get

$$\frac{de}{dt}=E_m \cos wt$$

at the times 0° and 180° or π°. The cosine is equal to 1 and −1 respectively and therefore the rate of change of voltage midway of the time interval T**0**–T**1**; T**1**–T2 etc. is equal to E_m and since at constant current charging

$$\frac{de}{dt}=\frac{Ia}{C} \qquad E_m=\frac{Ia}{C}$$

C equals the capacity in farads and is a known design factor. I*a* may be computed from the formula

$$Ia=\frac{2\int_0^{\frac{\pi}{6}} idt}{\frac{\pi}{3}}$$

where the voltage charging portions are taken at six equal intervals of one cycle of the three-phase voltage. It will be noted that the limits of the integral are set up between 0 and

$$\frac{\pi}{6}$$

and the resultant sum multiplied by 2 to obtain the total current. Therefore

$$Ia=\frac{6}{\pi}\int_0^{\frac{\pi}{6}} \cos wtdt$$

Since

$$\frac{de}{dt} \text{ is equal to } \frac{Ia}{C}$$

which are known values, the value of

$$\frac{de}{dt}$$

is known. Since this value is equal to E_m the proper rate of change of voltage is a function of the maximum instantaneous voltage generated by the alternator and an alternator of the proper size and frequency may therefore readily be calculated.

It is not necessary, however, to relate the frequency of the alternator to the charging time of the individual capacitors of the drum **8** so that they are completely charged during one of the voltage portions E*ch* of Fig. 9 but they may instead be arranged to be charged over any desired number of these voltage intervals. In such event the condenser being charged will be charged in increments of progressively smaller values until the end of the charging time that is the time during which

this particular condenser is placed between the brushes 12 and 16.

It will be apparent that, if desired, only intermediate portions of the single phase voltage curve E*ch* of Fig. 6 could be used for charging the capacitors in which event there would be time periods separating the charging time periods necessitated by the fact that the voltage is passing through a changing characteristic which is not desired for charging purposes. Since, however, the efficiency of charging between constant current and sinusoidal current is relatively small it is believed that in most instances of single phase charging it will be desirable to charge the condensers with sinusoidal current rather than picking off intermediate voltage portions. This is also true not only from the efficiency standpoint but from the standpoint of simplicity of the charging current control.

In Fig. 8 there is diagrammatically shown a control circuit for accomplishing the charging of the drum 8 in accordance with the diagrammatic voltage current representations of Figs. 9 and 10. The polyphase alternating source 306 is provided with the output phases connected to the conductors 308, 309 and 310, the conductors 308 and 309 being connected to the primary winding 312 of the transformer 314 having a center tapped secondary winding 316. The end terminals of the winding 316 are connected to the anodes of the rectifier valves 300, 301, the cathodes of which are connected to the positive bus 318 connected to the brush 12 of the drum 8. A negative bus 320 connects the center tap connection of the winding 316 with the negative brush 16. Similarily the conductors 309 and 310 are connected across the primary winding 322 of transformer 324 having the secondary winding 326, the end terminals of which are connected to the anodes of the valves 302, 303 and the center tap of which is connected to the bus 320. The conductors 308 and 310 are connected to the primary winding 328 of the transformer 330 having a center tapped secondary winding 332, the end terminals of which are connected to the anodes of the valves 304, 305 and the center tap of which is connected to the bus 320. The cathodes of all of the valves 302—305 are connected to the common positive bus 318 together with the cathodes of the valves 300, 301.

The conductivity of the valves 300, 301 is controlled by means of the grid to cathode bias placed thereon and which is derived from a polyphase phase shifter 334. The phase shifter 334 has an iron core 336 having a polyphase winding 338 connected by means of the conductors 340, 342 and 344 to the lines 308, 309 and 310. The phase shifter 334 has six output windings 346–351 each having one end operatively connected individually with the grids of the valves 300, 305 through a grid pulse oscillator 352 such as that shown and described in Principles of Radar, second edition, McGraw-Hill Book Company, pages 7–67. The other ends of each of these output windings 346–351 are connected through an adjustable source of direct current bias voltage 353 and oscillator 352 to the bus 318 and therethrough to the cathodes of the valves 300 to 305. The sets of windings 346—347, 348—349, and 351—350 are polarized with respect to the voltages impressed between the anodes and cathodes of the valves 300–305 such that there is a high positive grid to cathode bias voltage applied to the one of the valves 300–305 during the time interval that the valve is required to conduct as illustrated in Fig. 9.

The voltages induced in the sets of windings are phase shifted by means of the phase shifter 334 and the magnitude of the potential furnished by the bias 353 is such that the valves will conduct only through the desired intervals E*ch*1, E*ch*2, and E*ch*3. The polarity of the direct current is such that the net bias voltage placed on the oscillator is such that the grid to cathode bias of the valves does not pass the conductive threshold until at times T0, T1, T2, T3 etc. The shape of the voltage curves E*b*1, E*b*2, E*b*3 will of course be sinusoidal and shiftable with respect to the voltage waves E*g*1, E*g*2, and E*g*3 by means of the phase shifter 334. The time intervals between T0 and T1, T1 and T2, and T2 and T3 etc. will be adjusted by means of the magnitude of the direct current bias 353 and which should not be made longer than the time interval between the voltage portions E*ch* and as described above is preferably somewhat shorter to insure against any two of the valves 300 to 305 conducting at any one instant. The rotation of the drum 8 and of the alternator 306 are suitably tied in step by means of the diagrammatic cross connection shown by the dash-dash line 354. Any suitable interconnection either mechanical or electrical to maintain the alternator 306 and drum 8 in step may be utilized and consequently there is shown in this application only the diagrammatic interconnection.

What is claimed and is desired to be secured by United States Letters Patent is as follows:

1. In an apparatus of the character described, a plurality of condensers, means connecting said condensers in series and in a closed loop, an electrical conductor connected to the common point between each pair of said series connected condensers, a pair of conductors adapted to be supplied with electrical energy at a desired potential for charging said condensers, means for sequentially connecting said supplied conductors sequentially across pairs of said first-named conductors connected to opposite sides of said condensers to provide for sequentially charging said condensers, a pair of output conductors, and means for connecting said output conductors sequentially across second pairs of said first-named conductors connected to opposite ends of a series of said condensers.

2. In an apparatus of the character described, a plurality of electrical energy storage devices, conductors connecting said devices in series to form a closed loop, a rotatable member, a plurality of contact segments carried by said member, conductors connecting individual ones of said segments to individual ones of said first-named conductors, a plurality of contact making elements adapted to make contact with individual ones of said segments, supply conductors adapted to be connected to a source of electrical energy and connected to a pair of said elements, and output conductors adapted to be connected to an electrical load and connected to a pair of said elements.

3. The combination of claim 2 in which said first named pair of elements are spaced to make contact with adjacent said segments.

4. The combination of claim 3 in which said last-named pair of elements includes one of said first-named pair of elements.

5. The combination of claim 3 in which the said segments engaged by said last-named pair of elements are connected to diametrically opposite portions of said loop.

6. The combination of claim 2 in which said last-named pair of elements includes one of said first-named pair of elements.

7. The combination of claim 2 in which means is provided to rotate said rotatable member.

8. In an apparatus of the character described, a plurality of condensers, conductors connecting said condensers in series in a closed loop, a rotatable commutator having spaced contact bars, conductors connecting said bars individually with said first-named conductors in sequence whereby said condensers are connected between adjacent ones of said bars, a first pair of contact elements slidably associated with said bars and spaced to make contact with adjacent ones of said bars, and a second pair of contact elements slidably associated with said bars and spaced so that at least one said bar is between the ones of said bars engaged by said second pair of elements.

9. The combination of claim 8 in which the number

of said bars is an even number and said second pair of elements engage diametrically opposite ones of said bars.

10. The combination of claim 9 in which said second pair of elements includes one of said first pair of elements.

11. In an ignition circuit for an internal combustion engine, a source of direct current energy, means for increasing the potential of said energy and having output terminals, a circuit connected between said terminals for supplying said increased potential to a load, an electric valve controlling the flow of current in said circuit to such load and having a control electrode and a main electrode for controlling flow of current through said valve, and means for controlling the application of a control potential between said electrodes for controlling the current flow to said load.

12. The combination of claim 11 in which a series connected capacitor and electric valve are connected across said terminals.

13. In an apparatus of the character described, a plurality of condensers, conductors connecting said condensers in series in a closed loop, a rotatable commutator having spaced contact bars, conductors connecting said bars individually with said first-named conductors in sequence whereby said condensers are connected between adjacent ones of said bars, a first pair of contact elements slidably associated with said bars and spaced to make contact with adjacent ones of said bars, a second pair of contact elements slidably associated with said bars and spaced so that at least one said bar is between the ones of said bars engaged by said second pair of elements, means for rotating said commutator, a load circuit connected across said second elements and including an electric valve controlling the flow of current therethrough, said valve having a control electrode and a main electrode, means including a current limiting element connecting said electrodes across said first pair of elements, and a switch selectively connecting said electrodes together.

14. The method of changing the energy charge contained in a condenser which comprises the steps of connecting an apparatus in energy exchange relation with such condenser, controlling the time-voltage characteristic of the apparatus in energy exchange relation with such condenser to provide a changing voltage for regulating the current flow therebetween, and proportioning such changing voltage to produce a current having a form factor approximating unity.

15. The method of charging a condenser which comprises connecting a condenser to a source of pulsating current at substantially the time at which the rate of change in voltage of said source is zero, and disconnecting said condenser from said source at a subsequent time at which the rate of change in voltage of said source is zero.

16. The method of charging a capacitor which is initially charged to one polarity which comprises the steps of connecting said capacitor to a source of alternating voltage of a polarity the same as that of the charge on the capacitor and substantially at a point in the voltage wave of the source wherein the rate of change of voltage with respect to time is zero and of disconnecting said capacitor from the source at a second point on such voltage wave when the polarity of the source voltage is opposite to said first polarity and the rate of change of voltage with respect to time is substantially zero.

17. The method of charging a condenser from a source of alternating electrical potential having a substantially sinusoidal voltage wave with respect to time, which comprises the steps of connecting the condenser to such source in such manner that the potential is applied to the condenser solely during intermediate portions of said wave in which the rate of change in voltage is substantially maximum and the voltage is changing in the same direction.

18. The method of charging a plurality of condensers in series from a polyphase source of substantially sinusoidal voltage which comprises the steps of sequentially connecting such condensers to such source, and controlling the flow of current between the connected condensers and the source so that voltage is supplied to the condenser during the portions of such wave which are passing through their greatest rate of change in voltage with respect to time.

19. The method of claim 18 in which the greatest rate of change in voltage with respect to time occurs at substantially midway of said voltage portions.

20. The method of claim 19 in which the magnitude and frequency of the voltage wave are such that said portions are of sufficient magnitude and duration to completely charge such condenser during one such portion and such condensers are sequentially connected to such source at a rate equal to twice the product of the frequency and number of phases of such source.

21. The method of supplying a high unidirectional voltage to a load from a lower voltage source by means of a plurality of condensers connected in series to form a capacitative ring which comprises the steps of progressively connecting individual ones of said condensers across said source whereby the voltage on said connected condenser may be established at a predetermined value, and controlling the flow of current from such source to such condenser to provide a desired current form factor.

22. The method of supplying a high unidirectional voltge to a load from a lower voltage source by means of a plurality of condensers connected in series to form a capacitative ring which comprises the steps of progressively connecting individual ones of said condensers across said source whereby the voltage on said connected condenser may be established at a predetermined value, of controlling the flow of current from such source to such condenser to provide a desired current form factor, and of discharging said ring between diametrical points thereon into said load.

23. The method of supplying a high unidirectional voltage to a load from a lower voltage source by means of a plurality of condensers connected in series to form a capacitative ring which comprises the steps of progressively connecting individual ones of said condensers across said source whereby the voltage on said connected condenser may be established at a predetermined value, of controlling the flow of current from such source to such condenser to provide a desired current form factor, of discharging said ring between diametrical points thereon into said load, and of controlling the discharge of said ring into said load to provide a desired current form factor.

24. The method of supplying a high unidirectional voltage to a load from a lower voltage source by means of a plurality of condensers connected in series to form a capacitative ring which comprises the steps of progressively connecting individual ones of said condensers across said source whereby the voltage on said connected condenser may be established at a predetermined value, of controlling the flow of current from such source to such condenser to provide a desired current form factor, of discharging said ring between diametrical points thereon into said load, of controlling the discharge of said ring into said load to provide a desired current form factor, and of controlling the discharging time of said condenser ring so that the points of discharge are moved with respect to said ring not later than the instant that the voltage across said ring is lowered by an amount equal to one half the difference in charge between the two condensers furthest away from the condenser connected to the source.

25. The method of supplying high unidirectional voltage to a load from an alternating lower voltage source by means of an endless chain of series connected energy storage devices which comprises the steps connecting individual ones of such devices in predetermined timed sequence to said source, passing current from said source to such connected device solely in one direction, and

discharging said chain from symmetric opposite points into such load.

26. In an apparatus for transferring electrical energy from one potential to a second potential, a plurality of energy storage devices, means connecting all of said devices in an endless series, means including a nonsymmetrical current flow device connected to receive energy at said one potential for individually charging said devices in predetermined sequence, and means sequentially connected across groups of said series connected devices for supplying energy therefrom at said second potential.

27. In an apparatus of the character described, a plurality of energy storage devices, means connecting said devices into an endless series, a source of substantially sinusoidal alternating potential, unidirectional current flow means, means for connecting said source through said unidirectional flow means to individual ones of said devices in predetermined sequence, a load circuit including capacitative reactance, a second unidirectional current flow means, means including said second unidirectional flow means connecting said load circuit across a predetermined number of said series connected devices and movable relative to said devices whereby the predetermined number of said devices connected to said load circuit is maintained constant but the particular ones of said devices are changed in predetermined sequence with respect to said load circuit.

28. The combination of claim 27 in which said last named means includes an inductive reactance arranged in series connection with said second unidirectional flow device.

29. In a device of the character described, a plurality of electrical condensers, means connecting said condensers to form an endless chain of series connected condensers, a plurality of conductors adapted to be supplied from a polyphase source of alternating potential, a pair of terminals adapted to be connected across individual ones of said condensers in predetermined sequence, means including a unidirectional current flow device for connecting each of said conductors to said terminals, control means for controlling the conductivity of said devices, and timing means for controlling said control means to render individual ones of said devices conductive during the intervals in which the rate of change of the voltage of the conductor with which it is associated is maximum.

30. The combination of claim 29 in which said timing means acts to render solely one of said devices conductive at any one time.

31. In an apparatus of the character described, an energy storage device having a pair of terminals, a plurality of conductors adapted to be energized from a source of polyphase alternating current, current flow controlling means connecting each of said conductors to said terminals, means regulating the flow of current through said flow means, and timing means for controlling said regulating means whereby said flow means will permit current flow to said device at any one instant solely from one of said conductors and from the one of said phases having the greatest rate of change of voltage with respect to time.

32. In an apparatus of the character described, a pair of output terminals, a plurality of conductors adapted to be energized from a source of polyphase alternating voltage, a rectifying network connecting each of said conductors to said terminals, a phase shifting network adapted to be energized with a voltage having a frequency equal to that of such source and having a plurality of output voltage networks equal in number to the phases of said source and bearing the same phase relationships to each other as the phase relationships of said source, and means connecting said output networks to said rectifying networks whereby solely one of said rectifying networks is rendered conductive at a time and whereby the conductive one of said networks is the one of said networks associated with the one of said supply phases having the most constant rate of change of voltage with respect to time.

33. In an apparatus of the character described, a source of polyphase alternating current energy, a transformer for each of said phases of said source, each said transformer comprising a primary winding individually connected to its respective said source phase and secondary winding having an intermediate tap, a plurality of electric valves of the type in which current is permitted to flow or such current flow terminated between a pair of main electrodes by a control element in accordance with a bias potential placed between said element and a first of said main electrodes, means connecting corresponding ones of said main electrodes individually with end terminals of said secondary windings, a pair of output terminals, conducting means connecting the corresponding other ones of said main electrodes together and to one of said output terminals, conducting means connecting said intermediate taps together and to the other of said output terminals, a phase displacing network energized with an alternating potential synchronous with said source, and circuit means energized by said displacing network and having output connections connected between said elements and said first main electrodes of said valves for controlling the periods of conductivity of said valves.

34. The combination of claim 33 in which said phase displacing network is provided with winding portions individual to each of said valves and in which a constant voltage bias potential is provided in opposition to the output voltage of said displacing network of such a value that solely one of said valves are rendered conductive at one time.

35. The combination of claim 34 in which the phase of the output voltages of said winding portions is displaced 90° from the voltage across the said main electrodes with which said portions are associated.

36. In an apparatus of the character described adapted to be connected between a power supplying circuit and a power consuming circuit for transferring energy between such circuits, a plurality of electrical energy storage devices, each said device being connected in endless series with another said device to provide a closed endless ring of said devices which is endless independently of said circuits, means adapted to be connected to one of said circuits and arranged to sequentially transfer electrical energy from said one circuit to said devices at a plurality of locations on said ring, and means adapted to be connected to the other of said circuits and arranged to sequentially transfer electrical energy from said devices to said other circuit at a plurality of locations on said ring.

37. In an apparatus of the character described adapted to be connected between a power supplying circuit and a power consuming circuit for transferring energy between such circuits, a plurality of electrical energy storage devices, each said device being connected in endless series with another said device to provide a closed endless ring of said devices which is endless independently of said circuits, means adapted to be connected to one of said circuits and arranged to individually transfer electrical energy in a predetermined sequence between a plurality of groups of said devices and said one circuit, each said group comprising at least one said device, and means adapted to be connected to the other of said circuits and arranged to transfer electrical energy in a predetermined sequence between a plurality of groups of said devices and said other circuit, each said last named group comprising at least two said devices.

38. In an apparatus of the character described adapted to be connected between a power supplying circuit and a power consuming circuit for transferring energy between such circuits, a plurality of electrical energy storage devices, each said device being connected in series with another said device to provide a closed endless ring of said devices which is endless independently of said circuits,

means adapted to be connected to one of said circuits and arranged to transfer electrical energy in a predetermined sequence between said devices and said one circuit, said means acting to transfer energy between said one circuit and a plurality of groups of said devices, each said group comprising at least one said device, and means adapted to be connected to the other of said circuits and arranged to transfer electrical energy between said devices and said other circuit, said last named means acting to transfer energy between said other circuit and a plurality of groups of said devices, each said last named group comprising at least two said devices.

39. In an apparatus of the character described, a plurality of storage devices connected in series to form an endless chain of series connected said devices, conducting elements connected to said chain at spaced points therealong, said points being so spaced as to provide for an

equal number of said devices between each said element, means for successively connecting a source of electrical energy between each two of said elements which have a predetermined number of said devices connected therebetween whereby energy may be supplied to said chain, means for successively connecting an electrical load between each two of said elements which have a selected number of said devices connected therebetween whereby energy is removed from said chain.

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