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CIRCUIT ARRANGEMENT FOR ENERGIZING DISCHARGE DEVICES

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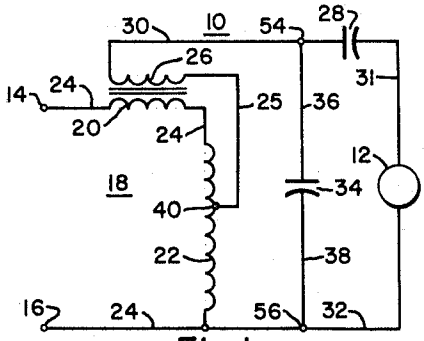


Fig. 1.

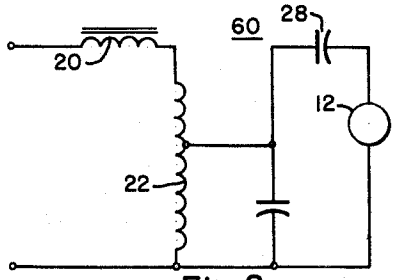


Fig. 2.

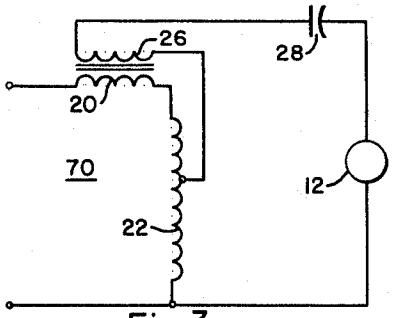


Fig. 3.

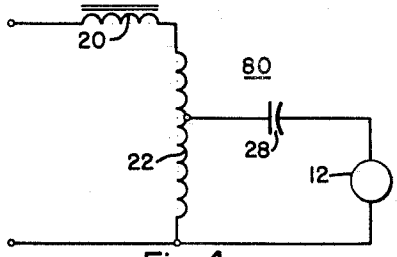


Fig. 4.

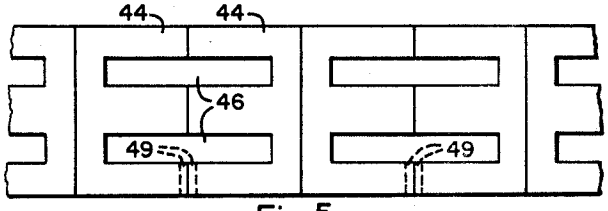


Fig. 5.

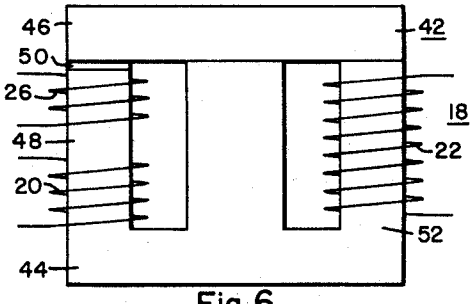


Fig. 6.

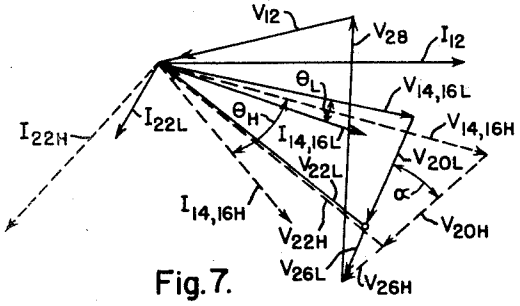


Fig. 7.

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CIRCUIT ARRANGEMENT FOR ENERGIZING DISCHARGE DEVICES

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The present invention relates to circuit arrangements for energizing discharge devices and more particularly to such arrangements of the constant power delivery type.

Where it is desired to energize a load or discharge device, for example one of the mercury vapor type adapted for producing light, it is usually necessary to supply to the device a starting voltage higher than the subsequent operating voltage of the device so as initially to ionize the device. The employed circuit should function to provide this necessary voltage condition. Once the starting condition has been fulfilled, the employed circuit ordinarily is required, as already indicated, to sustain across the device an operating voltage somewhat lower than that of the required starting voltage, and to provide impedance to limit the load current which might otherwise acquire an excessive value as a result of the negative resistance characteristic of the energized discharge device.

The starting and operating functions associated with energizing a discharge device generally are to be provided with the character just described, although the specific requirements for fulfilling these and perhaps other functions, will vary in accordance with prescribed or desired starting and operating conditions. In any case, it is desirable, as an economy in power delivery, that nearly unity power factor be provided for the circuit which energizes the employed device. It is also desirable where nonlinear elements may be employed in the energizing circuit that the crest factor, that is the ratio of peak to R.M.S. value, of the current delivered to the device, be restricted or reduced to a value which provides satisfactory operating efficiency and which will not lead, for example, to premature degradation or burn out of the device. In connection with the matter just considered, any tolerable current crest factor will usually be specified by the device manufacturer and it is then only necessary that current crest factor be restricted to the specified amount.

The circuit operation can be further refined to the extent that the rate of energy delivery (or the wattage as commonly denoted in the pertaining art) is held substantially constant under conditions of relatively widely varying circuit supply voltages. In the case of lighting discharge devices, substantially constant illumination is thereby assured and, in the case of some or all lighting as well as other devices, operating life may be relatively maximized since detrimental conditions of over-wattage or under-wattage are generally avoided. When providing a constant rate of energy delivery in a circuit arrangement for a discharge device, it should be provided in a technically proficient as well as an economic manner.

Thus, it is an object of the invention to provide a novel and efficient circuit arrangement for delivering substantially constant power to discharge devices.

Another object of the invention is the provision of a novel and efficient ballasting circuit for energizing a device having a negative resistance characteristic.

Another object of the invention is to provide a novel circuit arrangement as described in the preceding object, with the circuit arrangement including a linear reactor and a saturable reactor for generally delivering substantially constant power to discharge devices.

A further object of the invention is to provide a novel circuit arrangement as described in the second object, with

a compensatory winding also being provided in inductive relation with the linear reactor to develop a voltage which in the main will offset voltage variations of the saturable reactor occurring as a result of line voltage variations.

Another object of the invention is to provide a novel circuit arrangement as described in the second object, with the arrangement including an economically producible core upon which the winding for the linear reactor and the winding for the saturable reactor, and, if employed, the compensatory winding, can be disposed.

An additional object of the invention is to provide a novel circuit arrangement as described in the fourth object, with the core being in laminated form and with each lamina being formed from an E member and an I member which are stampable from strip magnetic material such as magnetic sheet steel without any resulting waste material except for a small amount which is removable from one of the legs of each E member to provide a high reluctance gap in the magnetic path associated with the linear reactor.

These and other objects of the invention will become more apparent upon consideration of the following detailed description of the invention along with the attached drawing, in which:

FIGURE 1 is a schematic view of a circuit arranged in accordance with the principles of the invention for energizing a discharge device;

FIGS. 2, 3 and 4 are schematic views of circuits arranged in respectively alternative manners in accordance with the principles of the invention;

FIG. 5 is a top plan view of strip magnetic material, with portions being broken away, showing the manner in which laminae of a laminated core can be formed for use with the circuits of FIGS. 1 through 4;

FIG. 6 is a top plan view of a core formed from laminae in accordance with the principles of the invention, with windings corresponding to certain elements of the circuit of FIG. 1 or FIG. 3 being shown here in a preferred arrangement; and,

FIG. 7 is a diagram of the vectorial relations of current and voltage for the circuit of FIG. 1.

With reference now to FIGS. 1 and 6, a circuit arrangement **10** is provided for energizing a discharge device or other load or, exemplarily, a mercury lamp **12**. The voltage of a suitable source (not shown) is applied in this instance to the circuit **10** in alternating, sinusoidal form across line terminals **14** and **16**.

Inductive means **18** are included in the circuit **10** for delivering starting and operating voltages to the device **12**. In this instance, the inductive means **18** comprise in aiding relation a winding **20** of a linearly inductive reactor and a winding **22** of a saturably inductive reactor with each functioning in a manner described more fully subsequently. As can be determined by inspection of FIG. 1, the windings **20** and **22** in conjunction with conductors or wires **24** comprise one circuit loop relative to the source previously denoted.

A circuit branch for delivering operating current to the device **12** includes a conductor **25**, an inductive or compensatory winding **26** forming a part of the inductive means **18** ballasting means or a ballasting capacitor **28**, and conductors **30**, **31** and **32**. For starting purposes, a capacitor **34** can be connected between conductors **30** and **32** with the use of conductors **36** and **38**. In certain applications, as will be described subsequently, the capacitor **34** can be omitted with starting being obtained by other means. If desired, the conductor **25** can be connected to the winding **22** in a tapped position as indicated by the reference character **40**. In this manner, a given discharge device or the device **12** can be operated from different nominal line voltages.

In this case, a single core **42** (FIG. 6) is also provided as a part of the inductive means **18**. The core **42** can be

in laminated form to reduce losses and can be provided with whatever dimensional parameters are desired for optimizing operating efficiency in any given application. To form the various laminae of the core 42, a continuous strip of magnetic material, for example magnetic silicon steel, can be stamped or cut to provide E and I members as indicated by the respective reference characters 44 and 46 in FIG. 5. By inspection, it is clear that no waste material results from this operation. With the removal of a small amount of material 49 (FIG. 5) from one leg 48 of each E member 44, an air gap 50 (FIG. 6) can be provided so as to characterize the previously mentioned reactor which includes the winding 20 with linearity. In this instance, the gap 50 extends completely across the leg 48, but in other applications varying geometries might be provided for the gap 50. If desired, filler material can be inserted in the gap 50 for filling purposes only or, if desired, for purposes of modifying the magnetic reluctance of the gap 50.

Once a plurality of E members 44 have been provided in laminated form, the windings 20 and 26 can be placed on the E leg 48 and the winding 22 can be wound on another E leg 52. Then a plurality of I members 46, also being provided in laminated form, can be positioned against the laminated E members 44, as viewed in FIG. 6. Securance of the laminated E and I members 44 and 46 can then be made, for example through the use of a suitably formed frame member (not shown). The desired structure of the core 42 enables the circuit arrangement 10 to be formed with marked economy and still to be functional in the advantageous manner now to be described.

Since the operating voltage across a discharge device is generally a fixed value, not dependent within practical limits on the current flowing through it, one means for providing a delivery of substantially constant power to the device is to maintain a substantially constant current through the device. This can be accomplished by providing a substantially constant voltage across a fixed impedance (such as a ballast capacitor) in series with the device. In this example of the invention, the ballast capacitor 28 and the device 12 are in series relation, and the voltage across the saturable reactor winding 22, in conjunction with the voltage across the compensatory winding 26 leads to this substantially constant voltage effect.

Thus, by suitably providing the dimensional and other parameters of the core 42 and the electrical parameters of the circuit 10, the core leg 52 can be characterized with a saturated magnetic flux condition during normal operation of the circuit 10. It is to be recalled that, as a general case, the magnetic flux density in a magnetic member rises generally linearly as a function of, and over a considerable range of, applied magnetomotive force. When the flux density acquires a saturating value, additional magnetomotive force leads to little or no further increase in the magnetic flux density. Thus, a curve of magnetic flux density as a function of applied magnetomotive force ordinarily is characterized with a first portion generally having a substantially positive slope and with a second portion generally having only a nominal or substantially zero slope. The segment of the curve between the two portions just described defines the saturating value of flux density and is generally nonlinear.

The degree of flatness or the value of slope of the second portion of the curve determines in large measure and for obvious reasons the quality of voltage regulating effect of the associated saturable reactor. It is clear that since the core leg 52 is a saturable one, variations in line voltage across the terminals 14 and 16 during circuit operation will result in relatively nominal voltage variations across the saturable reactor winding 22 generally in accordance with the slope of the nearly flat portion of the reactor magnetic curve.

Where it is preferred, as in the circuit arrangement 10, to compensate for relatively nominal variations in the voltage across the saturable reactor winding 22, the compensatory winding 26 is employed. The vector sum of the voltages across the windings 22 and 26 is substantially constant and, therefore, the voltage across the capacitor 28 and the device 12, the current through the device 12, and the power delivered to the device 12, are all substantially constant. To obtain this result, the compensatory winding 26 is placed, as already indicated, on the core leg 48 so as to be related inductively to the linear reactor winding 20.

With variations in line voltage, both the current through the linear reactor winding 20 and the flux in the core leg 48 vary. The voltage appearing across the compensatory winding 26 during circuit operation is nearly 90° out of phase with the line current, that is, the current through the linear reactor winding 20, and is, therefore, nearly 90° out of phase with the line voltage since the circuit 10 operates at nearly unity power factor over its operating range as will be described hereinafter. With variations in the magnitude of the line voltage, the line current varies in phase and to some extent in magnitude relative to the line voltage so as to affect the phase angle and the magnitude of voltage across the compensatory winding 26 accordingly. More particularly, with an appropriate number of turns being provided for the compensatory winding 26, the voltage across the windings 22 and 26 in series will be regulated substantially to be constant. From an alternate frame of reference, circuit voltage drops including those across the windings 20 and 26 will vary with line voltage variations so as to provide, when subtracted vectorially from the line voltage, a constant voltage across the capacitor 28 and the device 12. As will now be determined, the regulating effect is obtained principally through the changing in phase of the voltage across the compensatory winding 26 with variations in line voltage.

Thus, to clarify the voltage conditions just described, a vector diagram (FIG. 7) has been included in the drawings. In this figure, the solid lines represent the voltage and current vector relations for a relatively low line voltage and the dotted lines, being nominally displaced from the solid lines for illustrative purposes only, represent the voltage and current vector relations for a relatively high line voltage. The subscripts for the various voltage and current symbols are provided with reference to the corresponding circuit elements of FIG. 1. In addition, it is assumed in this instance that the conductor 25 is connected to the end of the saturable reactor winding 22 rather than in the tapped position 40.

θ_L and θ_H represent the phase difference between line voltage and line current for respective low and high line voltage conditions. The angle α represents the phase difference between the voltage across the compensatory winding 26 for the low line voltage condition relative to the same voltage for the high line voltage condition. It is clear that with increasing line voltage the circuit power factor angle becomes greater to some extent as represented by the difference $\theta_H - \theta_L$. The angle α, of course, necessarily also varies and therefore it follows that the changing phase and to some extent the changing magnitude of the voltage vector V_{26} lead to respective constant voltages V_{28} and V_{12} across the capacitor 28 and the device 12. Accordingly, slight variations in the voltage V_{22} across the saturable reactor winding 22 with variations in line voltage $V_{14,\ 16}$, as a result of the previously described departure from ideal saturating properties (zero slope) of the core leg 52, do not lead to variations in the voltages V_{28} and V_{12} across the capacitor 28 and the device 12; rather, with the offsetting magnitude and phase variations of the voltages V_{26} and V_{20} across the compensatory winding 26 and the linear reactor winding 20, the voltages V_{28} and V_{12} across the capacitor 28 and the device 12 are regulated to be substantially constant and therefore a delivery of substantially constant power is provided for the device 12.

The reactance of the windings 20 and 26 and the capaci-

tor **28** provide the principal ballasting effects relative to the device **12** in the circuit **10**. Thus, means are provided for ballasting or limiting the current through the device **12** within a rated range of values, while constant power is delivered to the device **12** for reasons already determined.

With the operating conditions of the circuit **10** being ascertained, it is desirable in the interest of clarity once more to consider the means by which starting is obtained. The flux density versus magnetomotive force or the B-H curve of the various magnetic branches of the core **42**, is, of course, non-linear to the extent already described and leads to the induction of harmonic voltages (relative to the fundamental or line voltage) including third harmonic voltages in some or all of the windings **20**, **22** and **26** of the inductive means **18**. Where the circuit parameters including those associated with some or all of the windings **20**, **22** and **26** are provided in such form as to lead to harmonic resonance in the circuit **10**, an elevated voltage relative to the line voltage can be obtained for starting purposes. Thus, in the example of FIG. 1, the capacitor **34** resonates at a selected harmonic frequency, for example the third harmonic frequency, in conjunction with the circuit inductive reactance to provide sufficient voltage between circuit junctions **54** and **56** to provide for initiating a discharge or for starting the deivce **12**.

Once steady state operation of the device **12** is obtained, the resonant effect of the capacitor **34** is substantially removed since new circuit parameters impose new conditions for resonance. Moreover, the impedance of the capacitor **34** is such as to lead to only nominal shunt current under normal operating conditions.

The circuit power factor, to which reference has previously been made, can have a range of values over the expected range of line voltage variation, for example +13% to —13%, with each power factor value being sufficiently close to unity to be acceptable on an efficiency basis. Thus, without interfering with the circuit functioning already described, the reactance values of the windings **20**, **22** and **26** and the capacitors **28** and **34** (although the latter as already determined has only nominal circuit effect during operation) can be selected to provide acceptable power factor results. If necessary, compensatory capacitive current can be provided, for example by connecting a capacitor (not shown) between the terminals **14** and **16**. Similarly, compensatory inductive current can be provided where necessary, for example by placing another bridged gap (not shown) in the core leg **52**.

In some cases where regulating specifications are more relaxed, the compensatory winding **26** of FIG. 1 may, if desired, be omitted. Thus, in FIG. 2, a circuit arrangement **60**, without the compensatory winding **26** is schematically diagrammed. In FIG. 2, as well as FIGS. 3 and 4, reference characters employed in FIG. 1 are employed for like elements. In FIG. 3, a circuit arrangement **70** is shown without the starting capacitor **34**. Thus, in some cases line voltage may be high enough to avoid the use of the capacitor **34**. Alternately, the saturable reactor winding **22** can be provided as a step up auto transformer (not shown) rather than as the step-down arrangement of FIGS. 1 to 4 to provide starting voltages where the line voltage is not sufficient in magnitude and where it is not desired to use the capacitor **34**. A circuit arrangement **80** is shown in FIG. 4 without the use of both the compensatory winding **26** and the starting capacitor **34**. In each of the modified circuit arrangements just described, circuit parameters would have to be adjusted to obtain proper functioning. Most importantly, the core **42** can be used with each of these circuit arrangements to provide the economic advantages described in connection with FIG. 1.

In the foregoing description, several circuit arrangements have been considered only to point out the principles of the invention. The description, therefore, has only been illustrative of the invention, and, accordingly, it is desired that the invention be not limited by the embodiments described here but rather, that it be accorded an interpretation consisent with the scope and spirit of its broad principles.

What is claimed is:

1. A circuit arrangement for energizing a discharge device, said circuit arrangement adapted for use with a source of fluctuating voltage, and said circuit arrangement comprising: ballast means connected in series with said device; inductive means including a linear reactor, a saturable reactor connected in series with said linear reactor, and a compensatory reactor inductively coupled with said linear reactor, said compensatory reactor adapted to cause the voltage across said device to remain substantially constant; and means connecting said inductive means to said ballast and to said device.

2. The circuit arrangement as specified in claim 1 wherein capacitive means are connected across said device, said capacitive means adapted to provide the necessary starting voltage for said device.

3. A circuit arrangement for energizing a discharge device, said circuit arrangement adapted for use with a source of fluctuating voltage, said circuit arrangement comprising means for ballasting and starting said device, said ballasting and starting means comprising: capacitive means connected in series with said device; inductive means including a linear reactor, a saturable reactor connected in series with said linear reactor, and a compensatory reactor inductively coupled with said linear reactor, said compensatory reactor adapted to cause the voltage across said device to remain substantially constant; and means connecting said inductive means to said capacitive means and to said device.

4. The circuit arrangement as specified in claim 3 wherein a starting capacitor is connected across said device and said capacitive means.

5. A circuit arrangement for operating, from a fluctuating source of alternating voltage, a discharge device which has a negative characteristic, said circuit arrangement comprising:

(*a*) inductive means comprising a series-connected linear reactor and a saturable reactor connected across said voltage source;

(*b*) a capacitor connected in series with said device;

(*c*) a compensatory reactor connected in series with said series-connected capacitor and device;

(*d*) said series-connected compensatory reactor, capacitor and device connected across a substantial portion of said saturable reactor; and

(*e*) said compensatory reactor inductively coupled to said linear reactor to cause the voltage applied across said device to remain substantially constant in spite of fluctuations in the voltage delivered by said voltage source.

6. The circuit arrangement as specified in claim 5, wherein a starting capacitor is connected across said series-connected capacitor and device.

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