

[54] **INCANDESCENT LAMP SERIES STRING HAVING PROTECTION AGAINST VOLTAGE SURGES**

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[58] Field of Search 315/46, 48, 71, 125, 205, 315/92, 58, 72, 122, 126, 123, 124

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[57] ABSTRACT

A body of sintered polycrystalline varistor material connected across the filament of an incandescent lamp shunts a transient voltage surge thereby protecting the lamp filament. Additionally, a plurality of such varistor shunt protected incandescent lamps may be serially interconnected in a series string. Upon the opening of a lamp filament in the series string, conduction continues through the varistor element so that the remaining lamps in the string continue to function.

5 Claims, 3 Drawing Figures

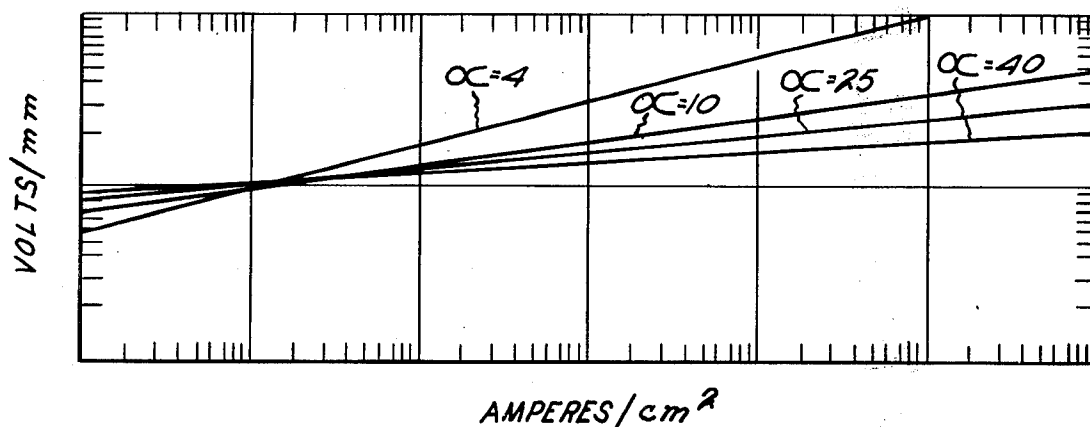


Fig. 1

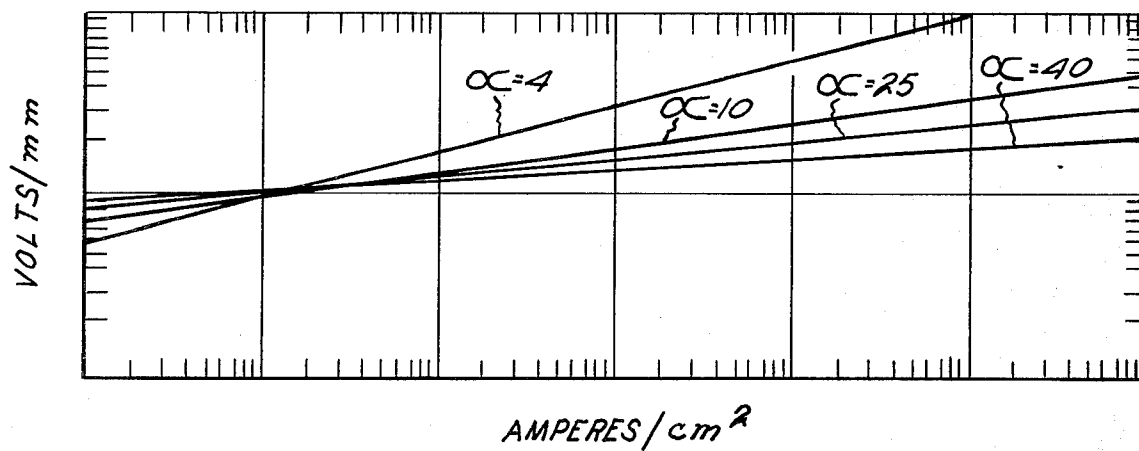
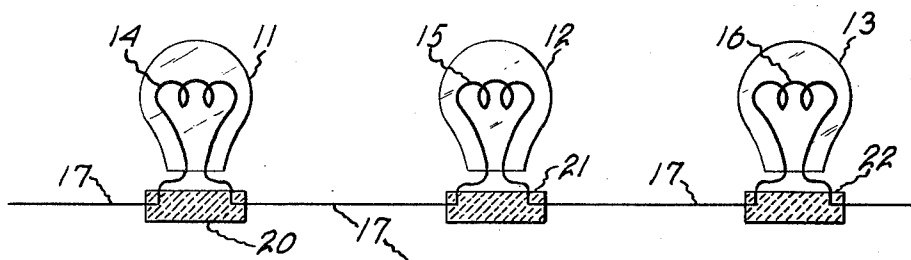
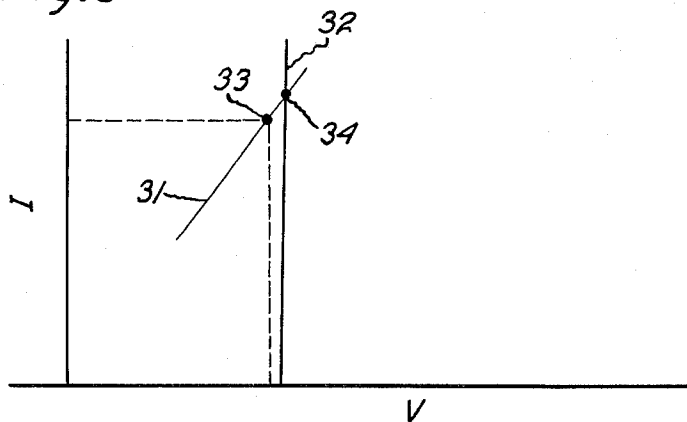


Fig. 2

Fig. 3



INCANDESCENT LAMP SERIES STRING HAVING PROTECTION AGAINST VOLTAGE SURGES

This invention relates to incandescent lamps. More particularly, this invention relates to protecting incandescent lamps from over-voltage damage by including a polycrystalline varistor electrically in parallel with the filament of the lamp. This invention further relates to series string arrays of incandescent lamps and more particularly relates to the inclusion of a polycrystalline varistor electrically in parallel with each lamp filament in the series string to protect the lamps of the string and to permit the remainder of the string to continue to operate upon the failure of some of the lamps in the string.

This invention is related to my concurrently filed application, Ser. No. 355,897. This related application is assigned to the assignee of this invention and is incorporated herein by reference thereto.

Incandescent lamps comprise a coiled tungsten filament contained in an envelope from which oxidizing agents are excluded. Tungsten metal is brittle and difficult to draw and, therefore, incandescent lamp filaments produced in an economically practical manner contain pinches, or thin regions therein. Because these thin regions have increased electrical resistance and decreased mechanical strength with respect to the rest of the filament, they represent weak spots at which filament failure is likely to occur when the lamp is subjected to an over-voltage condition on its supply line. Another filament failure mechanism results from the fact that the filament is coiled. Current flowing through the coiled filaments sets up a magnetic field which tends to pull the turns of the coil together. A voltage surge causes an increased current to flow through the filament which in turn increases the intensity of the magnetic field which further draws the turns together and may cause turn-to-turn shorting. Such shorting decreases the electrical resistance of the filament causing more current to flow further increasing the intensity of the magnetic field and shorting more turns in a chain reaction fashion until the filament burns out. As a result of these factors, it is empirically known that the operating lifetime of an incandescent lamp filament is inversely proportional to the voltage applied across the filament raised to the thirteenth power.

It is also known that incandescent lamp filaments exhibit a positive temperature coefficient of resistance such that the resistance of the filament of a lamp at operating temperature is approximately 10-20 times the resistance of the same filament when cold. Naturally, the currents through the lamp exhibit the same 10:1-20:1 ratio inversely to the resistance. Therefore, a lamp is most likely to fail at the moment of turn-on and is most susceptible to voltage transients on its supply line at that time.

It is, accordingly, one object of this invention to prevent supply line voltage surges from being impressed across the filaments of incandescent lamps to thereby prolong the operating life of the lamps.

It is frequently desirable to interconnect a plurality of incandescent lamps in such fashion that their filaments are connected electrically in series with each other. Obviously, in such a series string, the opening of the filament of any one lamp will extinguish all of the lamps in the string.

Accordingly, another object of this invention is to provide an alternative current path in parallel with each filament of a series string of incandescent lamps so that upon the opening of any filament in the series string, current conduction continues through the alternative path and the remaining lamps in the string continue to function.

It is another object of this invention to provide such a series string wherein the alternative paths comprise polycrystalline varistors.

It is another object of this invention to provide such protective polycrystalline varistors which have negligible switching times and negligible steady state leakage currents.

Briefly, and in accordance with one embodiment of this invention, there is provided a series string of incandescent lamps wherein each element in the string is shunted by a polycrystalline metal oxide varistor element which protects its associated filament from damage by voltage surges, and which switches from a very high impedance to a very low impedance state when its associated lamp element opens thereby permitting continued operation of the remainder of the lamps in the series string.

The novel features of this invention sought to be patented are set forth with particularity in the appended claims. The invention, together with further objects and advantages thereof, may be understood from a reading of the following specification and appended claims in view of the accompanying drawings in which:

FIG. 1 is a log-log graphical representation of the current density vs. voltage gradient characteristic of the polycrystalline varistor used in practicing this invention.

FIG. 2 is an electrical schematic diagram of a portion of a series string of protected incandescent lamps in accordance with this invention.

FIG. 3 is a graphical representation of the operating characteristics of the lamp and varistor elements of the series string of this invention illustrating the mode of operation thereof.

There are a few known materials which exhibit nonlinear resistance characteristics and which require resort to the following equation to relate quantitatively current and voltage:

$$I = \left(\frac{V}{C} \right)^\alpha$$

where V is the voltage between two points separated by a body of the material under consideration, I is the current flowing between the two points, C is a constant and α is an exponent greater than 1. Both C and α are functions of the geometry of the body formed from the material and the composition thereof, and C is primarily a function of the material grain size whereas α is primarily a function of the grain boundary. Materials such as silicon carbide exhibit nonlinear or exponential resistance characteristics and have been utilized in commercial silicon carbide varistors, however, such non-metallic varistors typically exhibit an α exponent of no more than 6. This relatively low value of α represents a nonlinear resistance relationship wherein the resistance varies over only a moderate range. Due to this moderate range of resistance variation, the silicon carbide varistor is often connected in

series with a gap when used in a circuit for transient voltage suppression since continuous connection of the varistor could exceed the power dissipation capabilities thereof unless a relatively bulky body of such material is used in which case the steady state power dissipation is a rather severe limitation. An additional drawback is the ineffectiveness of the voltage clamping action as a result of the limited value of silicon carbide alpha exponent. The moderate range of resistance variation results in voltage limitation which may be satisfactory for some applications, but is generally not satisfactory when the transient voltage has a high peak value.

A new family of varistor materials having alphas in excess of 10 within the current density range of 10^{-3} to 10^2 amperes per square centimeter has recently been produced from metal oxides. The metal oxide varistor is a polycrystalline ceramic material formed of a particular metal oxide with small quantities of one or more other metal oxides or halides being added. As one example, the predominant metal oxide is zinc oxide with small quantities of bismuth oxide being added. Other additives may be aluminum oxide, iron oxide, magnesium oxide, and calcium oxide for example. The predominant metal oxide is sintered with the additive oxide(s) to form a sintered ceramic metal oxide body. Since the varistor is fabricated as a ceramic powder, the material can be pressed into a variety of shapes of various sizes. Being polycrystalline, the characteristics of the metal oxide varistor are determined by the grain (crystal) size, grain composition, grain boundary composition, and grain boundary thickness, all of which can be controlled in the ceramic fabrication process.

The nonlinear resistance relationship of polycrystalline metal oxide varistors is such that the resistance is very high (10,000 megohms has been measured) at very low current levels in the microampere range and progresses in a nonlinear manner to an extremely low value (tenths of an ohm) at high current levels. The resistance is also more nonlinear with increasing values of alpha. These nonlinear resistance characteristics result in voltage versus current characteristics wherein the voltage is effectively limited, the voltage limiting or clamping action being more enhanced at the higher values of the alpha exponent as shown in FIG. 1. Thus, the voltage versus current characteristics of the polycrystalline metal oxide varistor is similar to that of the Zener diode with the added characteristics of being bidirectional and of operating over more decades of current.

The voltage versus current characteristics plotted in FIG. 1 of the drawings illustrate the nonlinear or exponential resistance characteristics exhibited by varistor material, and in particular, the increasing nonlinearity and enhanced voltage limiting obtained with increased values of the exponent alpha (α) wherein the top line $\alpha = 4$ is typical for silicon carbide varistors and the three lines $\alpha = 10, 25$, and 40 apply to varistors fabricated of polycrystalline metal oxide material. It should be understood that metal oxide materials are available having alpha exponents even greater than 40 which thereby obtain even greater enhanced voltage clamping action than that exhibited for the $\alpha = 40$ line.

FIG. 2 illustrates a series string of incandescent lamps in accordance with this invention comprising lamps 11, 12, and 13 having, respectively, filaments 14, 15, and 16. Filaments 14, 15, and 16 are connected in series by power line 17. Additionally, power line 17 connects

polycrystalline varistor members 20, 21, and 22 electrically in series. Polycrystalline varistor members 20, 21, and 22 are connected respectively electrically in parallel with filaments 14, 15, and 16. During normal steady state operating conditions, varistors 20, 21, and 22 behave essentially as open circuits in power line 17 and almost all of the current flowing in line 17 flows through filaments 14, 15, and 16. For example, in a typical steady state operating condition, 1 ampere flows through the filaments and less than 10 microamperes of leakage current flows through varistor members 20, 21, and 22. When a voltage surge exceeding the varistor voltage of varistors 20, 21, and 22 appears on power line 17, on the other hand, the varistor members switch to an extremely low impedance state and more than 99 percent of the surge current flows through the varistor members and less than one percent of the surge current flows through filaments 14, 15, and 16. Accordingly, the operating lives of lamps 11, 12, and 13 is greatly extended.

For large multi-lamp lighting installations, the use of a series string lamp arrangement in preference to parallel interconnected lamps is advantageous for a number of reasons. Among these reasons are: a saving of up to 50 percent of the interconnection wiring required may be obtained depending upon the configuration of the string; a series string comprises a plurality of low voltage lamps, the sum of whose voltage ratings equal the supply voltage, as opposed to the plurality of supply voltage rated lamps employed in a parallel interconnection, and low voltage lamps exhibit a longer life and higher efficiency in terms of lumens per watt than high voltage lamps; low voltage lamps are less expensive than high voltage lamps since, for a given wattage, the length of filament in a low voltage lamp is substantially less than in a high voltage lamp and filament support required in the lamp is accordingly greatly simplified.

Those skilled in the art will readily appreciate that varistors such as silicon carbide cannot be employed as heretofore described partly because the low alpha of silicon carbide, for example, varistors would allow too much surge current to pass through the filaments to be acceptably effective in preserving lamp life, but principally because of the excessive leakage currents through such varistors in the steady state condition which would waste an unacceptable amount of energy and would overly decrease the illumination provided by the series string.

In another facet of this invention, which takes advantage of the precise controllability of varistor characteristics of polycrystalline metal oxide varistors, in a preferred embodiment of this invention, the varistor voltage of varistors 20, 21, and 22 is made to be only slightly higher than the operating voltages of lamps 11, 12, and 13. The advantage of this feature of this invention may be appreciated with reference to FIG. 3 which indicates the resistance characteristics of the lamp filaments and of the varistor members. In FIG. 3, line 31 represents the resistance characteristic of a lamp filament and line 32 represents the resistance characteristic of a varistor member. Point 33 is the normal, steady state, operating point of a lamp filament. Should a filament, for example, filament 15 in FIG. 2, open, the voltage across the open filament and its associated varistor 21 begins to rise toward the supply voltage on line 17. When the voltage reaches the value at point 34, however, varistor 21 commences to conduct substan-

tial current. Accordingly, the opening of filament 15 does not cause the extinguishment of lamps 11 and 13. Since the rise of potential across varistor 21 to point 34 and the firing of varistor 21 into conduction occur in approximately 1 microsecond, the provision of illumination by the remaining lamps in the string other than lamp 12, continues without operational interruption.

In fact, one could, in accordance with this invention clamp lamp voltages to rated voltage by using varistors having varistor voltages equal to the lamp voltage. This, however, would result in a substantial increase in the average current flowing through the varistors over time as they switched responsively to minor supply voltage fluctuations and would consequently require heat-sinking of the varistors. Accordingly, this invention contemplates varistor voltages equal to approximately 125 percent of rated lamp voltage as preferred.

In addition to providing for continuation of illumination from the remaining lamps in a series string upon failure of some of the lamps thereof, this invention provides two other notable advantages. First, maintenance procedures are greatly simplified because a failed lamp announces itself by being unilluminated. Second, since conduction continues through a varistor element having a slightly greater voltage drop across it than the failed lamp had when operating, a lamp failure in a string in accordance with this invention results in a decreased stress on the remaining lamps of the string. This is a distinct advantage in cases in which the initial lamp failure is the result of a power system anomaly which may have a duration of several seconds. In such cases, the failure of the first lamp provides a real protection to the remaining lamps, some of which would otherwise also fail during the duration of such power system anomaly.

While this invention has been described with reference to particular embodiments and examples, other modifications and variations will appear to those skilled

in the art, in view of the above teachings. Accordingly, it should be understood that within the scope of the appended claims, the invention may be practiced otherwise than is specifically described.

The invention claimed is:

1. In a series string of incandescent lamps having a plurality of incandescent lamps therein, each said incandescent lamp having a filament, the improvement which comprises:

10 a plurality of bodies of polycrystalline varistor material, each said body being connected across a corresponding one of said filaments and electrically in parallel therewith for protecting said filaments against voltage surges by instantaneously decreasing impedance in response to increased voltage and by instantaneously increasing impedance in response to decreased voltage.

2. The improvement of claim 1 wherein said polycrystalline varistor material comprises zinc oxide as a major constituent and a minor constituent selected from the group consisting of other metal oxides and halides.

3. The improvement of claim 2 wherein said bodies have a varistor α exponent in excess of 10 in the current density range of 10^{-3} to 10^2 amperes per square centimeter.

4. The improvement of claim 1 wherein said bodies have a varistor voltage slightly higher than the voltage drop across said corresponding filaments for preventing leakage current through said bodies when said corresponding filaments are electrically conducting and for providing a low impedance current path through said bodies when said corresponding filaments are electrically open.

5. The improvement of claim 4 wherein said varistor voltage is approximately equal to 125 percent of the voltage rating of said lamps.

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