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3,538,382

TRIGGERED VACUUM GAP OVERVOLTAGE PROTECTIVE DEVICE

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ABSTRACT OF THE DISCLOSURE

A triggered vacuum gap device having a triggering circuit that includes among its desirable characteristics; a very low time lag, reliably stable operation, long maintenance free life, and the ability to operate with system power rather than requiring a secondary source of power. In one form, the triggering circuit includes a secondary gap electrically connected in series with a voltage dropping resistor across a line voltage that is applied to the main high voltage vacuum gap of the device. The voltage dropping resistor is connected in parallel with the triggering gap of the device to cause it to spark over when the secondary gap breaks down and allows current to flow through the resistor thereby developing a sparkover voltage across the gap.

This invention relates to electrical discharge devices that operate by the ionization of vaporized, normally solid material in an evacuated space, and more particularly to a triggering circuit for initiating ionization within such devices.

The use of various types of vacuum gap devices to limit the peak value of voltage surges occurring on high voltage transmission lines has been recognized as an inexpensive and desirable means of performing this function. As vacuum gap devices were developed for surge limiting functions, it was learned that their operating stability could be improved by providing triggering means for initiating a breakdown of the main vacuum gap at a lower voltage than it would ordinarily break down if untriggered. Accordingly, several methods of triggering a controlled breakdown of vacuum gaps within a relatively narrow range of operating voltages were developed. Basically, these methods all provide means for reducing the arc-over voltage of the gap by injecting electrons, ions or plasma into the main vacuum gap; the primary difference between the various methods being the speed of breakdown and rapidity of recovery of dielectric strength in the gap after an arc has been extinguished. However, it has been found that the method of triggering breakdown by injecting a plasma into the main vacuum gap gives the most rapid breakdown with a minimum amount of voltage instability.

One desirable way of injecting a plasma into a vacuum gap is to provide auxiliary gas-loaded triggering electrodes that evolve a plasma when energized. For example, a plasma evolving triggering arc may be initiated between hydrogen-loaded titanium electrodes that are separated by a few mils distance by applying a high voltage pulse across the electrode gap. Of course, the triggering gaps themselves require a substantial voltage to initiate sparkover. In some prior art devices, such triggering gaps have been sparked over by discharging a high voltage capacitor or other external source of high voltage energy into the gap. The problem with such a method is that the capacitors needed are both space consuming and expensive. Other prior art triggering circuits, which are more compact because they rely on the line voltage of the protected system as a source of energization, have the disadvantage of sparking over at different voltages depending on the polar-

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ity of the system voltage surge that actuates the triggering action.

The triggering apparatus of my invention avoids the foregoing problems inherent in prior art devices and provides a very low time lag triggering function which is insensitive to the polarity of an initiating voltage surge. Moreover, my triggering apparatus requires no external source of energy or large component parts, such as high voltage capacitors, for initiating the triggering. Further important advantages inure to my triggering apparatus due to its mode of operation. Specifically, the operating circuitry of my apparatus handles only a limited current; therefore, the operating characteristics of its components remain stable because they are not subjected to appreciable arcing. Also, the arcing that does occur across these components is external from the main vacuum gap and it is of very short duration because it is cleared instantly when voltage is collapsed across the components by the initiation of an arc across the main gap.

Accordingly, an object of my invention is to provide a triggered vacuum gap device having a reliable triggering circuit with very low time lag.

A further object of my invention is to provide a triggering circuit for a vacuum gap device which is insensitive to the polarity of an initiating voltage surge.

Still another object of my invention is to provide a vacuum gap device having triggering means disposed outside of the device thereby to increase the stability of the operating characteristics of the triggering apparatus.

A further object of my invention is to provide a triggered vacuum gap device for an electrical system to assure low time lag and very stable voltage limiting protection for the system.

Further objects and advantages of the invention will become apparent, and a more complete understanding of it will be gained, from the following description taken in connection with the accompanying drawings, wherein:

FIG. 1 is a schematic diagram of a circuit embodying one form of my invention illustrated in conjunction with a side elevation view, partly in cross section, of a vacuum gap device shown with respect to a high voltage transmission line conductor.

FIG. 2 is a preferred embodiment of the triggering apparatus of my invention shown with a schematic diagram of a circuit that is operatively connected to a vacuum gap device depicted in side elevation, partly in cross section, and connected in a circuit with a nonlinear resistor or other voltage surge limiting means to a high voltage power conducting system.

Referring to FIG. 1, there is shown, schematically, a portion of a high voltage transmission system conductor, or line 1, which is adapted to transmit electric power from a suitable high voltage source, such as a direct current generator 2, to some remote destination. Voltage limiting means must be provided in order to protect such transmission systems from damage due to high voltage surges which may be caused either by natural forces, such as lightning, or by transient voltages created during switching operations. To provide this protective function, a vacuum gap device 3 is connected by conductors 4 and 5 between the line 1 and ground. This vacuum gap device 3 is preferably constructed as shown and claimed in U.S. Pat. 3,087,092—Lafferty, assigned to the assignee of the present invention. Accordingly, it comprises a sealed envelope 6 that is evacuated to a hard vacuum, i.e., to a pressure of 10-5 millimeters of mercury or lower. The envelope 6 comprises a casing 7 formed of a suitable insulating material such as ceramic, and a pair of metallic end caps 8 and 9 joined in vacuum-tight relationship to the respective opposite ends of the insulating casing 7 by any suitable sealing means 10, such as brazing.

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Disposed within the evacuated envelope 6 and electrically connected to end plates 8 and 9, respectively, are main electrodes 11 and 12. Electrodes 11 and 12 define a main vacuum gap 13 therebetween.

It will be noted that a bypass circuit is formed across main gap 13 from line conductor 1 through conductors 4 and 5 and terminals 11 and 12 to ground, when the gap 13 is rendered conductive by having an arc formed across it. It will be understood that for given applications the length of gap 13 can be predetermined so that a single gap can be relied upon to withstand normal line-to-ground voltage without breaking down. Of course, higher voltage circuits could be protected with such (predetermined gap) devices by connecting an appropriate number of such gaps in series to form the bypass circuit, as is well known in the art.

Normally, the main gap 13 will be between three-eighths and five-eighths of one inch in length. Therefore, in order to cause the gap 13 to break down when the voltage to ground on the line 1 reaches a predetermined magnitude at which system components would be in eminent danger of flashing over, or insulation failure, there is provided a triggering gap 14 located within the conical recess 12a of electrode 12. The triggering gap 14 is formed by a cylindrical ceramic insulating support 15 which serves both as a bushing for conductor 16 to insulate it from the conductive end wall 9, and as a support for two thin layers of metal 17a and 17b bonded to its upper end with the gap 14 therebetween.

It will be noted that the conductor 16 terminates in a metal cap 18 which is hermetically sealed to the inner end of ceramic support 15 by any conventional ceramic-to-metal sealing technique that assure a vacuum-tight seal. The bonded metal layers 17a and 17b are formed of a metal, such as titanium, which is a good getter for active gases, such as hydrogen, and which is capable of absorbing a large quantity thereof. As is well known, the lines of field distribution at the interface between a metal and a ceramic body in intimate contact are highly favorable to a voltage breakdown at the interface. Accordingly, a relatively low voltage appearing across the triggering gap 14 can initiate a discharge from one of these interfaces across the trigger gap 14. In order to apply such a triggering voltage across the triggering gap 14, a series circuit is formed from conductor 16 through metal cap 18 and bonded metal layer 17a across the gap 14 the bonded metal layer 17b, which is in electrical contact with electrode 12, and thence through conductor 5 to ground. Therefore, in order to initiate a sparkover of triggering gap 14, it is only necessary to apply a voltage of predetermined suitable magnitude to conductor 16.

Pursuant to the teaching of my invention, such a voltage is provided by the triggering circuit 19 which includes a voltage-responsive current conducting means 20 electrically connected in series with the current-responsive voltage distributing means 21 between the line 1 and ground. In the embodiment of my invention illustrated in FIG. 1, the voltage distributing means 21 is depicted as a resistor 21a, and the voltage-responsive current conducting means 20 comprises a plurality of pairs of secondary arc terminals 22 each defining an arc gap 22a therebetween. A current limiting resistor 23 is connected in series with the arc gaps 22a and resistor 21a between the conductor 1 and ground to prevent an unduly large current from flowing through the series circuit 19 when it is conductive, thereby to assure the stable operation of the circuit. In order to grade the voltage across the arc gaps 22a, a plurality of voltage grading resistors 24 are connected respectively in parallel across each of the gaps 22a and are all connected in series.

It will be understood that the relative values of impedance and the operating characteristics of the component parts of circuit 19 can be varied to satisfy the particular requirements of given applications. However, by way of example, it has been found that suitable typical

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values for resistors 21a and 23 are 2500 ohms each when line 1 is a 15 kv. line, and the resistors 24 might be typically 25 megohms each in this case.

In this embodiment of my invention, the gaps 22a are preionized by a preionizer 22b connected in parallel therewith, as taught in U.S. Pat. 3,223,874—Carpenter, which is assigned to the assignee of the present invention. The body of preionizer 22b may be formed of a ceramic composition, plastic or mica as disclosed in the referenced patent. It will be understood that any other suitable preionizing means may be employed to afford the desired degree of consistency of sparkover voltage level. Also, resistor 23 is connected in parallel with a capacitor 25 for the purpose of shaping the volt-time sparkover characteristic of the circuit 19. It will be understood that the numbers and size of gaps 22a can be varied to suit the demands of particular applications without departing from the scope of my invention.

In operation, secondary gaps 22a are normally non-conductive but are adapted to be conductive when at least a predetermined magnitude of voltage exists on the conductor 1. This predetermined magnitude of voltage may vary with relation to the normal line voltage transmitted by conductor 1, from a value of two and one-half times normal line voltage in typical power transmission systems rated less than 345 kilovolts down to about 1.5 times normal line voltage for extra high voltage transmission systems ranging up to 1000 kilovolts. When a voltage surge equal to or greater than the predetermined magnitude of voltage occurs on the conductor 1, a suitably high voltage is distributed across the voltage grading resistors 24 to cause the pre-ionized secondary gaps 22a to sparkover and, thus, allow a current to flow through resistor 21a to ground. Since the value of resistors 23 and 21a have been preselected to allow an adequately large current to flow through resistor 21a under such voltage surge conditions to develop a voltage on conductor 16 that is sufficient to cause triggering gap 14 to sparkover, the gap 14 sparks over immediately. When triggering gap 14 sparks over, the bonded metal plates 17 and 18 evolve hydrogen gas sorbed therein, which rapidly breaks down the main gap 13 between main terminals 11 and 12, so that the surge voltage on line 1 is shorted to ground through the above mentioned bypass circuit including conductors 4 and 5 and the vacuum gap device 3.

It will be noted that as soon as main gap 13 arcs over the secondary gaps 22a cease to conduct because the voltage across circuit 19 is immediately collapsed through the lower resistance bypass circuit including the arc across main gap 13. Accordingly, the arcing occurring across gaps 22a is limited to a minimum amount of time and is usually shorter in duration than the arc occurring across the main gap 13. This fact, coupled with the small amount of current allowed to flow by resistor 23 through the secondary gaps 22a assures the rapid clearing of the secondary gaps and their stable operation regardless of the magnitude or duration of the voltage surge occurring on conductor 1.

It will be appreciated that while I have described my invention as embodying a triggering circuit 19 with air gaps 22a which may be shunted with a preionizer 22b, such as mica, it will be understood by those skilled in the art that other suitable secondary gap means, such as vacuum gaps, may be substituted for the illustrated air gaps without departing from the scope of the invention.

Referring now to FIG. 2 of the drawing, there is shown a preferred embodiment of my invention illustrated with respect to a high voltage transmission line conductor 1' that carries power from an alternating current source 2' to some remote point. A vacuum gap device 3' is electrically connected by conductors 4' and 5' in series with a non-linear valve resistor 26 between line conductor 1' and ground. The non-linear resistor 26 is illustrated diagrammatically simply as a labeled box, but it will be understood by those skilled in the art that a plurality of non-

linear resistors may be connected in series to form a lightning arrester or other suitable arc discharge means adapted to be connected in series with the arc discharge device 3'. The vacuum gap device 3' comprises a cylindrical ceramic side wall 7' sealed in vacuum-tight relation to metallic end walls 8' and 9' that in turn are electrically connected to the main gap terminals 11' and 12' which define main gap 13' therebetween. It will be understood that the trigger gaps 14' and 27 associated respectively with main electrodes 12' and 11' are identical in structure and function with the triggering gap 14 discussed above with reference to FIG. 1. Therefore, the arrangement and structure of these components and their associated elements will not be described again here. Conductor 16' electrically connects the gap 14' to the series connected voltage-responsive current conducting means 20' and current-responsive voltage distributing means 21', and conductor 28 electrically connects the triggering gap 27 to voltage distributing means 21b. The current responsive voltage distributing means 21' is formed by impedances 21a' and 21b which may be suitable resistors or any other voltage-dropping means that will develop a suitable voltage across triggering gaps 14a and 27 to cause them to sparkover when the current conducting means 20' are conductive. The current conducting means 20' comprises series connected resistors 29 and 30, a plurality of series connected pairs of secondary electrodes 22' each of which defines secondary gaps 22a' therebetween and each of which is preferably preionized with a shunt-connected block of insulating material 22b' so that the gaps 22a' will break down at a consistent voltage level. A plurality of voltage grading resistors 24' are each connected respectively in parallel across the secondary gaps 22a' and all connected in series with one another.

In operation, each of the components of voltage-responsive current conducting circuit 20' operates in the same manner as the like components operated as discussed above with reference to circuit 20 of FIG. 1. It will be understood that the current limiting resistors 29 and 30 may be shunted by capacitances as was done with current limiting resistor 23 and capacitor 25 in the embodiment of the invention depicted in FIG. 1 to improve the volt-time characteristics of the circuit as is well known in the art. Accordingly, no further discussion of the operation of this portion of my invention will be repeated here.

It will be noted that triggering circuit 19' is completed by connecting a conductor 31 between one end of resistor 21a' and conductor 5' to thereby connect the voltage distributing resistor 21a in parallel with the triggering gap 14'. As in the embodiment of the invention depicted in FIG. 1, a bypass circuit around triggering circuit 19' is provided from line conductor 1' through conductors 4' and 5' and the vacuum gap device 3' and valve resistor 26 to ground.

A major advantage of this preferred embodiment of my invention is that the main arc inducing triggering gap sparkover is initiated precisely at a predetermined volt-time value regardless of the polarity of the voltage surge initiating the sparkover at either gap 14' or 27. It will be understood by those skilled in the art that although I have shown the preferred embodiment of my invention with respect to a high voltage alternating current transmission line conductor 1', the invention can be equally as well utilized to protect transformers, circuit breakers and other component parts of high voltage systems by affording means for quickly and reliably grounding high voltage surges at a precise volt-time value regardless of the polarity of the over-voltage surge. Moreover, as illustrated by the embodiment of my invention depicted in FIG. 1, the invention may be utilized to improve the performance and reliability of protective gap devices incorporated in direct current systems where over-voltage surges of opposite polarity do not exist.

While I have shown and described particular embodi-

ments of my invention, it will be obvious to those skilled in the art that various changes and modifications may be made without departing from the invention in its broader aspects and, therefore, I intend all such changes and modifications to fall within the true spirit and scope of the invention.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. An electric discharge device comprising an evacuated envelope having mounted therein main arc-gap electrodes and a trigger electrode adjacent to one of said main electrodes but spaced therefrom to form a trigger gap, current-responsive voltage distributing means and voltage-responsive current conducting means electrically connected in series across said main electrodes to form a bypass circuit around the main electrodes, said current conducting means being adapted to be normally nonconductive and to be conductive only when at least a predetermined magnitude of voltage exists across said main electrodes, thereby to cause said current-responsive voltage distributing means to be actuated only when said current conducting means is conductive, and circuit means adapted to apply a voltage developed by said voltage distributing means across said triggering gap to cause the gap to sparkover when the voltage distributing means is actuated.

2. An electric discharge device as defined in claim 1 wherein said voltage-responsive current conducting means comprises at least one pair of spaced-apart secondary electrodes that define a secondary gap therebetween, said secondary gap being electrically connected in series with said current-responsive voltage distributing means.

3. An electric discharge device as defined in claim 2 including a substance adapted to pre-ionize said secondary gap disposed adjacent thereto.

4. An electric discharge device as defined in claim 3 wherein said substance is primarily mica.

5. An electric discharge device as defined in claim 2 wherein said secondary gap is an air gap.

6. An electric discharge device as defined in claim 2 including means to form a vacuum for said secondary gap, said secondary gap being disposed in said vacuum.

7. An electric discharge device as defined in claim 1 wherein said voltage-responsive current conducting means is disposed within said evacuated envelope.

8. An electric discharge device as defined in claim 1 wherein said voltage-responsive current conducting means is disposed outside of said evacuated envelope.

9. An electric discharge device as defined in claim 1 wherein said current-responsive voltage distributing means comprises an electrical impedance of predetermined magnitude, and said circuit means comprises conductors arranged to electrically connect said impedance in parallel with said triggering gap.

10. An electric discharge device as defined in claim 1 wherein said voltage-responsive current conducting means comprises a plurality of series connected pairs of spaced-apart secondary electrodes each of which defines a secondary gap therebetween.

11. An electric discharge device as defined in claim 10 including a plurality of voltage grading resistors each electrically connected in parallel with one of said secondary gaps and all connected in a series circuit across said main electrodes.

12. An electric discharge device comprising a highly evacuated envelope having mounted therein main arc gap electrodes and trigger electrodes disposed respectively adjacent to said main electrodes but spaced therefrom to form triggering gaps, current-responsive voltage distributing means and voltage-responsive current conducting means electrically connected in series across said main arc gap electrodes, said current conducting means being adapted to be normally nonconductive and to be conductive only when at least a predetermined magnitude of voltage exists across said main electrodes thereby to

cause said current-responsive voltage distributing means to be actuated only when said current conducting means is conductive, and circuit means adapted to apply a voltage developed across said voltage distributing means to at least one of said triggering gaps to cause it to spark-over when the voltage distributing means is energized.

13. An electric discharge device as defined in claim 12 wherein said current-responsive voltage distributing means comprises a plurality of resistors each respectively electrically connected by said circuit means in parallel with one of said triggering gaps.

14. An electric discharge device as defined in claim 13 wherein said voltage-responsive current conducting means comprises at least one pair of secondary electrodes arranged to define a secondary gap therebetween, and electrically connected in series with said resistors.

15. An electric discharge device as defined in claim 12 wherein said current-responsive voltage distributing means comprises an electrical impedance electrically connected in parallel with each of said triggering gaps whereby a voltage drop developed across said impedance will simultaneously be developed across said triggering gaps.

16. An electric discharge device as defined in claim 12 wherein said voltage-responsive current conducting means comprises a plurality of secondary gaps disposed outside of said envelope.

17. An electric discharge device as defined in claim 16 including a plurality of voltage-grading resistors each respectively connected in parallel with one of said secondary gaps and all electrically connected in series.

18. In an electric system that includes a high voltage electrical conductor and means for insulating said conductor from ground,

(a) a triggered vacuum gap device comprising:

(I) a highly evacuated envelope,

(II) a pair of spaced-apart main electrodes within said evacuated envelope defining a main vacuum gap therebetween, and

(III) means including a triggering gap within said evacuated envelope for injecting a concentration of charged conduction carriers into said main gap in response to sparkover of said triggering gap to produce an arc between said main electrodes,

(b) means for electrically connecting said main electrodes in a bypass circuit extending electrically between said high voltage conductor and ground,

(c) and triggering means for producing a sparkover of said triggering gap when a surge voltage occurs on said conductor comprising:

(I) at least one pair of spaced-apart secondary electrodes defining a secondary gap therebetween, said secondary gap being electrically connected in parallel with said main gap and being adapted to sparkover when a surge voltage of predetermined magnitude occurs on said conductor, and

(II) an electrical impedance connected in series with said secondary gap and in parallel with said triggering gap thereby to develop a voltage across said impedance and said triggering gap when the secondary gap sparks over, said developed voltage being effective to cause the triggering gap to sparkover.

19. An electrical system as defined in claim 18 including at least one nonlinear resistor electrically connected in series with said triggered vacuum device between said conductor and ground.

20. In an electric system that includes a high voltage electrical conductor and means for insulating said conductor from ground,

(a) a triggered vacuum gap device comprising:

(I) a highly evacuated envelope,

(II) a pair of spaced-apart main electrodes within said evacuated envelope defining a main vacuum gap therebetween, and

(III) means including a pair of triggering gaps within said evacuated envelope each disposed respectively adjacent one of said main electrodes, and adapted to inject a charge of conduction carriers into said main gap in response to sparkover of at least one of said triggering gaps thereby to produce an arc between said main electrodes,

(b) means for electrically connecting said main electrodes in a bypass circuit extending electrically between said high voltage conductor and ground,

(c) and triggering means for producing a sparkover of at least one of said triggering gaps when a surge voltage of predetermined magnitude occurs on said conductor comprising:

(I) at least one pair of spaced-apart secondary electrodes defining at least one secondary gap therebetween, said secondary gap being electrically connected in parallel with said main gap and being adapted to sparkover when a surge voltage of said predetermined magnitude occurs on said conductor, and

(II) an electrical impedance connected in series with said secondary gap and in parallel with each of said triggering gaps thereby to develop a voltage across said impedance and at least one of said triggering gap when the secondary gaps sparkover, said developed voltage across said impedance being effective to cause at least one of the triggering gaps to sparkover.

21. An electrical system as defined in claim 20 wherein said triggering means are disposed outside of said evacuated envelope, and including at least one valve resistor device electrically connected in series with said triggered vacuum gap device between said conductor and ground.

22. A triggering circuit for a spark gap triggered vacuum gap comprising current-responsive voltage distributing means and voltage-responsive current conductin means adapted to be electrically connected in series across said vacuum gap, said current conducting means being adapted to be normally non-conductive and to be conductive only when at least a predetermined magnitude of voltage exists across the extremities of said series circuit, circuit means for electrically connecting said voltage distributing means in parallel with said spark gap, said voltage distributing means being operative to cause said spark gap to sparkover when connected thereto through said circuit means and actuated by current passed through said conducting means in response to said predetermined magnitude of voltage occurring across the extremities of said series circuit.

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