SPARK GAP AND DISCHARGE CONTROL APPARATUS

Filed Oct. 11, 1966 2 Sheets-Sheet 1

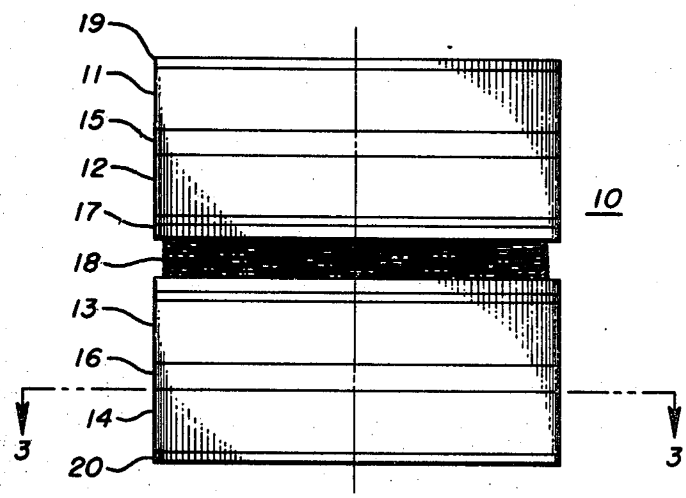

FIG. 1

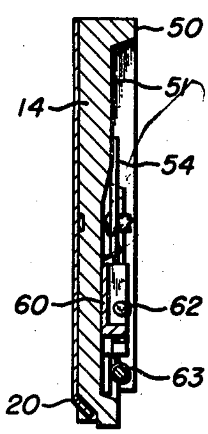

FIG. 4

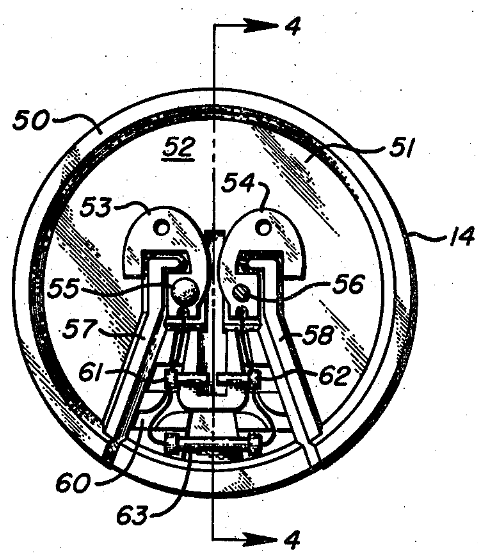

FIG. 3

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SPARK GAP AND DISCHARGE CONTROL APPARATUS

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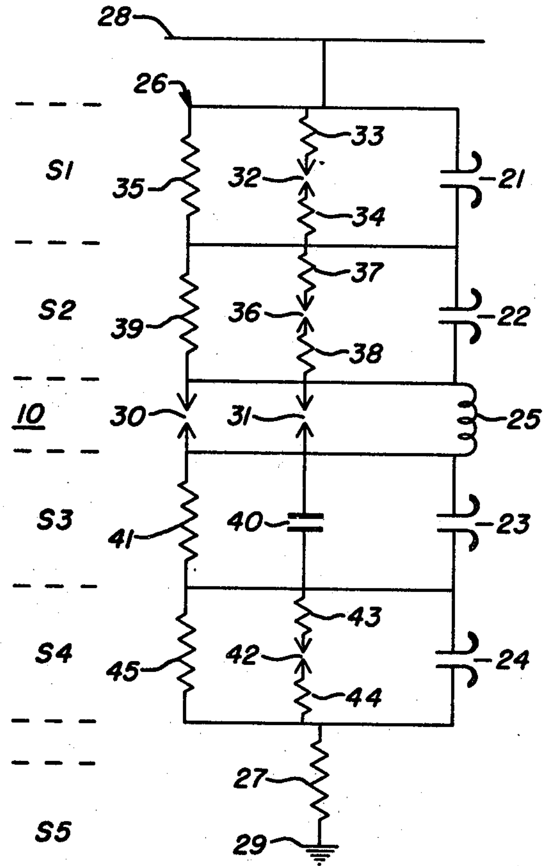
FIG. 2



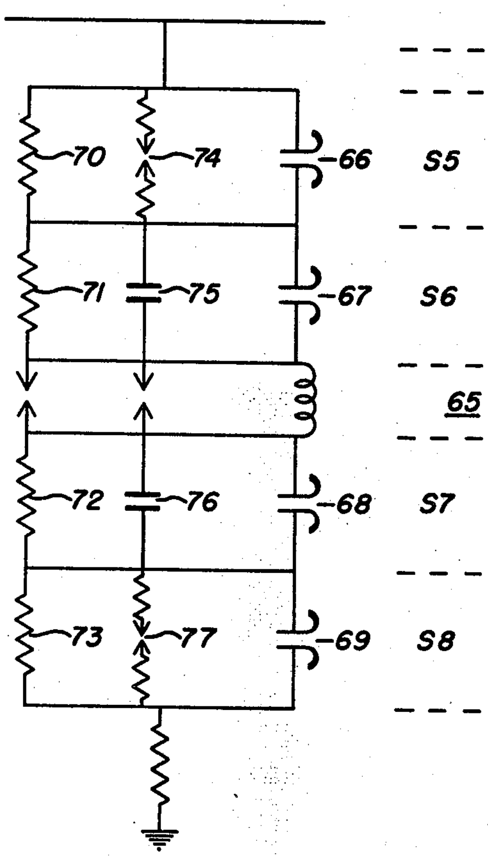


FIG. 5

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3,496,409

Patented Feb. 17, 1970

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3,496,409

SPARK GAP AND DISCHARGE CONTROL APPARATUS

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Filed Oct. 11, 1966, Ser. No. 585,846
Int. Cl. H02h *3/22, 9/06*
U.S. Cl. 315—36 10 Claims

This invention relates to spark gaps and preionizing and control devices for lightning arresters and overvoltage discharge devices and the like.

A principal object of the invention is to provide spark gaps for lightning arresters and overvoltage discharge devices and the like having constant breakdown voltages.

Another object of the invention is to improve the operating reliability of lightning arresters and the like for switching surges.

Another object of the invention is to provide a spark gap and preionizer arrangement in which the breakdown voltage is within a predetermined range of voltages from the design breakdown voltage over a long operating lifetime.

Another object of the invention is to provide a spark gap and preionizer arrangement in which the effect of production variations in dimensions of the gap parts and spacing of the gap electrodes on the breakdown voltage is minimized.

In lightning arresters and the like, it is known to illuminate the main gap by an auxiliary or preionizing gap which serves as a source of ions for imparting a conductivity to the atmosphere between the main gaps. The auxiliary gap is arranged to fire at relatively low current densities so that the spacing between the electrodes is maintained within close size and dimensional tolerances throughout the life of the arrester. Such arrangements are useful since the auxiliary gap is not in the main discharge path of the arrester and may be designed and constructed with precise parts and manufactured to within close tolerances and at relatively low cost. This result could not be achieved economically by design of the main gap.

However, the problem is of some complexity since, in order to achieve proper operation, it is necessary to insure response of the auxiliary gap to excess voltages in the circuit to which the arrester is connected and to insure operation of the main gap after the auxiliary gap is fired. Further, it is necessary to provide the electrical functioning a limited space and in the proper relation to the main gap of the arrester.

The present invention relates to a spark gap and a discharge control and preionizing apparatus, in which a novel arrangement of auxiliary switching gaps and voltage grading means is associated with the main gaps of the lightning arrester. The main gaps, auxiliary gaps, and grading means are arranged in a plurality of stages for cascade operation in which a first main gap is fired and then the other main gaps are fired in a sequence determined by the upset of voltage division between the various stages produced by the firing of the switching main gaps. Novel structural arrangements are provided for incorporating the main gaps, auxiliary gaps, and grading devices in a compact unitary assembly in a lightning arrester.

The invention, together with further objects, features, and advantages thereof, will be understood from the following detailed specification and claims and the appended drawings, in which:

FIG. 1 is a side elevation view of a spark gap apparatus embodying the invention;

FIG. 2 is a schematic diagram showing an overvoltage

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discharge circuit embodying the novel gap and discharge control and preionizing circuit;

FIG. 3 is a plan view of a gap plate, taken along the line 3—3 in FIG. 1 and showing the arrangement of electrodes and grading resistors on the gap plates;

FIG. 4 is a section view of the gap plate of FIG. 3, taken in the direction 4—4 in FIG. 3; and

FIG. 5 is a schematic diagram of a spark gap embodying an alternative arrangement of a discharge control circuit.

Referring to FIG. 1, there is shown the physical construction of the spark gap **10**, in which a plurality of gap plates **11**, **12**, **13**, and **14** cooperate with associated center plates **15** and **16** to define spark gaps, associated arc chambers, and control and discharge circuits of the gap control stages S1, S2, S3, and S4 of FIG. 2. The plates **11**, **12**, **13**, and **14** cooperate with associated center plates **15** and **16** along peripheral ridge and recess means and interengage the end faces of a plate member **17** which carries a magnetic coil **18** at the center position of the four gap plates. The entire assemblage is arranged in the form of a stack, and the elements are connected in series with two end plates **19** and **20** which function to connect the gap assembly to the terminals of the arrester housing, to the line conductor, and to the valve resistor, as the case may be.

Referring now to FIG. 2, the spark gap apparatus **10** comprises four main gaps **21**, **22**, **23**, and **24** connected in series and having certain associated gaps, resistors, and capacitors connected in parallel therewith to constitute four switching control stages, referred to generally as S1, S2, S3, and S4, all connected in series with a coil **25** associated with the gaps **21** to **24**. The apparatus **10** is connected in series circuit **26** which includes a nonlinear valve resistor **27**, a powerline conductor **28**, and a ground **29**, and constitutes a protective circuit or lightning arrester for the powerline **28**.

The coil **25** comprises a means for generating a magnetic field to elongate the arcs in the several gaps **21** to **24**. Two fixed gaps **30** and **31** are connected in shunt with the coil **25** and function during initial discharge of energy from the line **28** to the ground **29** through the gaps **21** to **24**. After a sufficient time interval, current flow, in the coil **25** extinguishes the arcs in the gaps **30** and **31** so that an increasing magnetic field is generated by the coil for moving the arcs in the gaps **21** to **24**. The gaps **30** and **31** may be replaced by arrangements of nonlinear resistors, as is described in U.S. Patents 2,825,008 and 3,019,367 to J. W. Kalb, or by arrangements of arc elongating electrodes, within the contemplation of the invention.

In the apparatus **10**, the gap control stage S1 is constituted by the gap **21**, a switching gap **32** having series connected switching resistors **33** and **34**, and a grading resistor **35**. Gap control stage S2 comprises the gap **22**, a switching gap **36** with series switching resistors **37** and **38**, and a grading resistor **39**. The gap control stage S3 comprises the gap **23**, a grading capacitor **40**, and a grading resistor **41**. The gap control stage S4 comprises a switching gap **42** with series resistors **43** and **44**, and a grading resistor **45**. The described parts are connected in a parallel circuit to constitute the designated stage.

The stages S1, S2, and S4 have the same grading resistances, that is, the grading resistors **35**, **39**, and **45** are equal, whereas the resistance of the grading resistor **41** of stage S3 is small relative to resistors **35**, **39**, and **45**. The switching gaps **32**, **36**, and **42** are designed and adjusted to sparkover at substantially the same voltage, less than the breakdown voltage of the mains gaps, but the associated series resistors, that is, the resistors **33** and **34** of the gap **32**, the resistors **37** and **38** of the gap **36**, and the resistors **43** and **44** of the gap **42**, are progressively smaller for the successive stages so that an unequal voltage division exists as between the main gaps **21**, **22**, and **24** after the switching gaps have fired.

The switching gaps **32**, **36**, and **42** are small gaps having precisely dimensioned electrodes positioned adjacent the main gaps **21**, **22**, and **24**. The switching gaps function as preionizers for the main gaps as well as a switching means for the several switching stages, and are adapted for discharge in a narrow, predetermined range of voltages over the range of design tolerances. In production, one of the gaps **32**, **36**, and **42** is selected to spark over at a voltage close to the design voltage, and minor production variations in the remaining switching gaps do not materially alter the overall functioning, inasmuch as the gap **32** determines the firing sequence of the stages because of the larger values of resistors **33** and **34**.

The functioning of the apparatus **10** is dependent upon the nature of the overvoltage on the conductor **28**. The functioning for line overvoltages which have slowly rising wave fronts or switching surge voltages, so called, is as follows:

The line voltages are divided between the several main gaps **21** to **24** in the same proportions as the resistance of the individual grading resistors **35**, **39**, **41**, and **45** to the total grading resistance constituted by the four resistors. Accordingly, with the grading resistances heretofore described and, prior to discharge of the switching gap **32**, the line voltage is divided with equal voltages across stages S1, S2, and S4 and a much lesser voltage across S3.

Upon the occurrence of an overvoltage on line conductor **28**, the switching gaps **32**, **36**, and **42** spark over and connect the switching resistors **33** and **34** in parallel with the grading resistors **35**, the switching resistors **37** and **38** in parallel with the resistor **39**, and the switching resistors **43** and **44** in parallel with the grading resistor **45**. The resistors **33** and **34** are substantially larger than the resistors **37** and **38**, which are in turn substantially larger than resistors **43** and **44**. Accordingly, after the switching gaps **32**, **36**, and **42** have fired, the distribution of line voltage as between the stages S1, S2 and S4 is altered so that a greater proportion of the line voltage appears across the gaps **21**, **22**, and **24**, in that order, in accordance with the inequality between the parallel resistances of the stages S1, S2, and S4. Accordingly, the gap **21** fires first, followed by the gap **22** and the gap **24**, whereupon all the line voltage appears across the gap **23** which is fired last. This completes the firing sequence and initiates the discharge sequence in which transient energy is discharged from the line conductor **28** to the ground **29**, through the valve resistor **27**. In the discharge sequence, the coil **25** functions to elongate the arcs of the main gaps **21** to **24** to terminate the discharge, all as described in the patents heretobefore referred to.

The resistor **41** is chosen so that its resistance is less than the parallel grading and switching gap resistances of the stages S1, S2, and S4 with the switching gaps fired, so that the main gap **23** is fired only after the main gap firing sequence, gap **21**, gap **22**, gap **24**, is completed. Resistor **41** is small in relation to the individual grading resistances **35**, **39**, and **45**, which insures that the switching gaps **32**, **36**, and **42** are fired before the main gap **23** is fired.

The functioning of the discharge control circuit for line overvoltages which have rapidly rising wave fronts, impulse voltages so-called, is as follows:

The impulse voltages are divided between the several main gaps in proportion to the impedance of a given stage, as the impedance of the capacitor **40**, or the combined impedances of the capacitor **40** and the grading resistor **41**, for the stage S3 or the resistance of the grading resistors **35**, **39**, and **45** for the stages S1, S2, and S4 to the series impedance of the combined stages. The capacitor **40** has a capacitance which is large in comparison with the distributed capacitances across the stages S1, S2, and S4, so that, for impulsive voltages having a sufficiently high rate of increase, the proportional impedance of the stage is low and the impressed voltage is divided substantially between the main gaps **21**, **22**, and **24**. Accordingly, the main gaps **21**, **22**, and **24** fire, although not necessarily in that order, whereupon the impressed voltage is applied directly across the stage S3 to fire the main gaps **23**.

The firing sequence just described is dependent primarily upon the voltage upset between the stages produced by the fast wave front impulses applied to the grading capacitor **40** and is not substantially determined by the functioning of the switching gaps. The firing order as between the main gaps **21**, **22**, and **24** will, generally speaking, be indeterminate rather than determined as to the gap **21** by the firing of the switching gap **32**.

In both embodiments of the invention, the voltage at which the switching gaps lose control of main gaps, that is, cease to determine the firing order, is dependent primarily upon the rate of rise of the impulse voltage, and the control function may be retained for faster impulses by equalizing the time constants of the stages.

Referring now FIG. 3 and FIG. 4, the construction of the stage S4 of the apparatus **10** is illustrated by the construction of the gap plate **14**. The plate **14** comprises a circular plate formed of arc resistant ceramic material and having a circumferential ridge **50** and an interior surface **51** of the plate defining an arc chamber **52**. Two main gap electrodes **53** and **54**, comprising the main gap **24**, are carried by the plate **14** and secured thereto and to the plate **16** by means such as epoxy adhesives and associated rivets **55** and **56**. Two ceramic barrier members **57** and **58** integral with the plate **14** define the extremities of the arc chamber **52** and the limit of elongating arc movement from the adjoining arcing faces of the electrodes **53** and **54** along the diverging extremities thereof and toward the radially outward extremities of the arc chamber under the influence of the magnetic field generated by the coil **18**.

A separate member **60** formed of ceramic material is secured to the surface of the plate **14** between the members **57** and **58**. The member **60** supports two electrodes **61** and **62** which constitute the switching gap **42** and have the bodies formed of resistive material to constitute the switching resistors **43** and **44**. The electrodes **61** and **62** are formed as cylindrical bodies of resistive material which are received in cylindrical openings in elevated portions of the member **60** and have the interior ends closely spaced at a predetermined distance to constitute the gap **42**. A resistor **63** is disposed between the radially outward extremity of the member **60** and the peripheral rim **50** of the plate **14** and constitutes the grading resistor **45** of FIG. 1. The lead wires of the resistor **63** are connected to the electrodes **61** and **62** and to the electrodes **53** and **54** to constitute the parallel circuit arrangement of stage S4.

The gap plates **11**, **12**, and **13**, comprising the stages S1, S2, and S3, may be constructed in the same way as the stage S4, just described. The stage S3 may be constituted by substituting a resistor corresponding to the resistor **41** for the two electrodes **61** and **62** and a capacitor corresponding to the capacitor **40** for the resistor **63** or, conversely, substituting the resistor **41** for the resistor **63** and the capacitor **40** for the electrodes **61** and **62**.

In the embodiment of FIG. 2, selection of main gaps for critical spacing is important only for the main gap **21** and the remaining gaps **22**, **23**, and **24** are relatively tolerant of production variations in spacing.

The spark gap apparatus **65** of FIG. 5 comprises an arrangement of main gaps and a discharge control and preionizing circuit in four stages S5, S6, S7, and S8, generally similar in construction and functioning to the spark gap and discharge control apparatus of FIG. 1 and FIG. 2. However, the apparatus **65** incorporates a symmetric arrangement of stages S6 and S7 with respect to the stages S5 and S8 so that the gap plate assembly **11**, **15**, **12** is identical with the gap plate assembly **13**, **16**, **14**.

As shown in FIG. 5, the main gaps **66**, **67**, **68**, and **69** are connected in parallel with associated grading resistors **70**, **71**, **72**, and **73** and associated switching gap **74**, grading capacitor **75**, grading capacitor **6**, and switching gap **7** to constitute the stages S5, S6, S7, and S8, respectively. The several stages are connected in series with each other and with a magnetic coil **78** having parallel connected gaps **79** and **80**, as in the apparatus **10** of FIG. 1.

The grading resistances **70** and **73** are equal and the grading resistances **71** and **82** are equal, with the resistances **70** and **73** much larger than the resistances **71** and **72**. Accordingly, line voltages and transient overvoltages impressed on the apparatus **65** are divided unequally between the main gaps **66** and **69** and main gaps **67** and **68**. The resistors connected in series with the switching gaps **74** and **77** are unequal, the resistors of the gap **74** being larger than the resistors of the gap **77** so that a transient overvoltage fires both of the switching gaps **74** and **77**, which in turn causes the main gap **66** to fire and then the main gap **69**. With gaps **66** and **69** conducting, the entire line voltage is impressed upon the main gaps **67** and **68** which causes them to fire. The gaps **67** and **68** fire simultaneously if resistors **71** and **72** are equal. If resistors **71** and **72** are unequal, as in a preferred embodiment hereof resistor **71** is 1 megohm and resistor **72** is 2 megohms, the gaps **76** and **75** fire in that order. In general, inequality of the grading resistors **71** and **72** equalizes the time constants of the two stages S6 and S7.

The functioning of the apparatus **65** for overvoltages with rapidly rising wave fronts is such that the grading capacitors **75** and **76** impress a substantial proportion of the line voltage across the main gaps **66** and **69** and the associated switching gaps **74** and **77**. Accordingly, these gaps are fired, and the line voltage is then impressed across the main gaps **67** and **68** which are fired to initiate the discharge sequence. The capacitances of the capacitors **75** and **76** may be in the order of 20 times the distributed capacitance, in practical devices, to impress more than 90 percent of the line voltage across the stages S5 and S8. Accordingly, the embodiment of FIG. 5 produces improved sparkover performance for impulse voltages as well as for switching surges.

The capacitors **75** and **76** may be made unequal and/or the grading resistors **71** and **72** may be made unequal to determine a voltage upset and preferential firing order of the stages S6 and S7.

A lightning arrester utilizing the circuit arrangement of FIG. 2 as a gap control and embodying the features of U.S. Patents 2,825,008 and 3,019,367, and features of copending applications 624,275 filed Mar. 20, 1967, and 598,467, filed Dec. 1, 1966, used the following values:

Grading resistors—R**35**, R**39**, R**45**, 15 megohms; R**41**, 0.5 megohm.

Switching resistors and switching gap—G**32**, R**33**, R**34**, 10 megohms.

Switching gap fired—G**36**, R**37**, R**38**, 6 megohms; G**42**, R**43**, R**44**, 1 megohm.

Grading capacitor—C**40**, 100 mmfd.

The apparatus, including spark gaps and magnetic coil, were incorporated in the gap assembly of FIG. 1 and utilized at a nominal operating voltage of 4.5 kilovolts. Tests demonstrated consistent sparkover performance for long duration surges and for impulse voltages.

The arrangement of the above described embodiments, in which the resistance of the series combination of switching gap and two switching resistors, when the switching gap is fired, is less than the resistance of the associated grading resistor, is preferred to arrangements in which the resistance of the switching gap and switching resistors is greater than the resistance of the associated grading resistor.

One advantage of the spark gap arrangements described herein, and particularly of the embodiment of FIG. 5, is that very high values of grading resistances may be utilized for determining the initial voltage distribution between the stages, or may be omitted entirely without affecting the order in which the main gaps are fired. Thus, in one embodiment of the apparatus of FIG. 5, the resistors **70** and **73** were omitted entirely and the remaining components had the following values:

Grading resistors—R**71**, 0.5 megohm; R**72**, 1.0 megohm.

Switching resistors and switching gap—G**74**, 8.5 megohms.

Switching gap fired—G**77**, 4.5 megohms.

Grading capacitors—C**75**, 200 mmfd.; C**76**, 100 mmfd.

Tests demonstrated consistent sparkover characteristics for long duration surges and for impulse voltages. In another embodiment of the apparatus of FIG. 5, the grading resistors R**70** and R**73** are each 15 megohms, and the other components having the same magnitudes.

One feature of the new spark gap apparatus is that a much larger gap electrode spacing may be utilized for a given breakdown voltage while maintaining a consistent sparkover function. Increase in gap spacing reduces the effect of variations in dimensions of the gap electrodes.

The term "time spectrum" is used to refer to the range of rise times or of delay times of the impressed wave of overvoltage or both.

It is to be understood that the foregoing description is not intended to restrict the scope of the invention and that various rearrangements of the parts and modifications of the design may be resorted to. The following claims are directed to combinations of elements which embody the invention or inventions of this application.

I claim:

1. Spark gap and discharge control apparatus comprising a plurality of gap electrodes and grading means therefor, said gap electrodes and grading means constituted as a plurality of stages of parallel connected elements in series connection, stage by stage, each stage comprising two electrodes constituting a main gap, a first resistive grading means in parallel with the main gap, the said first resistive grading means of the said several stages dividing voltages between the stages, and a switching gap and series switching resistor connected in parallel with the main gap, the switching gap of each stage having electrodes positioned adjacent the associated main gap electrodes and communicating with the main gap to constitute a preionizer therefor, the resistance of the series switching resistor and switching gap being unequal in the several stages to constitute a second voltage grading means for preferentially firing the main gap of one of the stages prior to the main gaps of the remaining stages.

2. Spark gap and discharge control apparatus in accordance with claim **1**, in which the resistance of the series switching resistor and switching gap of the said one stage is greater than the resistance of the series switching resistor and switching gap of each of the remaining stages and is less than the resistance of the first resistive grading means of the said one stage, all for predetermining the preferential firing of the main gap of the said one stage independent of firing sequence of the switching gaps.

3. Spark gap and discharge control apparatus in accordance with claim **2**, in which the main gap of the said one stage is critically spaced to predetermine the breakdown voltage thereof, the remaining main gaps being relatively independent of small variations in the spacing of the electrodes thereof.

4. Spark gap and discharge control apparatus comprising a plurality of gap electrodes and grading means therefor, said gap electrodes and grading means constituted as a plurality of stages of parallel connected elements in series connection, stage by stage, each stage comprising two electrodes constituting a main gap, a first resistive grading means in parallel with the main gap in each of the stages, the said first resistive grading means of the said several stages dividing voltages between the stages, a switching gap and series switching resistors connected in parallel with the main gap in at least one of the stages, the switching gap having electrodes positioned adjacent the main gap electrodes and communicating therewith to constitute a preionizer, all for firing the main gap in response to overvoltages having slow wave fronts, and capacitive grading means connected in parallel with the main gap in at least one of the stages for firing the main gaps of the remaining stages in response to overvoltages having fast wave fronts, and all providing predetermined firing sequences of the main gaps for a wide time spectrum of overvoltages.

5. Spark gap and discharge control apparatus in accordance with claim **4**, in which there are four gap stages connected in series and comprising three stages, similar to the described one stage, having switching gap electrodes connected in parallel with the main gap electrodes thereof, and one stage having a capacitor connected in parallel with the main gap thereof.

6. Spark gap and discharge control apparatus in accordance with claim **4**, in which there are four gap stages connected in series and comprising two stages having switching gap electrodes connected in parallel with the main gap electrodes thereof, and two stages having capacitors connected in parallel with the main gap electrodes thereof.

7. Spark gap and discharge control apparatus in accordance with claim **4**, in which there are two stages having switching gaps and switching resistances in parallel with the main gaps thereof and at least one stage having a capacitor connected in parallel with the main gap thereof, and the first-named two stages have equal time constants for control of the main gaps in response to overvoltages having fast wave fronts.

8. Spark gap and discharge control apparatus comprising a plurality of gap plates and a magnetic coil in stacked arrangement and a plurality of gap electrodes and grading means carried by the said gap plates, the said gap electrodes and grading means constituted as a plurality of stages of parallel connected elements in series connection, stage by stage, and in series with the magnetic coil, each stage comprising two electrodes constituting a main gap

having electrodes with divergent arc faces positioned in the field of the magnetic coil, a first resistive grading means in parallel with the main gap, the said first resistive grading means of the several stages dividing voltages between the stages, a switching gap and series switching resistors connected in parallel with the main gap in at least one of the stages for upsetting the voltage division produced by the first grading means, the switching gap having a breakdown voltage less than the breakdown voltage of the main gap and having electrodes positioned adjacent the main gap electrodes and communicating therewith to constitute a preionizer, all for firing the main gap in response to overvoltages having slow wave fronts, and capacitive grading means connected in parallel with the main gap for firing the main gaps of the remaining stages in response to overvoltages having fast wave fronts, and all providing a predetermined firing sequence of the said main gaps and initiating current flow in the magnetic coil.

9. Spark gap and discharge control apparatus in accordance with claim **8**, in which the switching gap electrodes comprise cylindrical members of resistive material constituting the series switching resistors, and means supporting the switching gap electrodes in spaced relation adjacent the electrodes of the main gap.

10. Spark gap and discharge control apparatus in accordance with claim **9**, in which the main gap electrodes are carried by a gap plate, and the means supporting the switching gap electrodes is carried by the gap plate.

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U.S. Cl. X.R.

313—326