A surge arrester for high voltage electric power applications comprises series-connected uncontrolled discharge devices each of which is shunted through resistors by a string of avalanche diodes connected in series opposition, and a capacitor. Connected in series with each uncontrolled discharge device is a controlled discharge device with its igniter electrode coupled to the output of a control unit of the discharge device with the output of a current sensor connected to its input, the input of the current sensor being placed in series with one said string paralleled by the controlled discharge device. In electric apparatus rated for above 100 kV it is expedient to use a surge arrester composed of a string of series-connected uncontrolled discharge devices and two controlled discharge devices.

5 Claims, 3 Drawing Figures
SURGE ARRESTOR FOR HIGH VOLTAGE ELECTRIC POWER APPLICATIONS

This is a continuation of application Ser. No. 255,272, filed on May 22, 1972, which is now aban-
doned.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to electric equipment and, more particularly, to surge arrestors for high-
voltage electric power applications.

One of the key factors which ensure the performance of electric apparatus with an abundant margin of safety is the stability of their operation in the presence of voltage variations in A.C. or D.C. supply mains.

An important factor, in particular, is the maximum voltage that can be safely tolerated by the insulation of apparatus, the magnitude of this voltage being determined either theoretically or experimentally. From this point of view, the insulation strength of industrial electric equipment must be such as to be able to withstand maximum voltages applied thereto. In each concrete case, a selected value of insulation strength is governed by design and economic considerations and also by the probability of maximum excess voltages.

2. Description of Prior Art

Since in actual practice of operating electric installations maximum overvoltages do occur, the electric strength of their insulation is usually designed for voltages somewhat lower than the maximum values, and protection from breakdown under excess voltages which are liable to damage the insulation of a selected electric strength, is achieved by using various surge arrestors which are commonly arranged in parallel with the installation they are intended to protect.

The operating principle of known surge arrestors is that they are actuated as soon as overvoltages applied reach levels which may be dangerous for the insulation of the electric equipment (see, for example, British Patent No. 795,307, class 3911d; U.S. Pat. Nos. 2,611,108, cl. 315–36; 2,818,527, cl. 315–36; 2,492,850, cl. 315–181; 2,659,839, cl. 315–150; 2,611,107, cl. 315–36; Foreign Pat. Nos. 754,646 and 1,056,716, cl. 21c, gr. 72; USSR Inventor's Certificates Nos. 154,921, cl. 21c, gr. 72, and 130,571, cl. 21d, gr. 2.

Surge arresters manufactured in the Soviet Union and abroad are put to performance tests on A.C. and D.C. mains and also on devices for suppressing switching transients, lightning arrestors, etc.

Analyzing the prior art practices in the USSR and other countries, it can be inferred that surge arrestors have to meet clearly conflicting requirements.

On the one hand, design and economic considerations dictate that electric equipment must have a minimum margin of sustaining strength determined by the upper limit at which the surge arrestor operates when overvoltage arises; on the other, the lower limit of surge arrestor operation must be able to ensure reliable performance of the installation without exceeding the permissible frequency of operation of the surge arrestor.

An additional complication is the fact that surge arrestors themselves which are generally a set of spark gaps also require the introduction of certain unpredictable corrections, since their switching voltages may vary within a broad range depending on atmospheric conditions, design features, etc.

All the above considerations have made it imperative to appreciate the increase in switching voltages and the margin of the insulating strength of electric apparatus.

Invariably existing electric apparatus operate in conditions when the margin of their insulating strength is used but very rarely, which factor raises to a considerable extent the operational costs of such apparatus. Therefore, of major practical importance have become semiconductor diodes with an avalanche current-voltage characteristic at reverse voltages which characteristic permits dissipation of a certain portion of electric energy at these diodes. Studies of the applicability of a string of avalanche diodes connected in series opposition for surge suppression have been conducted at the Krzhizhanovsky Power Institute.

The operation of such a protective device is as follows. An external voltage applied to a string of avalanche diodes connected in series opposition is impressed mainly on the avalanche diodes in antiphase to the voltage applied, because a voltage drop across the avalanche diodes connected in phase with the voltage is in this case negligible. As soon as the voltage applied exceeds the sum of voltages determined by the voltage-current characteristics at reverse voltages, current starts flowing in the circuit and its electric power is dissipated mainly at the avalanche diodes on which reverse voltage is impressed.

The duration and magnitude of this surge current must not exceed the permissible power value which is one of the basic parameters of avalanche diodes of this type.

The effect of this protective arrangement lies in that during the entire overvoltage period, voltages of either polarity across a string of avalanche diodes connected in series opposition are not above the sum of voltages at avalanche diodes coupled in antiphase to the voltage applied. The level of voltages imposed on the protected electric installation is thus reduced.

All the above is reported in the transactions of the Krzhizhanovsky Power Institute for 1964–1966.

With a view to suppressing commutation transients in high-voltage thyristor converters, the companies AEG, Siemens, BBC (see B.B.M., 1969, 56, No. 2 "Thyristorstromrichter fur 100 kV Bruckenleichspannung") employed a surge arrestor composed of a string of avalanche diodes connected in series opposition.

In such a series-opposition array of avalanche diodes however commutation overvoltages of both polarities imposed on the controlled-rectifier converter being protected are limited to the sum of reverse voltages at series-connected avalanche diodes.

Besides, a surge protector may itself fail under some severe overvoltages imposed on the electric installation to be protected.

Theoretical and experimental investigations of electromagnetic processes in electric equipment in transient conditions and in the presence of excess voltages carried out by the applicants made feasible a new approach to the development of surge arresters to be described below.

SUMMARY OF THE INVENTION

Switching transients in electric equipment can be dif-
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ferentiated not only by the amplitude as was done in the prior art, but also from the energy point of view. Thus, for example, triggering of electric apparatus or commutation of valves in high-voltage converters may give rise to high-frequency (10^5 - 10^6 Hz) oscillations with the amplitudes reaching high levels even in the presence of damping circuits, while their power is rather low. It has been found possible to limit the amplitude and dissipate the power of such excess voltages, for instance, by avalanche diodes.

Such an approach to the development of surge arresters permits appreciable reduction in the margin of electric insulating strength of high-voltage electric equipment because any transient voltage applied to this equipment will stay below the voltage impressed upon the avalanche diodes.

However, apart from the above high-frequency oscillations, transient voltages may contain also medium-frequency (10^2 - 10^4 Hz) and low-frequency (10^0 - 10^2 Hz) components the energy of which may exceed the power dissipation rating of the voltage limiting device used.

An object of the present invention is to provide a device for suppressing commutation and other overvoltages in high-voltage electric power applications which use avalanche diodes in combination with spark-gap discharge devices.

A specific object of the invention is to provide a means for suppression of surges in electric installations in the frequency range from 10^3 to 10^6 Hz whereby overvoltages applied to the insulating of the electric equipment are reduced to a permissible level without damaging the protective device itself.

In many cases differentiation of transient overvoltages with respect to their energy enables one to substantially cut down the size and costs of the protected electric installation, the frequency of operation of a set of spark gaps remaining unchanged.

The concept presented above has been used for developing a surge arrester for high-voltage controlled-rectifier sections of the Kashira-Moscow D.C. transmission line, resulting in a 25 percent reduction in the voltage ratings of the protected installations and consequent reduction of their size, weight and costs.

The surge arresters designed and manufactured in accordance with these principles have been put to a set of type and performance tests which have fully confirmed the validity of the selected approach. It should be pointed out that the use of such surge arresters in the conditions of the mentioned transmission line would make it possible to bring substantial reduction in the voltage rating of each electric apparatus and consequently to cut down the weight and size of the equipment.

The invention is aimed at providing in a surge arrester including at least one controlled discharge device and at least one voltage limiting string of at least two avalanche diodes connected in series-opposition and provided for limiting voltage thereacross, at least one controlled discharge device governed by a current sensor and connected in series with at least one uncontrollable discharge device, each of the uncontrolled and controlled discharge devices being shunted via a decoupler by said voltage-limiting string placed in parallel with a capacitor, while in series with at least one said string paralleled by said controlled discharge device is connected the input of a current sensor with the output thereof being coupled through the control units to the igniter and working electrodes of said discharge device.

It is advantageous to make the said decoupler in the form of a linear resistor.

It is also advantageous that at least one discharge device be series-connected with a surge current limiter.

It is advantageous to make said surge-current limiter in the form of a non-linear resistor.

It is also advantageous that at least one additional avalanche diode be connected in phase with each avalanche diode of at least with one said string of diodes poled in series opposition.

The present invention will become more clear upon consideration of the following description when taken in conjunction with the accompanying drawings in which concrete specialized terms are used. However, most terms are used in a broader meaning, i.e. each particular term covers all equivalent elements operating in an identical manner and employed for the same purposes as the present invention. Thus, a current sensor may be a current transformer or some other device.

BRIEF DESCRIPTION OF THE DRAWING

Additional objects and advantages of the invention may be better understood from the following description of a preferred embodiment thereof with reference to the accompanying drawings wherein:

FIG. 1 is a circuit diagram of a surge arrester for high-voltage electric power applications composed of uncontrolled discharge devices in series with one controlled discharge device;

FIG. 2 is a circuit diagram of a surge arrester as in FIG. 1, illustrating in detail units 2 and 8;

FIG. 3 is a circuit diagram of a surge arrester for high-voltage electric power applications comprising uncontrolled discharge devices connected in series relation with two controlled discharge devices, with two additional avalanche diodes being placed in series with each avalanche diode connected in series opposition.

DESCRIPTION OF THE PREFERRED INVENTIVE EMBODIMENT

The surge arrester includes series-connected uncontrolled discharge devices 1a-1m (FIG. 1) each of which is paralleled via resistors 2a-2n by a string of avalanche diodes 3a-4a, 3b-4b . . . 3n-4n connected in series opposition, and by a respective of capacitors 5a, 5b . . . 5n. Connected in series relation with the uncontrolled discharge devices is a controlled discharge device 6a shunting a string of avalanche diodes 3n-4n connected in series opposition, an igniter electrode 7 of the controlled discharge device 6a being coupled to the output of a discharge device control unit 8 with its input connected to the output of a current sensor 9, while the input of the current sensor is in series arrangement with the avalanche diodes 3a-4a, 3b-4b . . . 3n-4n.

The current sensor 9 has a secondary which is connected to the input of current integrator 10 of the unit 8 which controls the discharge device 6a (FIG. 2). The surge arrester is connected to an electric installation to be protected via terminals 11' - 11". The current integrator 10 is a rectifier 12 built around diodes 13, 14, 15, 16.
The output of the rectifier 12 is connected across a storage capacitor 17 through a resistor 18. The capacitor 17 is shunted by a resistor 19. The output of the current integrator 10 is coupled to the control electrode of a thyristor 20 via a decoupling diode 21, dynistor or switch-over diode 22 and a limiting resistor 23, and to the cathode of the thyristor 20.

The cathode of the diode 21 and the anode of the dynistor 22 are connected to the cathode of diode 24, while its anode connects a capacitor 25 in shunt with a Zener diode 26, the anode of the diode 24 and the free plate of the capacitor 25 being coupled with the cathode of the thyristor 20, and a D.C. voltage source 27 is placed in parallel with the Zener diode 26.

The thyristor 20 is connected into a circuit composed of a primary 28 of a pulse transformer 29 and a capacitor 30 with a D.C. voltage source 32 connected thereacross through a resistor 31.

A secondary 33 of the pulse transformer 29 is connected to the main electrode 34 and the igniter electrode 7 of the controlled discharge device 6a.

In normal operating conditions, the voltage applied to the installation does not exceed the total reverse voltage at the avalanche diodes of one polarity: 3a - 3n or 4a - 4n (depending on the sign of voltage impressed on the string of diodes), and, consequently, all the diodes of one polarity cannot be simultaneously driven into the avalanche portion of the current-voltage characteristic. Current flowing through the primary winding of the current transformer (current sensor 9) is the leakage current of the avalanche diodes and is insufficient to produce a trigger signal for starting the discharge device 6a in the control unit 8.

In the presence of overvoltages, voltage across the terminals 11' - 11'' rises up to the total reverse voltage at the diodes 3a - 3n or 4a - 4n, where upon all diodes of one polarity are driven into the avalanche portion of the current-voltage characteristic, and as a result, voltage at the terminals 11' - 11'' ceases to grow. Surge current starts flowing through the string of avalanche diodes, the amplitude and duration of which is determined by the electric characteristics of the voltage applied and may be as high as tens and even hundreds of amperes.

The surge arrester is capable of limiting voltage across the terminals 11' - 11'' in the presence of excess voltages until the energy held in the avalanche diodes 3a - 3n or 4a - 4n goes above the permissible value or until the current flowing through the avalanche diodes reaches the breakdown level.

Then, the unit 8 delivers a signal to activate the controlled discharge device 6a upon operation of which the uncontrolled discharge devices 1a - 1m operate and voltage from the terminals 11' - 11'' is removed.

Since after the avalanche diodes begin to operate in the avalanche portion of the current-voltage characteristic, voltage across the terminals 11' - 11'' can be considered constant in the first approximation, the energy stored in the avalanche diodes will be proportional to the integral of current flowing through these diodes.

The unit 8 performs periodic comparison of the energy stored in the strings of avalanche diodes with the permissible value. In FIG. 2 the member responsible for such a comparison is the element 10 which integrates current passing via the strings of avalanche diodes by way of the storage capacitor 17 charged through the bridge rectifier 12 employing diodes 13 - 16. The capacitor 17 is charged by current passing through the strings of avalanche diodes and the current from the secondary winding of the current transformer (current sensor 9) delivered to the input of the integrator 10.

Voltage across the capacitor 17 is proportional to the energy in the strings of avalanche diodes. The set-point voltage is the switching voltage of the dynistor 22. As soon as voltages across the capacitor 17 and resistor 18 become equal to the switching voltage of the dynistor 22, the dynistor starts to conduct and builds up a discharge path for an additional capacitor 25 that has been charged from the source 27. The capacitors 17 and 25 have decoupling diodes 21 and 24 connected therebetween. Voltage across the capacitor 25 is regulated by means of the Zener diode 26 and its magnitude is substantially smaller than the switching voltage of the dynistor 22. When discharging, the capacitor 25 forms a pulse which goes via the decoupling diode 21 and the limiting resistor 23 to turn on the thyristor 20. Triggering of the thyristor 20 to conduction causes discharge of the capacitor 30 that has been charged from the source 32 through the resistor 31. The capacitor 30 discharges through the primary winding 28 of the step-up pulse transformer 29 with its secondary 33 connected to the igniter electrode 7 and the working electrode 34 of the discharge device 6a.

The control unit 8 is set so that the dynistor 22 switches over either in the case of maximum permissible power at the strings of avalanche diodes, or if current flowing through the avalanche diodes exceeds a predetermined level at least for some short time (current cut-off) which also prevents the breakdown of the avalanche diodes by overcurrents.

The resistor 18 of the integrator 10 serves for setting cut-off current and the resistor 19 accomplishes periodic discharge of the capacitor 17.

If, under excessive voltage applied, the power dissipated in the strings of avalanche diodes remains below the permissible level and the current does not exceed the current cut-off value, the discharge device 6a is not actuated. Then the surge arrester affords its protective action only by limiting overvoltage across the terminals 11' - 11'' of the protected installation to the permissible value of the total reverse voltage at the avalanche diodes. If, on the other hand, the overvoltage energy is larger than the permissible power dissipated by the strings of avalanche diodes, the control unit 8 sends a trigger signal to the discharge device 6a. In this event the operation of the controlled discharge device is the proper action of the surge arrester.

The surge arrester described above (FIGS. 1 and 2) can be recommended for use in electric installations rated for about 100 kV, irrespective of the polarity of peak voltages.

In order to provide overvoltage suppression in installations carrying voltages above 100 kV, it is most advantageous to use a surge arrester comprising two serially connected uncontrolled discharge devices 1a and two controlled discharge devices 6a and 6b (FIG. 3).

Connected in series with each of the uncontrolled discharge devices 1a - 1m and controlled discharge devices 6a and 6b are surge current limiting elements 35a - 35n (FIG. 3). Connection of the elements 35a - 35n in series with each discharge device 1a - 1m and 6a - 6b is chosen for design reasons. If necessary, all the ele-
ments 35a - 35n can be serially connected in common to any of the discharge devices 1a - 1m or 6a - 6b. Each of the avalanche diodes 3a - 3n and 4a - 4n coupled in series opposition is connected in series with two additional avalanche diodes 3’a - 3’n, 3’n’ and 4’a, 4’n’a - 4’n, 4’n’.

Control of the controlled discharge devices 6a and 6b is accomplished by units 8a and 8b identical to those described above.

As more severe overvoltages must be expected in electric installations rated for above 100 kV it is advisable to increase the permissible dissipation power at the avalanche diodes of the surge suppressor which is achieved by connecting additional avalanche diodes 3’a, 3’n’a - 3’n, 3’n’ and 4’a, 4’n’a - 4’n, 4’n’.

Besides, the actuation of all the surge suppressors in such high-voltage installations causes the appearance of large short-circuit currents which would damage the equipment (e.g. surge suppressors, transformers and the like). The surge current limiters 35a - 35n are included in the circuitry with a view to reducing such short-circuit currents.

Finally, in order to increase the operation reliability of uncontrolled discharge devices in the event of the terminals 11’ - 11” carrying voltages above 100 kV, voltage across each of the discharge devices must be substantially raised. This is accomplished through using a larger number of controlled discharge devices operating in the presence of severe overvoltages.

What is claimed is:

1. A surge arrester for protecting apparatus in high-voltage electric power applications, comprising: at least one string of at least two avalanche diodes connected in series opposition, said at least one string serving for limiting voltage across the electric apparatus being protected;

2. A surge arrester as of claim 1, wherein said decoupler comprises a resistor.

3. A surge arrester as of claim 2, further comprising a surge current limiter connected in series with at least one said discharge device.

4. A surge arrester as of claim 3, wherein said surge current limiter comprises a nonlinear resistor.

5. A surge arrester for high-voltage electric power applications as of claim 4, further comprising at least one additional avalanche diode connected in series aiding with each of the avalanche diodes connected in series opposition, said additional avalanche diodes serving to increase permissible power dissipation in a string of avalanche diodes connected in series opposition.

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