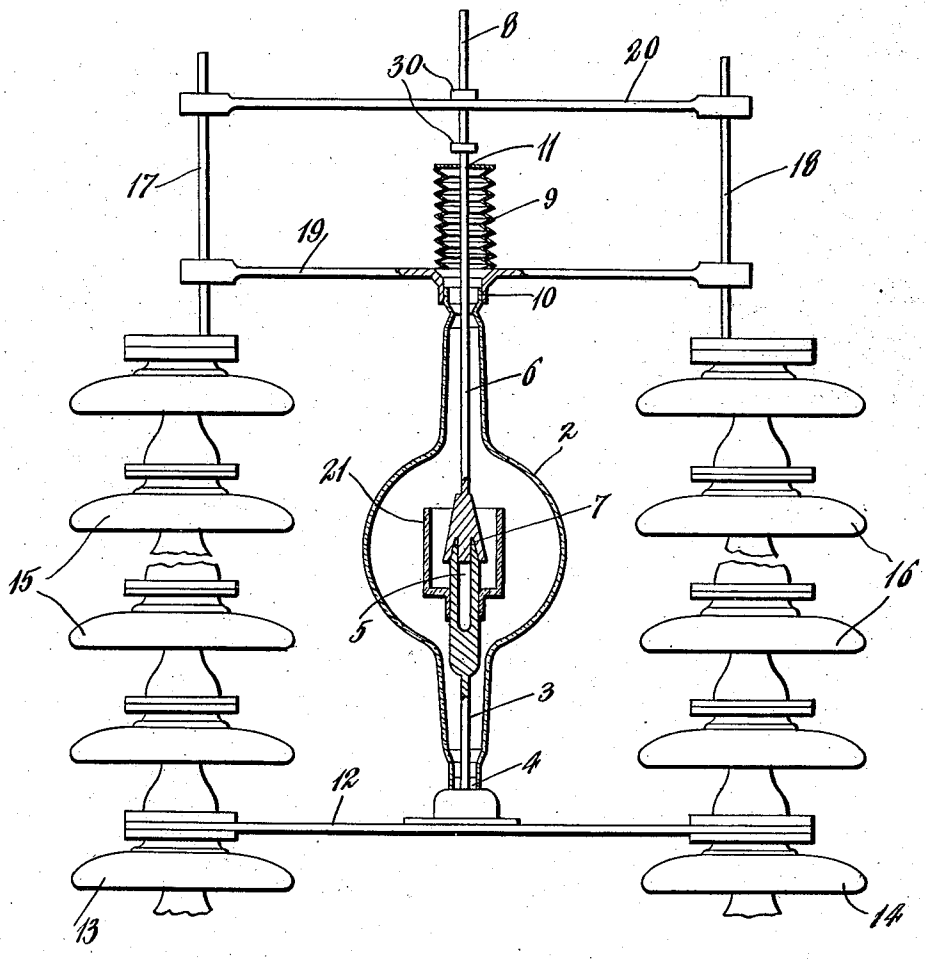
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ALTERNATING POWER CURRENT INTERRUPTER

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ALTERNATING-POWER-CURRENT INTERRUPTER

Application filed September 5, 1928. Serial No. 304,158.

The object of our invention is the production of a new and improved switch or current interrupter for high power electric circuits which will break an alternating current without the production of an alternating current arc.

Another important object of our invention is to provide a device which will break an alternating power current in such a way as to avoid the high voltage surges common to air and oil circuit breakers.

Another object of our invention is to provide a means of interrupting alternating power currents more economically and with greater safety than by the means heretofore employed for that purpose.

Our invention is based upon the adaptation of certain fundamental discoveries that we have made as to the phenomena of the electric arc, except for which the production of a practical vacuum circuit breaker would be entirely a matter of chance and conjecture contrary to previous accepted electrical theory. To apply the new phenomena that we have discovered to the production of a device of the character desired, we have found it necessary to practice deep out-gassing of a character different from the methods of out-gassing and electrode conditioning heretofore employed in the art.

This application is a continuation in part of our applications having Serial Numbers 714,545; 148,418; and 199,580, filed May 20, 1924; November 15, 1926; and June 17, 1927, respectively.

In the transmission and distribution of electric power it is necessary to use circuit breakers or switches which will open electric circuits while current is flowing. In electric power systems using alternating current it has been the practice during recent years to use almost exclusively devices known to the trade as oil switches or oil circuit breakers for this work. These breakers, while the best obtainable for the purpose, have the disadvantages of oil leaks, oil fires, explosions, damaged parts such as burned contacts under extreme overload interruption, and high cost of manufacture and maintenance. To eliminate these difficulties many other types of switches have been tried both for circuit breakers and disconnect switches. Each type so used has been designated by the kind of service for which it is to be used and by the switch or circuit breaker ambient, as for example an "oil circuit-breaker", or an "air-break disconnect switch".

A type of circuit breaker or switch which has been heretofore suggested is one in which the ambient is a high vacuum. Such a switch, if practicable, would eliminate many of the disadvantages stated above. But previous to our discoveries and inventions disclosed below, no knowledge has been available as to what potentials can be supported by a vacuum disconnect switch, nor as to whether a vacuum switch could be made to operate practicably as a current breaker at all, nor as to what steps might be necessary to make it so operate.

Previous to our discoveries and invention, due to lack of all knowledge of the characteristics of arcs in vacuum, or as to the very existence of discharges in vacuum due to potential gradients alone, or as to methods of producing "deep" outgassing and electrode-conditioning, inventors and experimenters have been limited in the use of high vacuum as a switch ambient to disconnect switches of completely unknown high voltage characteristics and to mere conjecture as to the possibilities of making a power circuit breaker operate at all in vacuum.

The use of a high vacuum ambient for a disconnect switch differs from our use in that a vacuum disconnect switch involves no knowledge of high vacuum technique other than the common knowledge that a high vacuum is a good insulator, and a knowledge of the usual methods of removing gases from the surface or from close to the surface of electrodes. It has long been known that such a disconnect switch, if properly designed and constructed, would when open, prevent voltages not too high from breaking down the vacuum space between the electrodes. It might even operate to break a small charging current to a capacitor or to an unloaded section of line. But, without the application of discoveries and inventions herein disclosed,

it could not serve as a means of breaking or interrupting a flow of current at distribution or transmission voltages and energies in electric power systems.

A device employing a high vacuum ambient adapted to the interrupting of such current flow, particularly in high voltage power alternating systems, has been greatly desired by users of electric power. As a result of our discoveries we have made possible a high vacuum current interrupting switch or circuit breaker which before our work was considered by both physicists and engineers as impossible.

Our first discovery is that sufficiently high electrical fields alone can cause a current to pass through the highest vacuum (we have named such currents "field currents").

Our second discovery is that of the voltage necessary for, and the laws governing such "field currents".

Our third discovery is that separating, in the highest vacuum, metallic electrodes through which alternating current is passing, will produce an ordinary alternating current arc, even when the electrodes have been subjected to all previously known methods of outgassing such as baking at high temperatures, heating by induction furnace methods, or by electron bombardment.

Our fourth discovery is that it is possible by deep outgassing to so condition electrodes that an alternating current arc does not form when current carrying electrodes are separated in a high vacuum. One such process consists of striking an ordinary alternating current arc at suitable voltages by opening the contacts carrying alternating current, permitting the arc to continue for some time, stopping the arc by removing the source of current, and repeating this operation at increasing voltages until the alternating current arc will no longer form, the evolved gases being removed very completely during this process. The electrodes are thus "conditioned" and can be used successfully for switching at voltages at least as high as the highest used in conditioning the electrodes.

Our fifth discovery is that after the electrodes have been suitably conditioned, for example as above, so that when separated they do not permit of the formation of an ordinary alternating current arc, they do permit the formation of a new kind of arc described as follows:

As the electrodes begin to separate, but are still only infinitesimally removed from contact, the strong electric field existing between them pulls out of the cathode, a large pure electron "field current", the energy of which in traversing the gap releases therein vapors of the electrode material. The positive ions due to these vapors transform the pure electron current into a low voltage constant potential arc (approximately 20 volts for copper electrodes), which maintains the current in practically unchanged wave form until it approaches or passes through its next zero value.

Our sixth discovery is that the carriers are only free electrons and vapors of refractory metals, and they disappear so rapidly, in the case of commercial frequencies, that the arc cannot reform during the next half cycle. This new form of arc which disappears at the first passage of the current through the zero value, we have named "fractional cycle arc" to distinguish it sharply from the "ordinary alternating current arc" heretofore known.

Our seventh discovery is that in view of the formation of the above mentioned field currents and the formation of a fractional cycle arc the current is stopped by the opening of our vacuum switch without the production of destructive high potential surges that would necessarily arise if the current stopped suddenly as the switch contacts separate.

Our eighth discovery is that when the electrodes have been suitably conditioned and seasoned by repeated switching, it is no longer necessary to maintain an extremely high vacuum, such conditioned switches having been continuously operated by us at pressures greater than 10^{-4} mm. of mercury.

Our ninth discovery is that when the interrupter has been thoroughly conditioned, the further operation of the switch results in a "getter" action which continues to reduce the pressure within the interrupter. The metallic vapors which are formed during the fractional cycle arc disappear as the current approaches zero and gather with them molecules of gas which they hold and carry to the walls of the apparatus or shield thereof, reducing the gas pressure within the interrupter. This holding of gas molecules to the walls of the interrupter compensates, for any further release of occluded gases, if any takes place, and permits continuous use of the interrupter without the necessity of further pumping, provided the container is vacuum tight.

Our tenth discovery is that when the interrupter has been conditioned and becomes an operating interrupter, the deep outgassing becomes more complete with each switch operation, thus automatically improving the operation of the switch as its use continues. This continued use is frequently equivalent to conditioning at a higher voltage.

Various further objects and advantages and discoveries of the present invention will be understood from a description of an example of a preferred switch embodying the invention.

For this purpose, we have illustrated a switch embodying the present invention, such

switch is shown in the accompanying drawing, in which

The figure discloses the switch in elevation and partially in vertical section.

Referring to the drawing, the switch comprises a chamber or housing 2 of insulating material, such as glass. The housing may have an enlarged central portion and reduced necks of substantial length, extending from said body portions in opposite directions, a sufficient distance to prevent a potential applied to the switch from arcing over around the housing.

3 indicates a fixed contact sealed at one end 4, to the lower neck of the housing 2 and extending into the center of the housing. The inner end of the fixed contact is indicated as cored out at 5 to assist in centering the fixed and moving contacts of the switch and secure adequate contact. 6 indicates a moving contact for the switch adapted to make contact with the fixed contact 3, when the switch is closed. Said moving contact 6 has an annular recess 7 at its inner end for engaging the annular end of the stationary contact.

The moving contact 6 is indicated as connected with a rod 8, which extends without the housing 2 so that the upper end may be connected with a mechanical mechanism (not shown) by which the switch may be operated.

To connect the switching circuit, one conductor is attached to the end of the rod 3 which extends through the housing 2 and another conductor is attached to the rod 8 without the housing 2. The rod 8 of the moving contact is likewise sealed to the housing of the switch. In order to accomplish this, while still permitting the rod 8 to be moved for opening and closing the switch, the housing 2 includes a bellows 9 enclosing the rod 8, or is otherwise formed with its neck of flexible material. One end of said bellows 9 is sealed to the glass portion of the housing, as indicated at 10 and the other end of the bellows 9 is sealed with a rod 8, as indicated at 11.

For mounting the switch, the switch is indicated as mounted at its lower end on the conductor bar 12, which it is understood, is connected with the rod 3. Bar 12 is indicated as mounted upon insulators 13 and 14. Above the bar 12, at each end, there is a plurality of further insulators 15 and 16, the respective ends of which mount vertical guide bars or standards 17 and 18. Said guide bars mount a bar 19 engaging the switch housing 2 and holding the same in vertical position and also a bar 20 slidably secured to the rod 8 for guiding said rod in its vertical motion. 30 indicates stops on the rod 8 to limit the motion of said rod, thereby preventing excessive strains being placed on the bellows 9.

Secured to one of the contacts, or otherwise mounted within the vessel or chamber, is provided a shield 21 indicated as surrounding the contacts or electrodes and spaced between the contacts or electrodes and the chamber walls. Said shield 21 prevents the metallic or refractory vapors or ions thrown off from the contacts or formed between the contact in opening the switch from being deposited upon the walls of the chamber 2. A shield 21 thus prevents said walls being covered with metal and rendered conductive to electric currents.

In constructing the switch and in conditioning the switch for the operation of interrupting power transmitting or distribution circuits, the chamber formed by the housing 2 must be evacuated to very low pressure. Preferably, this evacuation is as thorough as possible. It has been found, however, in accordance with the principles of the present invention, that the highest obtainable vacuums are not strictly necessary to the operation of the present switch.

In construction of the switch, it is understood that a suitable vacuum pump is connected with the housing 2. This pump connection is not shown, inasmuch as the switch is sometimes operated sealed off from the pump after conditioning of the switch, as herein described. It is possible, however, to leave the pump connected to the switch, even during the practical use of the switch.

The pressure within the chamber of the switch must be reduced to provide around the electrodes of the switch, an ambient which contains insufficient gas ions to themselves establish an arc when the electrodes of the switch are interrupted to break the power circuit.

The evacuation is preferably first conducted so that the pressure within the vessel is reduced to 10^{-6} mm. of mercury. However, after full conditioning of the switch for operation, higher pressures may be permitted within the housing, such, for example, as 10^{-4} mm. of mercury.

After securing the desired vacuum within the switch, the switch must then be conditioned for operation in interrupting the current of the power circuit. The operations of conditioning the switch for interrupting the power circuit will depend somewhat upon the difficulty of getting deeply occluded gases out of the particular material used to form the electrodes, and also upon the potential across which the switch is to operate and the current which the switch is to interrupt. The electrodes of the switch may be formed of various materials, such as, carbon, aluminum, copper, tungsten, or iron, but we prefer to employ copper or aluminum electrodes.

One example of a process of conditioning

a switch for operation in interrupting power circuits is as follows:

Assuming that the switch is to interrupt power circuits carrying 15,000 volts at 50 to 15,000 amperes, the switch is first connected in a line and a suitable load, such as 50 or 100 amperes is passed through the switch, (the voltage of the circuit being preferably about 15,000 volts) and the switch is closed. As soon as the load is established the switch is opened and an arc struck between the electrodes which operates to expel easily ionized material, including occluded gases from the electrodes. The established arc is permitted to endure for a period of a few seconds, or until such time as there is danger of injury to the switch. The arc is then extinguished, either by interrupting the current by other means, or by closing the switch. This operation is repeated and the gases driven from the electrodes are removed from the space within the housing of the switch. The gases are removed from the housing of the switch preferably between operations of establishing the arc, in order to avoid danger of grounding the switch through the pump.

The operations of establishing and extinguishing the arc are repeated until it is found that upon opening the electrodes of the switch, an alternating current arc will no longer be established.

Under the conditions described in this example of the invention, we have ordinarily found that it requires about 180 to 200 openings of the switch to effect this result.

The switch thus conditioned, will operate satisfactorily for interrupting currents at 15,000 volts potential, including currents up to 15,000 amperes. It may also operate satisfactorily for interrupting currents at somewhat higher voltages. For interrupting currents of materially higher voltages it is, however, necessary to conduct the arcing treatment of the switch at substantially higher voltages, preferably at a voltage as high as the voltage of the circuit on which the switch is to be used.

If the switch is to be subjected to extremely high voltages, the conditioning treatment, in order to avoid danger from excessive arcing, is preferably conducted by arcing the switch at successively higher voltages, the switch being processed at the successively higher voltages until at each voltage, the outgassing treatment has proceeded sufficiently so that the switch will not arc at that voltage. Following this line of treatment, we have been able to interrupt 2000 to 3000 amperes of current at 90,000 volts.

In certain cases it may be preferable to process the switch and electrodes thereof by other or ordinary outgassing processes, before subjecting the switch to the arcing method of driving out the occluded gases.

As an example of such treatment, we have found that by subjecting a switch to outgassing treatment, such as by baking the switch in an oven at a temperature of about 400° C., or as high as the glass will stand, for appreciable periods, and then placing the switch in a high powered line and further outgassing by the arcing method, the outgassing treatment by the arcing method can be considerably reduced.

In any case, it is necessary, before using the switch of the present invention for interrupting power circuits, to condition the switch by the general procedure before described, or its equivalent, to remove those deeply occluded gases or other materials which ordinary methods of outgassing vacuum apparatus apparently do not remove.

If ordinary methods of outgassing the switch only are employed, occasional successful operations of the switch may occur at 1500 to 3000 volts, although frequent failures will also be observed. At 15,000 volts, if the switch is subjected only to ordinary outgassing methods, an opening of the switch without the formation of a persistent arc is unusual. At higher voltages, such as 50,000 volts, a switch conditioned only by ordinary outgassing methods, cannot be opened without the formation of an alternating current arc and failure to open the circuit.

In the operation of the switch of the present invention on high powered lines after it has been conditioned in accordance with the present invention, there is still the formation of what is termed herein a "fractional or partial cycle arc" on separation of the electrodes. In the separation of the electrodes, even under perfect vacuum and with a complete removal of occluded gases, there is a formation of an electric discharge at the instant of separation, due to the pulling of a pure electron "field current" from the electrodes. The electrode surfaces are never absolutely flat and when the electrodes separate, there is always a last infinitesimal point of separation. At the instant of separation, there is concentrated upon this infinitesimal point for an infinitesimal distance of separation, the entire voltage between the contacts. This voltage is sufficient to cause electrons to be directly pulled from the electrodes. The effect of this action causes a vaporization of a small amount of electrode material which enters the field between the electrodes and maintains a current discharge therebetween, until the current of the power line passes through the balance of the cycle and reaches the zero value. If during this operation there are any occluded gases, even deeply buried in the electrodes, which can be drawn into the electric field, the arc will be maintained as an alternating current arc as the current passes through the zero value. When, however, the switch has been processed in accord-

ance with the present invention, there exists only ions or vapors of the electrode material in the electric field and these vapors disappear from the field so rapidly that there is not present in the field sufficient material to re-establish the arc.

The action of the switch of the present invention, in establishing a partial cycle arc, for the remainder of the cycle, when opened, is of great benefit to the switch, in that it prevents the current from being interrupted at a high instantaneous value, which would cause a potential surge to be placed on the line, that would be ruinous to various electrical appliances connected therewith.

Moreover, the particular character of the electrical discharge or arc which exists when a switch of the present invention is opened, is of special value in that the arc is maintained at a low voltage drop and with a low energy loss. Arcs established when ordinary switches are opened, for example, oil type switches, have an arc voltage drop of around 200 volts; whereas, with the switch of the present invention, the partial cycle arc has a voltage drop of about 20 volts or less. The fact that the arc developed possesses a low voltage drop is an additional factor which permits the switch of the present invention to be employed without developing high potential surges on the power transmission line.

Another characteristic of the interrupter of the present invention which is of value is that the vapors of metals which are freed from the electrodes during the fractional cycle arc when the electrodes are opened to interrupt a power circuit, are capable of acting as "getters". Thus, there is present in the switch, a means dependent only upon operation of the switch, for removing gas molecules so that further pumping is not necessary and so that any increase of gas pressure either from further removal of gases from the electrodes, if any takes place, or from passage of gas through the vessel walls, is compensated for.

While the particular form of a power interrupter as herein described, is well adapted for carrying out the objects of the present invention, it is understood that various modifications and changes may be made without departing from the principles of the invention, and this invention includes all such modifications and changes as come within the scope of the following claims.

We claim:

1. A power circuit interrupter comprising electrodes relatively movable to open and close a power circuit, a vacuum ambient for said electrodes containing insufficient gas to establish an arc when the electrodes are separated, the electrodes being sufficiently free of occluded gases as to have the capacity of producing a fractional cycle arc only, when the electrodes are separated while carrying a power current.

2. A power circuit interrupter, comprising electrodes and a vacuum ambient for said electrodes containing insufficient gas to establish an arc when the electrodes are separated, the electrodes being sufficiently free of occluded gases so that the opening of the switch while carrying the power current produces a fractional cycle arc only and the electrode vapors formed thereby operate as "getters" removing from the ambient of the interrupter any gas molecules which are expelled by the operation.

3. A power circuit interrupter comprising electrodes and a vacuum ambient for the electrodes with insufficient gas to establish an alternating current arc between separated electrodes, the electrodes being sufficiently free of occluded gases so that they have the capacity when interrupting a power circuit of establishing an arc, the carriers for which are electrons and vapors of the metallic electrode material, resulting in a fractional cycle arc possessing a low energy loss and containing only vapors which will drop out of the circuit as the energy approaches the zero value.

4. A switch for interrupting power circuits which comprises separable electrodes which have been deprived of gas and gas-forming material to such a degree that there is in operation of the switch a low energy loss by reason of the low potential drop across the arc between the separating electrodes, the electrodes having the capacity of establishing a fractional cycle arc only when separated while carrying a power current.

5. A switch for interrupting power circuits with relatively low energy in the arc, which comprises separable electrodes, a vacuum ambient for the electrodes possessing insufficient gas to itself establish an arc when the electrodes are separated, the electrodes being of such metal and sufficiently free of occluded gases as to establish on separating, while carrying a power current, a fractional cycle arc sustained by free electrons and vapors of the electrode metal and possessing a low energy loss, the electrons and vapors of the electrode metal being capable of disappearing from the arc field sufficiently rapidly so that when the current approaches the next zero value after separation of the electrodes, the arc is extinguished.

6. An electrical current interrupting switch for interrupting the current of transmission or distribution lines, which comprises electrodes, means for separating the electrodes, and a vacuum ambient for said electrodes containing insufficient gas to establish an alternating current arc while the electrodes are separating, the electrodes being of such metal and sufficiently free of occluded gases, that the surge of energy during separation of the

electrodes is incapable of drawing ions into the field therebetween, except those ions which drop from the field when the current approaches the next zero value.

7. An electrical current interrupting switch or circuit breaker for interrupting the power circuit of transmission or distribution lines, which comprises electrodes and a vacuum ambient with insufficient gas therein for the establishment of an alternating current arc between the separating electrodes, the electrodes being denuded of gas-evolving material to such an extent that the resulting arc is characteristic of free electrons and vapors of electrode material only when the electrodes are separating, and establish an arc for a fractional cycle only.

8. A switch for breaking circuits carrying high power which comprises a housing, electrodes within the housing operative to carry large currents, means for opening the electrodes while the current is flowing therethrough, the vacuum of the housing being so denuded that there are insufficient ions to sustain an arc, the switch being deprived of occluded gases to such an extent that the surge of energy during separation of the electrodes is not capable of drawing occluded gases from the contacts for establishing a gaseous field sufficient to maintain an arc between the contacts, whereby in operation an electrical discharge is developed between the contacts only while the current is passing to the next point of zero value.

9. A switch for breaking high power circuits, comprising, a housing, electrodes within the housing and operative to carry large currents, and means for opening the electrodes while the current is flowing therethrough, the vacuum of the housing being so denuded that there are insufficient ions to sustain an arc, the electrodes of the switch being sufficiently free of occluded gases which the power between the electrodes would be capable of drawing therefrom at the time of separation, so that in operation an electrical discharge is developed between the electrodes by vapors of the electrodes themselves which disappear when the current passes to the next point of zero value and a fractional cycle arc only is developed.

10. An electric current interrupting switch or circuit breaker for interrupting the power current of transmission or distribution lines, which comprises electrodes and a vacuum ambient with insufficient gas therein for establishment of an alternating current arc between the separating electrodes, said electrodes being denuded of gas evolving material to such an extent whereby an arc can be maintained for a fractional cycle only.

Signed at Los Angeles, California, this 29th day of Aug., 1928.

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