

[54] **IMPEDANCE-INCREASING SYSTEM AND IN-LINE DEVICE THEREFOR**

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[58] Field of Search 317/11 R, 11 C, 58, 16; 335/72, 68, 74, 71, 75, 6, 16; 200/61.39

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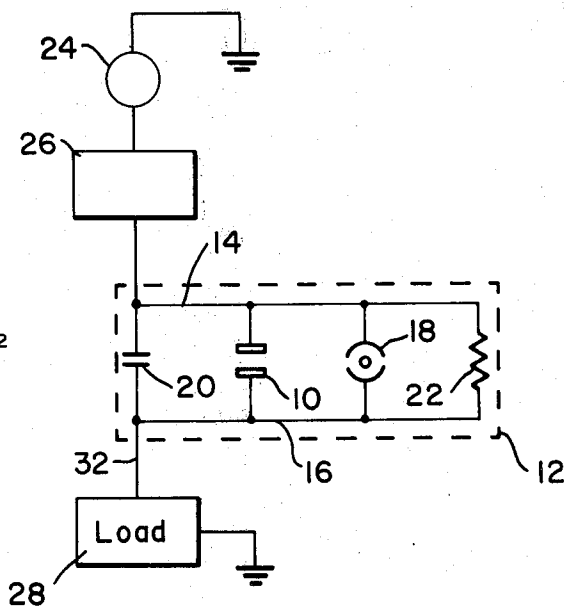
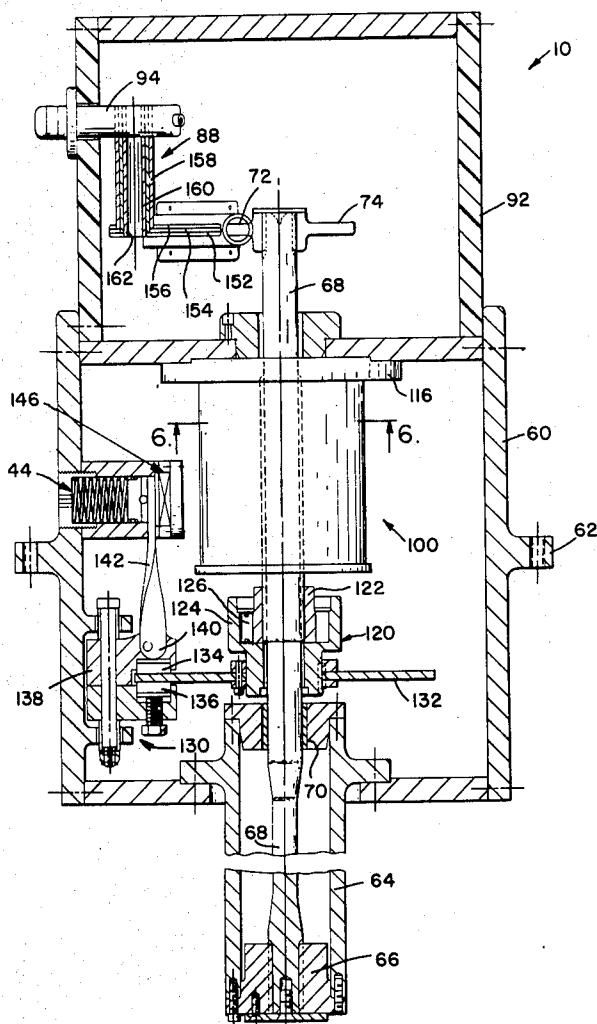
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[57] ABSTRACT

Rotating shaft carries contact arms which are stressed into the switch closed position where they are in contact with two stationary contact fingers by the torque of a stressed torsion bar. An electrodynamic drive motor additionally stressed the torsion bar to rotate the contacts on the contact shaft away from the stationary contact fingers. The contacts are held in the open position by a one-way clutch and disc brake. Release of the disc brake permits the torsion bar to return the rotating contact shaft bar to the switch closed position.

28 Claims, 7 Drawing Figures



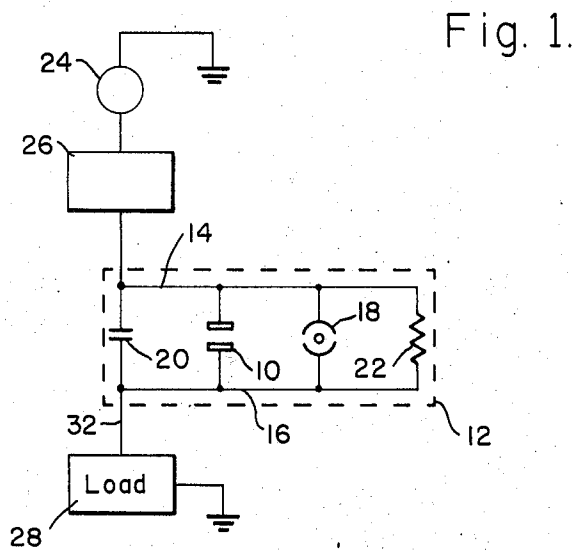


Fig. 2.

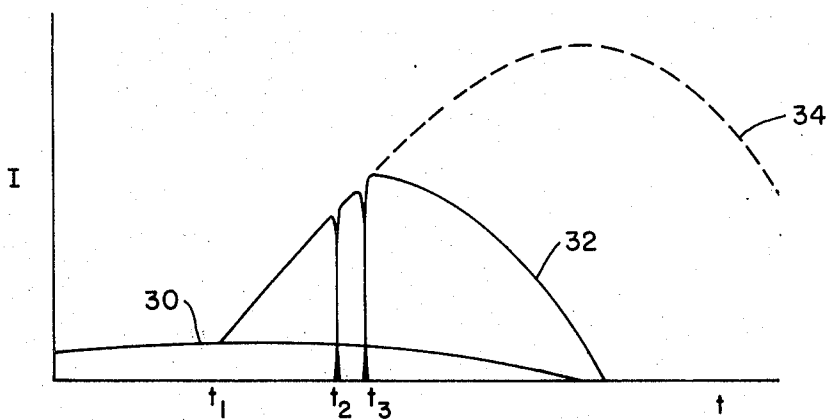


Fig. 3.

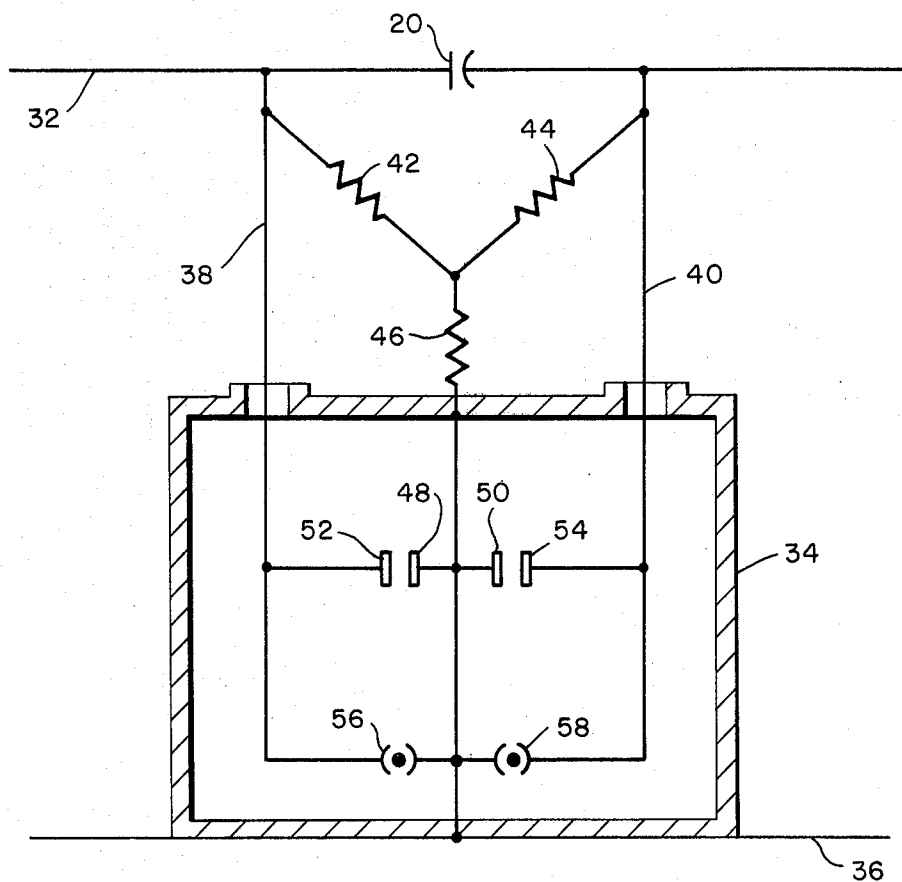


Fig. 4.

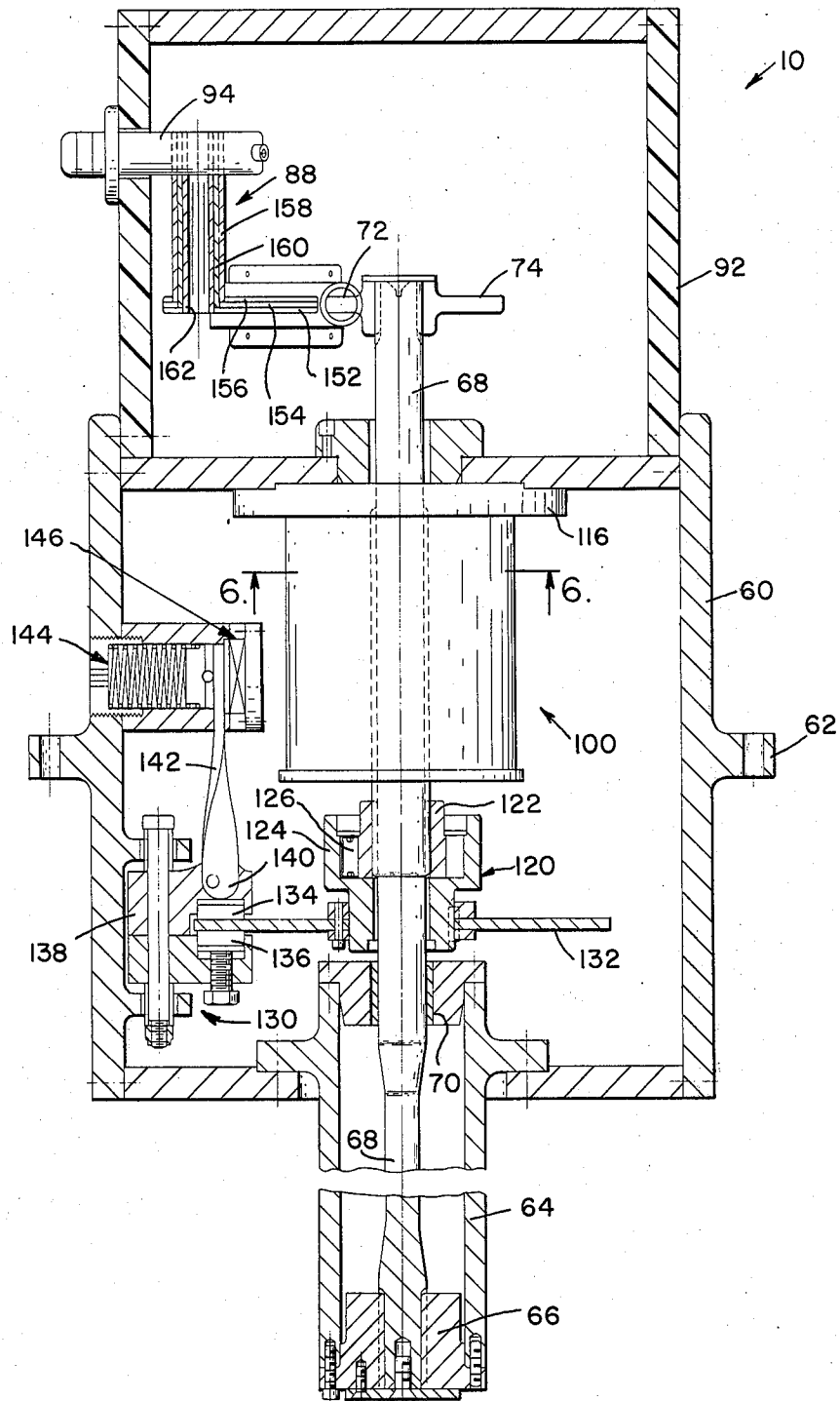


Fig. 6.

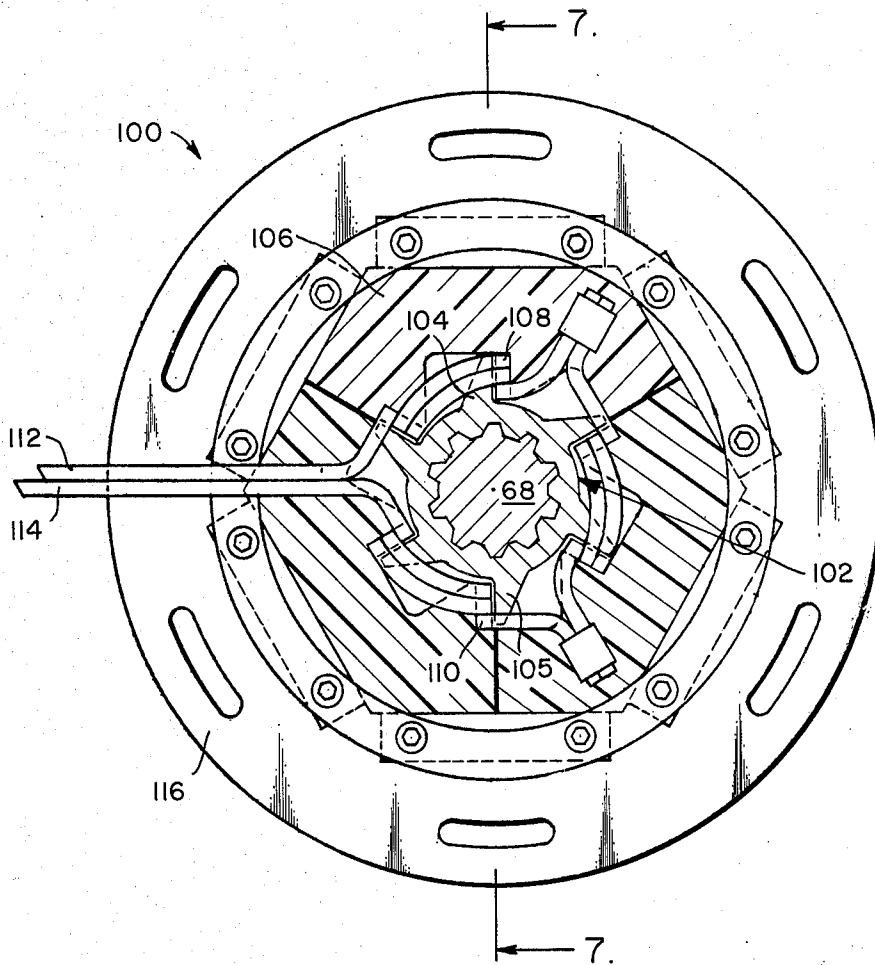
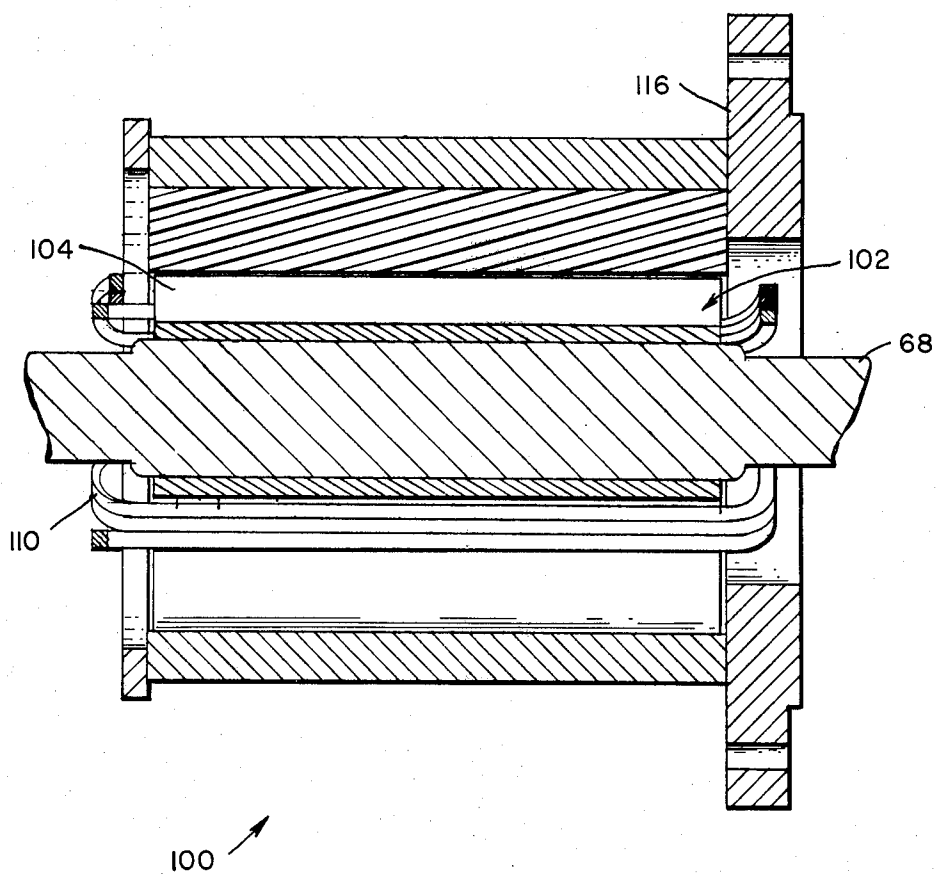


Fig. 7.



IMPEDANCE-INCREASING SYSTEM AND IN-LINE DEVICE THEREFOR

BACKGROUND OF THE INVENTION

This invention is directed to a fast opening and in-line rotary fast closing device.

In some electric utility systems, the short circuit current capability has steadily grown to the point that existing station equipment, in particular circuit breakers, is marginal or inadequate in its fault current ratings. The cause of this trend is primarily the continuing increase in power consumption per unit area. However, the problem is compounded by the requirements of system security which have prompted stiff ties to neighboring systems and multiple parallel transmission lines within each system. The growth in short circuit capability may occur at a geometric rate. This factor combined with increased installation costs and lengthened lead times for procurement of new equipment argue strongly for current limiting devices as an alternative to the historic approach of replacement and upgrading of breakers as their ratings are surpassed.

Various devices have been utilized to limit fault current. These include resonant L-C links, saturable reactors and at low voltages, static breakers using force-commutated thyristors. The above devices have individual advantages and disadvantages, but all share in common the disadvantage of significant power losses while operating with normal load. In addition, the schemes utilizing reactive elements tend to be quite bulky and introduce to the system additional problems from transient overvoltages or harmonic currents.

The insertion during the fault of a resistive element in series with a bus or feeder has certain attractive advantages, but requires rapid response and sophisticated sensing and control. In order to be effective, the device should be capable of inserting the current limiting resistor into the transmission line within about 1 millisecond of the occurrence of the fault. Further, owing to the extensive interconnection common within many systems, operation at transmission voltages, 138 kV and higher, is desirable.

SUMMARY OF THE INVENTION

In order to aid in the understanding of this invention, it can be stated in essentially summary form that it is directed to an in-line switching device comprised of rotary contacts which are torque urged to the closed position, drive motor for driving the contacts open, holding means for retaining the contacts in the open position, and releasable means for permitting reclosing the contacts.

It is thus an object of this invention to provide a high speed, high current switch which serves to mechanically open the normal current path in an electric system. It is a further object to provide an in-line switching device which is capable when closed of conducting high currents with low impedance and yet is capable of quickly mechanically opening the current path. It is another object of this invention to provide an interruptor for a current-limiting and/or circuit breaker system at multimegawatt levels.

Other objects and advantages of this invention will become apparent from the study of the following portion of the specification, the claims and the attached drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic circuit diagram of an AC current-limiting circuit.

FIG. 2 is a graph of current versus time showing the effect of the AC current limiter of this invention.

FIG. 3 is a further detailed schematic circuit diagram of an AC current-limiting circuit which employs the in-line switching device of this invention.

FIG. 4 is a longitudinal section through the in-line switch device of this invention.

FIG. 5 is a transverse section through the switch device showing the contacts, taken generally along the line 5—5 of FIG. 4.

FIG. 6 is another transverse section of the device, taken generally along the line 6—6 of FIG. 4, showing the contact opening motor.

FIG. 7 is a longitudinal section taken generally along the line 7—7 of FIG. 6, further showing the electrodynamic motor.

DESCRIPTION

The in-line switch device of this invention is generally indicated at 10. FIG. 1 illustrates a current limiter circuit 12 for the insertion of impedance 22 into a circuit, particularly an alternating current circuit, to limit fault current. The impedance value is sufficient so that, once the resistor impedance is inserted, the subsequent current level is quite modest permitting the fault to be cleared at a current well within the capability of the conventional station circuit breakers 26. Until recent developments including the in-line switching device 10 of this invention, devices were not available which were capable of both rapid response and operation at sufficiently high voltage and current to make current-limiting by resistor insertion practical in transmission line applications.

Current limiter circuit 12 comprises three major circuit elements. The elements are connected in parallel between buses 14 and 16 which are connected in series in the main power circuit. In-line switch device 10 is described in more detail herebelow. Crossed field switch device 18 is a cold cathode, glow discharge tube which requires for its conduction an externally applied magnetic field. When this field is turned off, the current between the main electrodes falls to zero in a few microseconds. The interelectrode gap has vacuum insulation properties and easily withstands high voltage. Particular examples of crossed field switch devices are shown in M. A. Lutz and R. C. Knechtli U.S. Pat. No. 3,638,061; R. E. Lund and G. A. G. Hofmann U.S. Pat. No. 3,641,384; G. A. G. Hofmann U.S. Pat. Nos. 3,604,977; 3,769,537; G. A. G. Hofmann and R. C. Knechtli U.S. Pat. No. 3,558,960; and M. A. Lutz and G. A. G. Hofmann U.S. Pat. No. 3,678,289.

Capacitor 20 may be required to limit the rate of voltage rise during resistor insertion. Impedance 22 is preferably a resistor of Thyrite blocks, which have an increasing resistance with decreasing current. The non-linear characteristics of such resistors permit them to reduce the current to normal levels while minimizing the initial voltage surges due to resistor insertion. Control logic is also included. Various types of control logic are practical, but it is important to sense the fault as early as possible to insert the current limiting resistor 22 as early as possible. For high level faults, detection and operation should be sufficiently fast that in-line

switch device 10 starts its opening cycle within 1 millisecond after initial fault detection, and switch opening is completed in 1 millisecond. Suitable control circuits are shown in patent application Ser. No. 488,634 filed July 15, 1974 by Wolfgang Knauer concurrently herewith, entitled "Power Distribution Control System" and carrying the Huges Aircraft Company docket number PD-73358, and in patent application Ser. No. 555,770 filed March 6, 1975 by Arthur F. Dickerson concurrently herewith, entitled "Control System for AC Power Distribution" and carrying Hughes Aircraft Company docket number PD-73391.

In operation, the current limiter circuit 12 normally has its switch 10 closed. Current from generator 24 is supplied through the conventional station breaker 26 through limiter circuit 12 to load 28. Normal current is represented by curve 29 in FIG. 2. When a fault is detected, switch 10 is opened at t_1 and is arcing. Crossed field switch device 18 is conductive at time t_2 for sufficiently long time to receive the current by passing switch 10, to permit quenching and deionization of arc in device 10. Thereupon, the crossed field switch device 18 is turned off at time t_2 with the rate of voltage rise being limited by capacitor 20 if necessary. Resistor 22 is thus inserted in the circuit to hold the fault current sufficiently low as represented by curve 30 rather than unrestricted fault current represented by curve 31 that it can be handled with the normal system circuit breakers 26.

FIG. 1 is a graphic schematic electric circuit, while FIG. 3 shows the electric schematic diagram in somewhat more detail. Buses 32 and 33 have the capacitor 20 therebetween. Capacitor 20 is optional, depending upon the need to control rate of voltage rise during off-switching. Tank 34 is conveniently sulfur hexafluoride filled to minimize electrical problems. Tube 34 is mounted on platform 36 which is isolated from ground, as by being mounted on insulator legs. It serves as a suitable mounting for some of the components of the current limiter system. Buses 38 and 40 are connected to buses 32 and 33 on opposite sides of capacitor 20 and are connected together externally of the tank through series resistors 42 and 44. The center tap between the series resistors 42 and 44 is connected through base resistor 46 to tank 34. Resistors 42, 44 and 46 are the same as the more schematically shown resistor 22 in and FIG. 1, being the resistors that are inserted in the circuit under various conditions.

Switch device 10 is mounted in the tank and has separate contacts 48 and 50 which are at the potential of tank 34 which move with respect to contacts 52 and 54. Contacts 52 and 54 are electrically connected to buses 38 and 40. Crossed field switch devices 56 and 58 was also located in the tank. Series switch devices are employed, because increased hold-off voltage of the current limiter is desired. The center connection between the crossed field switch devices is also connected to tank and platform potential.

Assuming that base resistor 46 has half the resistance of either one of branch resistors 42 and 44, redundancy is provided. For example, in normal operation the in-line switches is first opened with contacts 48, 50, 52 and 54 open, the current is transferred to the switch tubes 56 and 58, which are subsequently made nonconductive. This inserts the series connection of resistors 42 and 44 into the line. However, if one of the switches or one of the crossed field switch devices did not open,

potentials would be different. For example, if switch tube 58 did not deionize but continued conducting through arcing, tank voltage would be the same as the voltage of bus 40. Now, from the center connection of the branch resistors, current flow would be in parallel both through branch resistors, current flow would be in parallel both through branch resistor 44, and through the series base resistor 46 and arcing switch tube 58. Thus, the tank to bus voltage would be at three-quarters of the voltage of bus to bus voltage of normal operation resistor insertion, rather than half of it. Thus, switch tube 56 is protected against the entire voltage due to insertion, but only carries three-quarters of it. While the current increases one third in such a circumstance, this level is still quite acceptable from a point of view of effective current limiting. Thus, redundancy is provided by the circuit. An additional advantage of the configuration shown is that all drive and control functions can be performed from one potential level, that of the tank.

FIGS. 4 through 7 illustrate switch device 10 in more detail. As illustrated in FIG. 4, switch device 10 has housing 60 which is of metallic construction for strength and conductivity. It is mounted on flange 62 for directly mounting in the tank, and is at tank potential. Extension tube 64 extends downward and forms a bottom extension of housing 60. Hub 66 is an anchor secured on the bottom of the extension tube and carries fixed therein the bottom end of torque bar 68. The torque bar is of sufficient length and diameter and of proper material to be able to apply the desired torque through appropriate rotational operating angles. Torque bar 68 extends through guide bearing 70 up into housing 60. Principal twisting occurs in the smaller diameter portion between hub 66 and bearing 70. Above the bearing it is the operating cog shaft of the switch.

At its upper end, see FIG. 5, shaft 68 carries moving contact arms 72 and 74. The outer ends of the moving contact arms respectively carry moving contacts 48 and 50.

The contacts must satisfy a variety of requirements. First, during normal load current flow, the contacts must furnish a low impedance connection which does not overheat in operation. This is accomplished by use of sufficiently massive contact of high conductivity material, such as dispersion hardened high conductivity copper, the application of sufficiently high contact pressure in the order of 100 pounds per contact finger, and the provision of more than one contact finger per break. Stationary contacts 52 and 54 are respectively mounted on stationary contact arms 84 and 86 which swing about mounting assemblies 88 and 90. These are mounted from insulated panels 92 which are secured on the top end of housing 60.

As is seen in FIG. 4, parallel contact fingers 152, 154 and 156 are provided. The resiliency of these fingers is provided by separate concentric torque tubes. Torque tubes 158, 160 and 162 are illustrated. These are mounted in post 94 so that separate contact application force is applied. The three contact fingers together act as a single contact, except for their ability to each apply contact force in the closed position. With contact forces on the order of 100 pounds for each contact finger, currents in excess of 80 KA can be carried without contact separation due to inductive repulsion. During contact closing resistance due to contact bounce is re-

duced by using three contact fingers. The resiliency move back slightly under the force of moving contact arms 72 and 74 to reduce closing shock and to substantially equalize contact pressures on the two moving contacts. High spring rates limit forward and backward motion of arms 84 and 86 when they are not engaged by the moving contacts. Contact arms 84 and 86 are electrically isolated from each other, and each is mounted on its own post which extends out of insulated panels 92. Only post 94 is shown in FIG. 4 for ease of illustration. Post 94 is connected to bus 38, as indicated in FIG. 3, and mounting assembly 90 through its post is connected to bus 40.

Torque bar 68 is connected through housing 60 to tank 34 and platform 36. By this means, rotation of torque bar 68 opens both of the contacts of the in-line switch device. When torque bar 68 is otherwise unrestrained, the torque therein provides the necessary contact pressure to minimize contact resistance.

Motor 100 is an impulse motor which serves to produce the torque which overcomes the contact closing torque of torque bar 68 and produce the torque to overcome inertia for fast contact opening. The torque results from the repulsion between an externally applied current instator windings and its eddy current counterpart in the rotor. Torque bar 68 carries rotor 102 on splines. Rotor 102 has six rotor arms. The rotor is of low resistance metallic construction and is lightweight, preferably of high conductivity aluminum. The rotor arms each face a stator winding. Stator block 106 is of insulator material and provides faces against which stator windings are mounted. Stator winding 108 is seen facing rotor arm 104 in FIG. 6, and stator winding 110 is seen facing rotor arm 105. The windings are connected together and the two leads 112 and 114 are brought out.

The efficiency of this thrusting process in terms of the ratio of kinetic energy generated to the electric energy supplied increases with duration of the current pulse. However, time decay of the eddy currents counteracts this increase leading to an optimum thrusting time of about 500 microseconds. Under these conditions, the efficiency can be expected to be about 10 percent. With a moment of inertia of all moving parts of about 10,000 gram centimeters squared and with a contact opening time of 1 millisecond for a gap of 2 centimeters, a kinetic energy of approximately 150 joules must be provided. Accordingly, each contact opening event consumes about 1,500 joules of electrical energy.

With proper impedance matching between a capacitor current source and the stator windings the proper energy with a peak current of about 30,000 amperes at about 500 volts is provided. The voltage is sufficiently low to minimize spark-over problems. The physical structure of the motor is secured in such a manner as to permit the stator to resist the torque forces. Motor 100 has end flange 116 by which it is mounted in housing 60 to provide the necessary torque resistive mounting. By pulsing motor 100, the moving contacts are opened so that each has a gap of 2 centimeters in 1 millisecond.

Clutch 120, see FIG. 4, is an overrunning or one-way clutch. Its inner race 122 is fixed to the torque bar while its outer race 124 is fixed to the frame, except when contact closing from the open to the closed position is desired. For the meantime, it can be considered

to be fixed to the frame. One-way clutch dogs 126, sometimes called sprags, are positioned between the inner and outer races of the one-way clutch. When motor 100 rotates the upper end of torque bar 68 in the contact opening direction, inner race 122 fixed to the torque bar rotates freely under clutch dogs 126. As soon as the rotation in the opening direction stops and starts toward the closing direction, the clutch dogs jam between the inner and outer races to prevent any appreciable motion in the closing direction. Under these circumstances, the contacts are held in the open position.

Brake 130 includes brake disc 132 which is mounted on outer race 124 of clutch 120. Brake disc 132 is engaged between pads 134 and 136 in caliper 138. The caliper is axially floating to equalize pad loads. Lower pad 136 is adjustable, while upper pad 134 is the moving pad and is thrust into disc clamping engagement by cam 140 on the end of brake lever 142. As seen from FIG. A, movement to the right of the upper end of brake lever 142 causes brake engagement and rotational restraint of torque bar 68, while lefthand motion frees the brake disc to permit contact closing. Compression spring 144 urges the lever to the right.

Pulse motor 146 is in the form of a repulsion coil under the metallic upper end of brake lever 142. When a current is discharged through the coil, the upper end of the brake lever is repelled compressing spring 144 and releasing disc 132. The torque in torque bar 68 thereupon closes the contacts.

During a downstream fault when current limiter action is required, the parting contacts must be able to arc at currents up to 10 KA without damage to the contact surfaces. An arc resistant material is provided on the contact surfaces, and an arc rail is provided opposite each of the stationary contacts. Arc rails 164 and 166 are positioned opposite contacts 84 and 86 which are also arc rails. Arc rails 164 and 166 are positioned in line with the ends of the moving contacts when they are in the open position. The arc rails are at the potential of frame 60 and at the potential of the moving contacts when they are open. The divergent arc rails, form a nozzle through which a fast gas blast quickly moves the arc away from the actual contact surfaces out along the arc rails and aid in quenching the arc. A gas blast system is provided for each of the contact pairs. One of the gas blast sources is indicated at 170 and the other at 172. They are identical, but the source 170 is shown in more detail and will be described. Nozzle 174 directs gas from gas chamber 176 to the space between the open contacts and vents between the arc rail and stationary contacts. Coil 178 of an impulse motor, when actuated, drives valve disc 180 to the left to open gas chamber 176 to nozzle 174 so that the gas is quickly discharged. An appropriate gas is sulfur hexafluoride which is supplied from a high pressure gas source. The entire tank 34 preferably contains sulfur hexafluoride or similar gas and can be used as the suction for the high pressure source. Thus, the gas discharge through nozzle 174 out between the open contacts returns to the tank.

This invention having been described in its preferred embodiment, it is clear that it is susceptible to numerous modifications and embodiments within the ability of those skilled in the art and without the exercise of the inventive faculty. Accordingly, the scope of this invention is defined by the scope of the following claims.

What is claimed is:

1. A switch comprising:
 - a housing;
 - shaft rotatably mounted on said housing;
 - a switch contact arm mounted on said shaft to swing from an open to a closed position upon rotation of said shaft;
 - a fixed contact mounted on said housing to be contacted by said moving contact arm when said shaft is rotated to a contact closed position;
 - torque means connected to said shaft to torque said shaft in a rotational direction toward contact closed position and to maintain contact pressure of said moving contact on said fixed contact in contact closed position;
 - motor means connected to said shaft for rotating said shaft against the torque of said torque means to move said moving contact away from said fixed contact to open said contacts; and
 - restraining means for restraining said shaft in a rotated position wherein said moving contact is out of contact with said fixed contact.
2. The switch of claim 1 wherein said restraining means is releasable so that said shaft can be released from the open position to rotate under torque of said torque means to move said moving contact against said fixed contact.
3. The switch of claim 2 wherein said restraining means includes a clutch having a race secured to said shaft and a race which is fixable to said housing and engagement means between said races for permitting said shaft mounted race to rotate with respect to said housing fixable race in one direction and restrain it in the other direction.
4. The switch of claim 3 wherein a brake is interconnected between said housing and said housing fixable race so that when said brake is engaged, said motor means can turn said shaft from contact closed to contact open position and said clutch and said brake restrain said shaft in contact open position and so that upon release of said brake said shaft is torqued by said torque means to contact closed position.
5. The switch of claim 4 wherein said brake is a disc brake, said disc brake having a disc secured to said fixable race and having a caliper mounted on said housing, at said caliper having brake pads therein, one on each side of said disc, one of said brake pads being movable to engage said disc.
6. The switch of claim 5 wherein a cam engages against said movable pad and a lever is connected to move said cam against pad, resilient means for urging said lever in a brake engaging direction, and motor means for urging said lever in a brake disengaging direction, so that actuation of said brake disengaging motor means permits said torque means to close said contacts.
7. The switch of claim 1 wherein said motor means is a dynamic repulsion motor.
8. The switch of claim 7 wherein said motor means comprises a rotor connected to said shaft, said rotor being electrically conductive, and stator means connected to said housing, windings in said stator adjacent said rotor so that current flow in said windings causes eddy current in said rotor and mutual repulsion forces so that upon energization said motor mean said shaft is torqued in a direction to cause contact disengagement.

9. The switch of claim 8 wherein said rotor has at least two radially extending rotor arms having substantially radial faces and said stator has at least two windings, with one winding positioned to face each rotor arm so that torque forces are developed in a substantially tangential direction at said rotor arms.
10. The switch of claim 9 wherein there is a plurality of rotor arms greater than two with a stator winding adjacent the face of each rotor arm.
11. The switch of claim 1 wherein said torque means is a torque bar, one end of said torque bar being secured to said shaft and the other end of said torque bar being secured to said housing, said torque bar lying substantially coaxially with said shaft.
12. The switch of claim 1 wherein said housing mounted stationary contact comprises a plurality of contact fingers, each of said contact fingers being mounted on a torque tube extending substantially parallel to said shaft so that said contact fingers are separately torqued into engagement with said moving contact.
13. The switch of claim 1 where there are first and second contact arms mounted on said shaft to comprise first and second moving contact arms, and there are first and second stationary contacts mounted on said frame so that rotation of said shaft causes both said first and second moving contact arms to move away from said first and second stationary contacts to open to contact gaps.
14. The switch of claim 13 wherein a gas blast nozzle is directed toward each contact gap, a source of high pressure arc quenching gas and a valve connected between said gas source and said nozzle, said valve being opened by a dynamic repulsion motor.
15. The switch of claim 13 wherein said torque means is a torque bar, one end of said torque bar being secured to said shaft and the other end of said torque bar being secured to said housing, said torque bar lying substantially coaxially with said shaft.
16. The switch of claim 15 wherein said motor means is a dynamic repulsion motor.
17. The switch of claim 16 wherein said motor means comprises a rotor connected to said shaft, said rotor being electrically conductive, and stator means connected to said housing, windings in said stator adjacent said rotor so that current flow in said windings causes eddy current in said rotor and mutual repelling forces so that upon energization said motor mean said shaft is torqued in a direction to cause contact disengagement.
18. The switch of claim 17 wherein said housing mounted stationary contact comprises a plurality of contact fingers, each of said contact fingers being mounted on a torque tube extending substantially parallel to said shaft so that said contact fingers are separately torqued into engagement with said moving contact.
19. The switch of claim 18 wherein said restraining means is releasable so that said shaft can be released from the open position to rotate under torque of said torque means to move said moving contact against said fixed contact.
20. The switch of claim 19 wherein said restraining means includes a clutch having a race secured to such shaft and a race which is fixable to said housing and engagement means between said races for permitting said shaft mounted race to rotate with respect to said hous-

ing fixable race in one direction and restrain it in the other direction.

21. The switch of claim 20 wherein a brake is interconnected between said housing and said housing fixable race so that when said brake is engaged, said motor means can turn said shaft from contact closed to contact open position and said clutch and said brake restrain said shaft in contact open position and so that upon release of said brake said shaft is torqued by said torque means to contact closed position.

22. The switch of claim 21 wherein said brake is a disc brake, said disc brake having a disc secured to said fixable race and having a caliper mounted on said housing, at said caliper having brake pads therein, one on each side of each disc, one of said brake pads being movable to engage said disc.

23. The switch of claim 22 wherein a cam engages against said movable pad and a lever is connected to move said cam against pad, resilient means for urging said lever in a brake engaging direction, and motor means for urging said lever in a brake disengaging direction, so that actuation of said brake disengaging motor means permits said torque means to close said contacts.

24. An impedance inserting circuit comprising:
a source of electric power, a series connection of said source, a circuit breaker, an in-line switch and a load, an electronic switch and a parallel resistor in parallel to said in-line switch so that upon opening of said in-line switch, current passes through said electronic switch and upon off-switching of said electronic switch said impedance is inserted into said circuit to limit current between said impedance and said powersource, said in-line switch comprising:

a frame, a shaft rotatably mounted in said frame, a movable contact arm mounted on said shaft and a stationary contact mounted on said frame, torque means for torquing said movable contact arm into contact with said stationary contact, motor means for rotating said shaft so that said movable contact arm is moved away from said contact and selective restraining means for selectively restraining said shaft against torque of said torque means for maintaining said contact arm away from said contact.

25. The circuit of claim 24 wherein said electronic switch is a crossed field switch.

26. The circuit of claim 24 wherein the connection between said in-line switch and said load is a load bus and wherein the connection between said inline switch and said source is a source bus, first and second branch resistors serially connected between said source bus and said load bus, a base resistor connected between said branch resistors said switch having first and second movable contact arms and first and second stationary contacts, said first stationary contact to being connected to said load bus and said second stationary contact being connected to said source bus and said movable contact arms being connected to said base resistor.

27. The circuit of claim 26 wherein there are first and second electronic switches, said first electronic switch being connected between said load bus and said moving contact arms and said second electronic switch being connected between said moving contact arms and said source bus.

28. The circuit of claim 27 wherein both of said electronic switches are crossed field switch devices.

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