

Aug. 16, 1960

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2,949,568

PROTECTION OF PARALLEL CONNECTED D.-C. SOURCES

Filed July 13, 1956

4 Sheets-Sheet 1

FIG. 1

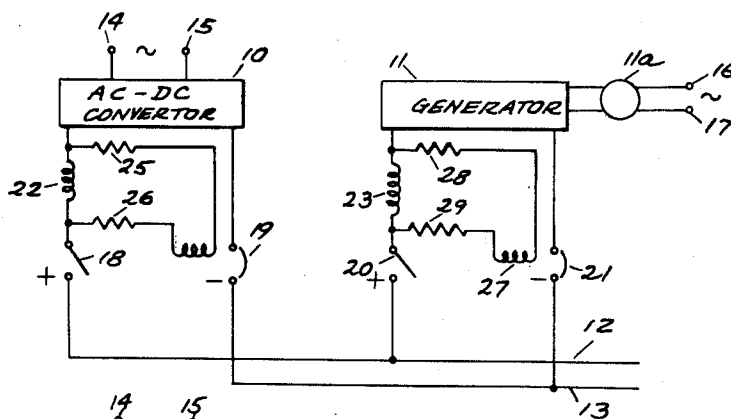


FIG. 2

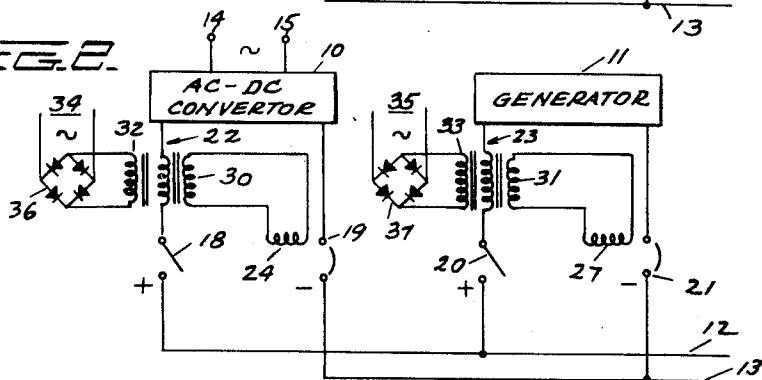
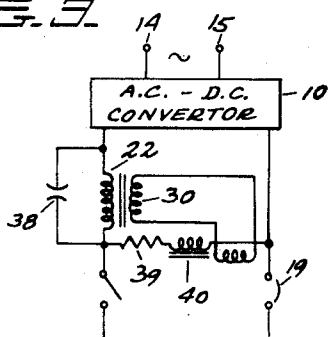
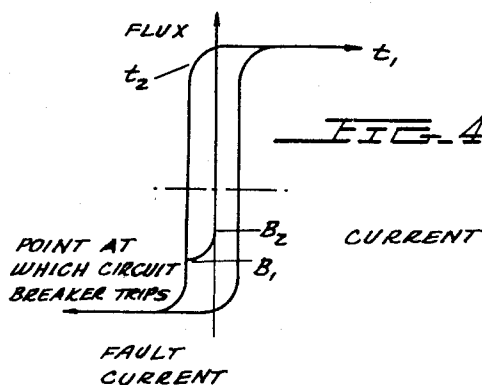


FIG. 3



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FIG. 5.

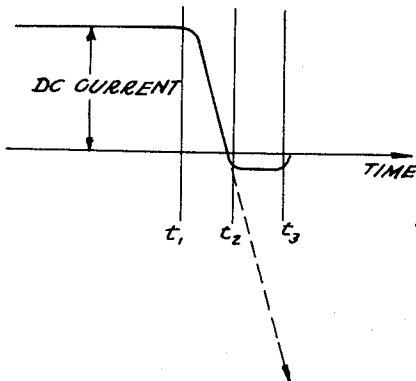


FIG. 6.

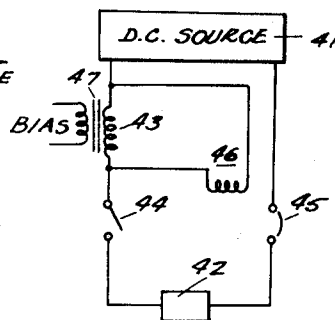


FIG. 7.

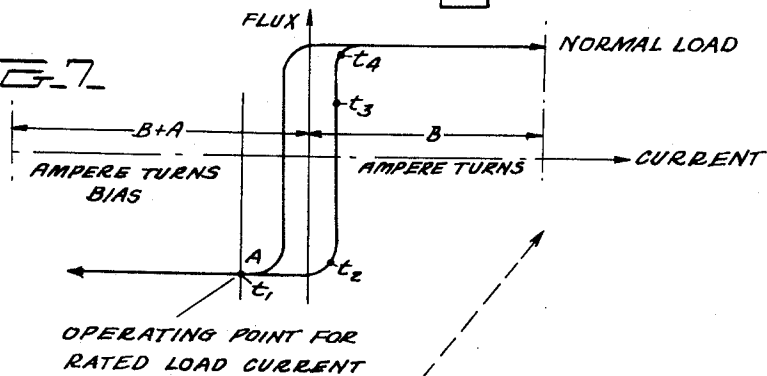
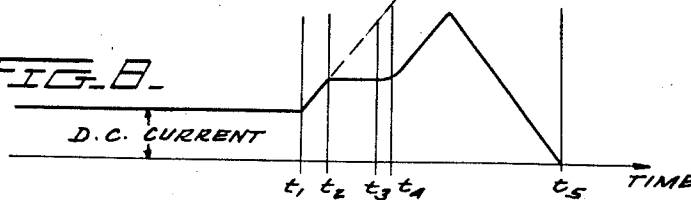


FIG. 8.



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FIG. 9.

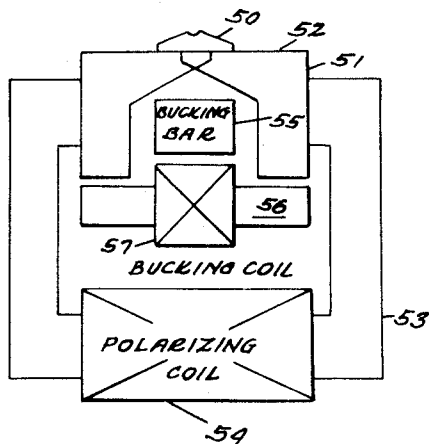


FIG. 10.

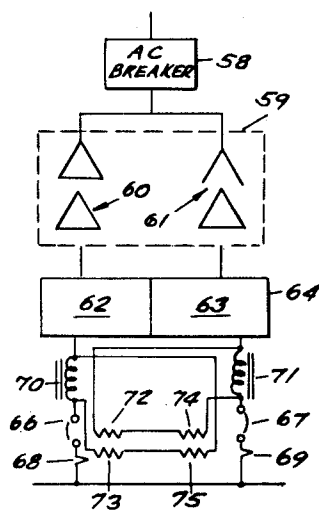
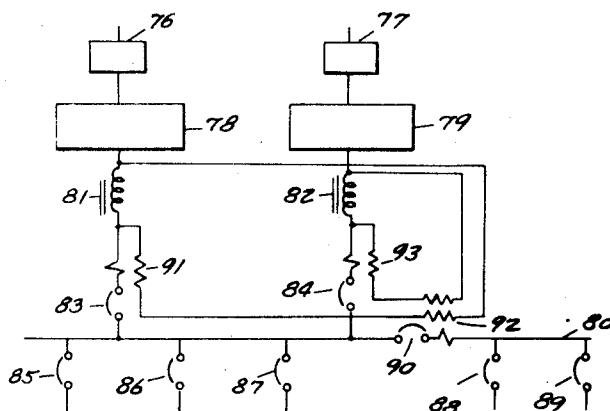


FIG. 11.



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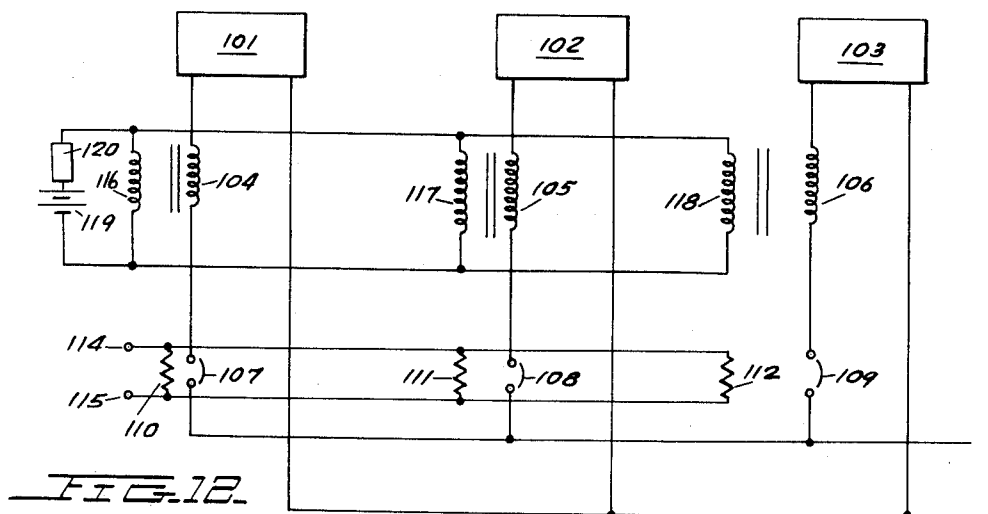
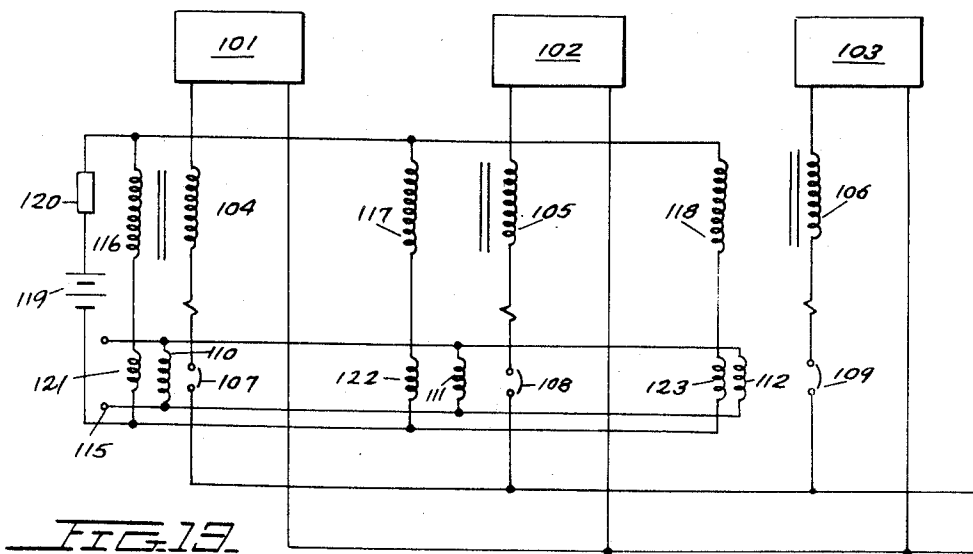
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## PROTECTION OF PARALLEL CONNECTED D.-C. SOURCES

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Filed July 13, 1956, Ser. No. 597,781

5 Claims. (Cl. 317-26)

This invention is a continuation-in-part of my co-  
pending application Serial No. 541,709, filed October 20,  
1955, now abandoned, and is more specifically directed to  
a system for limiting back-feed current which arises when  
one of two or more parallel sources feeding a common  
load is short-circuited and to allow the simultaneous  
closing of a first and second parallel connected rectifier  
on a single load.

More specifically, my invention is directed to a system  
which includes a substantially non-linear reactor which  
is connected in series with each of the D.-C. sources, with  
circuit connections being provided to impress the voltage  
appearing across this non-linear reactor across the trip  
means of a current interrupting device connected in series  
with the D.-C. source. Hence, during normal current  
conduction, the non-linear reactor which may be of the  
saturable reactor type will be fully saturated in a forward  
direction and present a very low impedance.

Upon a fault on the D.-C. source, however, the parallel  
connected D.-C. sources will feed current into the faulted  
D.-C. source in a direction opposite to its normal current  
flow. Therefore the current of the faulted D.-C. source  
will be driven through zero and to a high negative value  
in the absence of a non-linear reactor in series with this  
faulted D.-C. source. By connecting a non-linear reactor  
in series with this source, however, the reactor must be  
first unsaturated and then saturated in an opposite direc-  
tion before the feed back current can increase to a sub-  
stantial negative value. If no bias is used, the current will  
go through zero immediately to a small negative step  
current.

During the period of unsaturation or flux change in the  
non-linear reactor, a voltage will appear across the re-  
actor, this voltage being impressed upon the trip means  
of a circuit interrupting means associated with the faulted  
D.-C. source. Therefore at the very beginning of the low  
current interval which is maintained by the unsaturated  
non-linear reactor, a signal is given to the interrupting  
device to open the faulted circuit. It is then possible to  
have full current interruption take place either during this  
low current interval or slightly after the low current in-  
terval and before the negative current is of high mag-  
nitude, thereby decreasing the duty on the circuiting in-  
terrupting device as well as preventing large fault currents  
on the parallel connected D.-C. sources which are feed-  
ing current into this faulted unit.

I have also found that my novel system can be used  
for overload protection for a single D.-C. source. This  
end is accomplished by providing a non-linear reactor in  
series with a D.-C. source, current interrupting means, and  
D.-C. load in which the non-linear reactor has a biasing  
winding which will supply a larger number of ampere  
turns in opposition to the ampere turn supplied by the  
load winding. Circuit connections are then provided to  
impress the voltage across a non-linear reactor winding  
on the tripping means of the circuit interrupter. If now  
the D.-C. load current is greater than some predetermined

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value, it is seen that the ampere turns of the load winding  
will exceed the ampere turns supplied by the biasing wind-  
ing and the flux of the non-linear reactor will have to be  
reversed before the load current can increase any further.

Hence an interval of relatively constant current is pro-  
vided by the non-linear reactor and a voltage will appear  
across the load winding of the reactor. This voltage will  
now be impressed upon the trip coil or similar tripping  
device of the circuit breaker to initiate operation of the  
circuit interrupting device while the load current is main-  
tained at a relatively constant value which need be only  
slightly higher than the rated load current. That is, the  
load current will be maintained at a value low as com-  
pared to the available short circuit current of the system,  
thereby decreasing the duty on the circuit interrupting  
device.

One application of my novel invention may be seen  
with respect to mechanical or mercury arc rectifiers op-  
erating in parallel. It is clearly seen that rectifying de-  
vices operating in parallel feed into a back-fired or faulted  
unit through the D.-C. connections. The current con-  
tributed by the unfaulted rectifiers may then cause dam-  
age to the faulted rectifier, and damage to the faulted re-  
ctifier D.-C. breaker if the feed-back current exceeds the  
interrupting capacity of the breaker and may cause the  
other rectifiers to back-fire due to the overload in them.

In the past, linear air-core inductors have been con-  
nected in the D.-C. leads in the rectifiers to limit the rate  
of rise of the back-feed current. The more rectifiers there  
are parallel, the smaller the inductor required to limit  
the current contribution of each rectifier, but the larger  
it would need to be to limit the back-fire current in the  
faulted unit.

It is to be noted that air-core inductors have been gen-  
erally found more economical than linear iron-core in-  
ductors because of the air gap required in the iron-core  
to keep it linear. On the other hand, the losses of an  
air-core inductor are higher than the losses of an equiv-  
alent iron-core inductor.

Furthermore, any form of linear inductor greatly adds  
to the duty of the circuit breaker because of the large  
amount of energy stored in the inductor, which energy  
must be dissipated in the breaker arc, and also shows up  
as increased recovery voltage. Moreover, linear inductors  
of sufficient size to limit the current to a reasonable value  
become very large and expensive.

It is to be clearly noted that my invention differs from  
the prior art in the use of a non-linear reactor which is  
electrically connected to cooperate with a circuit inter-  
rupting device. Therefore, the iron-core inductors with-  
out air gap which in accordance with my novel invention  
normally operate fully saturated in one direction will,  
upon the occurrence of a reverse current such as back-  
feed current, have their flux fully reversed before the  
back-feed current can assume an appreciable negative  
value.

During the reversal of this flux, the net ampere turns  
is held to the small value of the magnetizing ampere turns  
of the non-linear reactor for a time equal to the net change  
of flux linkages or volt seconds of the reactor divided  
by the D.-C. bus voltage which is impressed across the  
non-linear reactor during the fault. Since the associated  
current interrupting device receives the fault signal at the  
point at which the non-linear reactor is first unsaturated,  
it is possible to have the circuit interrupted at some point  
during the step or slightly after the end of the step, there-  
by assuring that circuit interruption takes place on a rela-  
tively small current.

Accordingly, a primary object of my invention is to limit  
the back-feed current when one of two or more paralleled  
D.-C. sources feeding a common load is short-circuited.

Another object of my invention is to provide a means for a D.-C. source which is operative to limit overload current to a value small with respect to the short circuit capacity of the system.

Another object of my invention is to provide a relatively non-linear reactor in series with each D.-C. source of a system of parallel connected sources, these non-linear reactors being fully saturated under normal load current conditions and connected to initiate tripping of a circuit interrupting device upon reversal of the normal load current.

A still further object of my invention is to limit the interrupting duty required of circuit breakers protecting the rectifiers of a system of parallel connected rectifiers whereby circuit breaker operation is initiated by the voltage appearing across a non-linear reactor connected in series with a faulted rectifier.

Still another object of my invention is to decrease the overload current carried by each rectifier of a system of parallel connected rectifiers when one of the rectifiers faults.

A still further object of my invention is to provide an overload protective system for a D.-C. source by connecting the D.-C. source in series with a substantially non-linear reactor, a current interrupting device and the D.-C. load and to provide biasing means for the substantially non-linear reactor which supplies ampere turns in an opposing direction to, and of greater magnitude than the ampere currents supplied by the load current whereby reversal of load current is effective to reverse the flux of the non-linear reactor, and the non-linear reactor in turn is effective to energize operation of the circuit interrupting device on a relatively constant current.

Another feature of my novel invention is that two or more parallel connected rectifiers may be simultaneously closed on a common load even though the individual switching means connecting the individual rectifiers do not close simultaneously.

When parallel connected rectifiers are provided with individual switching means such as circuit breakers which are simultaneously energized to connect the rectifiers to a common load, one of the switching means will almost always close at a different time than the other. Hence, the rectifier associated with the switching means that closes first will carry an extremely high current until the other parallel rectifier is connected to the load. This condition is particularly severe when the load is of the type having a high inrush current and in any case, the rectifier which is energized first may be taken out of service due to the overload.

However, by providing non-linear reactors which are magnetized in the reverse direction for carrying the D.-C. current of each rectifier and connecting these reactors in parallel so that they will go through their step in the same time, then a low current step will be provided for each rectifier starting with the closing of the first circuit breaker and ending at the same instant. Thus, each rectifier will be capable of passing only its own portion of the total load current even though the circuit breakers of the associated rectifiers are not closed simultaneously. This novel feature allowing simultaneous closing of two or more parallel connected rectifiers may be used with or without the interconnection between the non-linear reactor and its associated circuit interrupter tripping means which can also be the switching means for connecting its rectifier to the load.

By way of example, each rectifier need only have a non-linear reactor connected to carry the D.-C. current of the rectifier with a biasing means for biasing the reactor in a reverse direction prior to the connecting of the rectifier to its load and to then connect the reactors of each rectifier in parallel.

If now it is desired that back feed current be limited as set forth above, then each reactor only need be connected to energize the switching means trip coil when its flux is reversed to its state prior to the closing of the switch-

ing by reverse current. It is to be noted that the trip means utilized here should be of the type or should be adapted to respond to a unidirectional signal so as to prevent tripping of the breaker when the rectifier is initially closed and the non-linear reactor flux is reversed to provide the parallel closing step.

Accordingly, a further object of my invention is to allow the simultaneous closing of two or more parallel connected rectifiers on a common load.

Another object of my invention is to provide a non-linear reactor for each of two or more parallel connected rectifiers which is connected to carry the D.-C. current of its associated rectifier and to connect these reactors in parallel and energize them in a reverse direction prior to simultaneously connecting each rectifier to a common load.

A still further object of my invention is to provide the above described system for simultaneously connecting two or more parallel connected rectifiers to a common load wherein each reactor is connected to automatically trip the associated circuit breaker in response to reverse current in its associated rectifier.

These and other objects of my invention will become apparent when taken in conjunction with the drawings in which:

Figure 1 is a circuit diagram showing the application of my novel invention to a system including two D.-C. sources connected in parallel to feed a common D.-C. bus system.

Figure 2 is similar to Figure 1 and shows a modification of the circuit diagram of Figure 1.

Figure 3 shows a still further modification of my novel invention as shown in Figures 1 and 2.

Figure 4 shows the flux-current characteristics of the non-linear reactor of Figures 1, 2 and 3.

Figure 5 shows the current-time characteristic of the circuits of Figures 1, 2 or 3 upon the occurrence of a fault.

Figure 6 shows a circuit diagram of the application of my invention to an overload protective system.

Figure 7 shows the flux-current characteristics of the non-linear reactor used in the circuit of Figure 6.

Figure 8 shows the current-time characteristics of the circuit of Figure 6 upon the occurrence of a fault on D.-C. load.

Figure 9 shows a specific type of tripping means that could be used for a circuit breaker operating in a protective system utilizing my invention.

Figure 10 shows a further application of my invention to a system requiring tripping of all parallel connected sources responsive to a fault current from any one of the sources.

Figure 11 shows a still further application of my invention to a system having essential and non-essential loads.

Figure 12 is a circuit diagram showing my novel invention as being adapted to allow simultaneous closing of three parallel connected rectifiers on a common load.

Figure 13 shows the circuit of Figure 12 when adapted to provide automatic trip of a circuit breaker responsive to reverse current in its associated rectifier.

Referring now to Figure 1, a first D.-C. source 10 is shown as being connected in parallel with a second D.-C. source 11 for energization of bus bars 12 and 13 which are then attached to a D.-C. load which is not here shown. Although the D.-C. sources 10 and 11 of Figure 1 are indicated as being an A.-C., D.-C. converter and a D.-C. generator, respectively, they could have been shown as comprising any type of D.-C. power source.

In the case of the D.-C. source 10, it is seen that A.-C. power is impressed upon the terminals 14 and 15 and is rectified by the converter device 10, which may be a rotary converter, whereas the D.-C. generator 11 and its driving motor 11a converts the A.-C. power appearing at the leads 16, 17 to D.-C. power.

The first D.-C. source 10 is shown to be connected to

the bus bars 12 and 13 through a disconnect switch 18 in the lead connected to the bus 12 and a circuit breaker 19 in the D.-C. lead 13. Similarly, the second D.-C. source of 11 is connected to the D.-C. bus bars 12, 13 through the disconnect switch 20 and a circuit breaker 21. It should be noted, however, that the use of disconnect switches 18 and 20 is arbitrary and is not necessary in the practice of my novel invention.

Each of the D.-C. voltage sources 10 and 11 are further shown in Figure 1 to have non-linear reactors 22 and 23 respectively, connected in series with D.-C. bus 12. The core of reactors 22 and 23 can be made of special magnetic materials such as highly saturable type iron or standard transformer steels, or if desired, oriented transformer steels.

It is, however, desirable to keep the magnetizing current as low as is consistent with economical design not only to prevent damage to the D.-C. source, but also to reduce the duty on the breaker which will be required to break an inductive current. That is to say, the recovery voltage across the breaker will be determined largely by the energy stored in the reactor at the instant of interruption, this energy being  $LI dI$ . Hence, it is important to keep the magnetizing current small. Magnetic materials having square hysteresis loops are most favorable since the magnetizing force can be brought to zero with the least change of flux.

Circuit connections are then made from the non-linear reactor 22 to a tripping means 24 of the circuit breaker 19 through the current limiting resistors 25 and 26. Similar circuit connections are then made between the non-linear reactor 23 to the tripping means 27 of the circuit breaker 21 through the resistors 28, 29.

The tripping means 24 and 27 are so constructed as to be operable upon energization thereof to cause circuit interruption by means of the circuit breakers 19 or 21. Clearly, the coils 24 and 27 will be energized when a voltage appears across the non-linear reactors 22 or 23 respectively. Therefore, when either reactor 22 or 23 is unsaturated, the circuit breaker 19 or 21 will, in view of the energization of its tripping means 24 or 27, be opened.

The tripping means can be any conventional type but is preferably of the bucking-bar type with a coil arranged to act magnetically in the same manner as the bucking-bar but retaining the bucking-bar for back-up protection.

It is now possible to consider the operation of my novel invention as described in Figure 1 in conjunction with the current-flux diagram of Figure 4 and the current-time diagram of Figure 5. Referring first to Figure 1, during normal operation the current due to the first D.-C. source 10 and the current of D.-C. source 11 are combined in the D.-C. bus bars 12 and 13 to energize any load placed across these bus bars. In the event of a fault, however, a high back-feed current will be supplied to the faulted D.-C. source from the source that is operating normally. This feed-back current might, particularly in the case of many paralleled units, be so high as to completely destroy the faulted unit as well as placing severe overloads on the parallel D.-C. supplies which are still operative.

If now it is assumed that during operation, the D.-C. source 10 fails, it is seen that since this source is effectively short-circuited, a back-feed current will be driven through it by the D.-C. source 11 which is in parallel with the short-circuited source 10 and the load across the bus bars 12 and 13.

As will be shown in conjunction with Figures 4 and 5, however, as soon as the feed-back current through the short-circuited D.-C. source 10 passes through zero current and attempts to go to its high negative value, the nonlinear reactor 22 will unsaturate to provide a low current step. Furthermore, since the reactor 22 is unsaturated, a relatively high voltage will appear across its winding to operate the tripping means 24 of the circuit breaker 19. Circuit breaker 19 therefore effects

subsequent interruption of the feed-back current which is being held at a low value by the unsaturated reactor 22.

Referring now to Figures 4 and 5, it is seen that the reactor 22 is fully saturated at a time  $t_1$ , this time corresponding to a time at which normal D.-C. load current is flowing. Upon the occurrence of a fault on unit 10, it is seen that the current flowing through the non-linear reactor 22 in a positive direction is reversed since the source 10 is effectively short-circuited and the source 11 feeds through the short circuit to drive the positive D.-C. current through the reactor 22 to a negative value.

As shown in Figure 5, the current through reactor 22 is driven negatively until at time  $t_2$  the current is at a low enough value to unsaturate the non-linear reactor 22. In view of the unsaturation of the non-linear reactor 22 at the time  $t_2$ , the current can be maintained at a relatively low current step for a time which would be determined by the volt second rating of the non-linear reactor 22 and the D.-C. voltage which is impressed across the non-linear reactor 22.

That is to say, that upon unsaturation of the reactor 22 at time  $t_2$ , practically the full D.-C. voltage will appear across the reactor 22, this voltage being used to energize the tripping means 24. Therefore, initiation of operation of circuit breaker 19 occurs at the time  $t_2$ .

After initiation of the circuit breaker operation, complete current interruption occurs at slightly later time  $t_3$ . Hence it is seen that by providing the low current step beginning at time  $t_2$ , the current interrupted by the circuit breaker 19 at time  $t_3$  is the relatively small value of magnetizing current of the non-linear reactor 22 rather than that current shown in the dotted line of Figure 5 which would have existed in the absence of the non-linear reactor 22 or in the presence of a linear reactor.

In the case of Figure 5 it has been assumed that the speed of operation of the circuit breaker 19 and the length of the low current step due to non-linear reactor 22 were such that current interruption takes place within the low current step. If, however, this were not the case, and current interruption takes place at some time after the end of the low current step, considerable advantage is still afforded since the negative rise of fault current is delayed and the instantaneous value of current to be interrupted is considerably decreased from the value it would have had in the absence of a non-linear reactor.

Figure 4 also illustrates how the interrupting duty on the circuit breaker is decreased by using magnetic material having a square loop characteristic. In Figure 4, it is seen that if current interruption takes place at time  $t_3$ , the reactor flux is changed from a value  $B_1$  at time  $t_3$  to a value of  $B_2$  which corresponds to zero current. The interrupting duty placed on the breaker is, as mentioned heretofore, a function of the flux change in the inductor. As illustrated in Figure 4, the change  $B_1-B_2$  is, in view of the square loop characteristic, relatively small. Therefore, the interrupting duty on the circuit breaker is also relatively small.

Similar remarks as were made in the foregoing are applicable in the case of a fault on the second D.-C. source 11 rather than the source 10. Furthermore, the same operation as was previously described would be obtained in the case of a plurality of D.-C. sources being connected at parallel to energize the bus bars 12 and 13 and one or more of these plurality of sources were short-circuited or faulted.

With regard to the tripping means 24 and 27 of the circuit breaker 19 and 21, respectively, it is to be realized that they could be of any desired type in which energization thereof would be effective to operate the main circuit breaker or current interrupter contacts. By way of example, the trip coil 24, 27 could be a shunt trip or special reverse current trip of the circuit breaker.

A specific tripping means which could be used is seen with reference to Figure 9 in which an armature 50,

which is constructed of magnetic material, is operatively connected to a pair of circuit breaker contacts which are not shown. However, the connection is such that when the armature 50 is sealed against the magnetic structure comprising the interleaved plates 51, 52, the contacts will be in the engaged position.

The magnetic structure including plates 51, 52, is completed by the magnetic structure 53 which has a polarizing coil 54 wound thereon. The above noted magnetic structure is further energized by the bucking-bar 55 which circulates magnetic flux in the auxiliary magnetic circuit which includes the interleaved plates 51, 52 and magnetic member 56 which has a bucking coil 57 wound thereon.

Hence, upon energization of the bucking coil 57, responsive to unsaturation of a non-linear reactor, the magnetic flux through interleaved plates 51, 52 will be bucked down and the armature 50 will be released to allow operation of the circuit breaker contacts to their disengaged position.

It is, however, seen that by arranging the bucking bar and bucking coil to act magnetically in the same manner, that the bucking bar is retained for back-up protection.

In some applications it may be desirable that the energization of the tripping means 24 and 27 be taken from an isolated circuit rather than directly from the reactor main winding as shown in Figure 1. A variation of this type may be seen with reference to Figure 2 which is essentially the same as the circuit of Figure 1, and in fact operates almost identically therewith.

The energization of the tripping means 24 and 27 of the circuit breakers 19 and 21, however, is taken from an auxiliary winding 30 and 31 of the reactors 22 and 23, respectively. It is further seen in Figure 2 that D.-C. bias windings 32 and 33 have been added to the non-linear reactors 22 and 23, respectively. This D.-C. bias may prove necessary when the D.-C. sources 10 and 11 are rectifiers which may backfire when not carrying sufficient current to saturate the inductor in the forward direction.

Hence, a bias current may be applied through separate windings 32 and 33 to assure saturation of the inductor in the forward direction to thereby assure operation of the reactor 22 and 23 in the event of short circuit conditions during no load operation of the source. In the case of Figure 2, this bias current is shown to be supplied by A.-C. sources 34 and 35 and rectifiers 36 and 37 respectively.

Figure 3 is similar to Figures 1 and 2 but shows the connection of only one D.-C. source in which a surge suppressor 38 has been connected across the main winding of the non-linear reactor 22. Figure 3 goes further to indicate how a D.-C. bias may be utilized in the case of a rectifier such as a mechanical rectifier which requires a base-load circuit for its operation. Base-load circuits as related to mechanical rectifiers are clearly described in copending application Serial No. 497,744, filed March 29, 1955, now Patent No. 2,883,602, and assigned to the assignee of the instant application.

In the case of Figure 3, the base-load circuit D.-C. current is carried by the main winding of the non-linear reactor 22. Therefore, it is assured that the non-linear reactor 22 is saturated in a forward direction in case of back-firing of the D.-C. power source 10 during base-load operation. More specifically, the base-load circuit of Figure 3 comprises the resistor 39 and inductor 40, this connection being made ahead of the disconnect switch 18 and circuit breaker 19. Here again, it would be possible to take the connection of the base load circuit components 39 and 40 through an auxiliary winding of the non-linear reactor 22 to obtain isolation as was shown in the circuit of Figure 2.

Figure 6 shows the application of my novel invention to an overload limiting function for limiting of the rise of forward current above a desired current level for a

predetermined length of time. In Figure 6, D.-C. source 41 which may be of any type energizes a D.-C. load 42 through a non-linear reactor 43, disconnect switch 44 and circuit breaker 45.

Here again, circuit connections are provided whereby voltage appearing across the non-linear reactor 43 is impressed upon the trip means 46 of the circuit breaker 45. The bias coil 47 is provided with a number of ampere turns which are in an opposite direction and of greater magnitude than the ampere turn provided by the maximum permissible current in the load circuit.

The flux-current diagram of the non-linear reactor 43 of Figure 6 is shown in Figure 7 and it is seen that the operating point for rated load current at point A of Figure 7 is determined by the difference between the bias current which is at a magnitude  $B+A$  ampere turns and the normal load current ampere turns shown as B. If now the normal load current is increased above a predetermined value of B ampere turns, it is clear from Figure 7 that the non-linear reactor 43 must go from a negatively saturated state to a positively saturated state.

It is now possible to consider the operation of the circuit of Figure 6 under overload conditions which could be caused by a short-circuiting of the D.-C. load 42. This condition is shown in Figure 8 in which the D.-C. current, which is at a rated value at time  $t_1$  begins to increase at a rate given by the system voltage and the impedance of the system after the short circuit. The current will rise until at time  $t_2$  the non-linear reactor 43 of Figure 6 will unsaturate as is seen in Figure 7.

In view of the unsaturation of the non-linear reactor 43, a high voltage will appear across it and this voltage will be impressed upon the tripping means 46 of the circuit breaker 45 to thereby initiate the tripping action of this circuit breaker. At time  $t_3$  the circuit breaker 45 begins to open to denenergize the load circuit. At time  $t_4$  the reactor 43 is completely saturated and finally at time  $t_5$  the circuit is completely opened.

It is therefore seen in conjunction with Figure 8 that the maximum instantaneous current interrupted by the circuit breaker 45 is smaller than the current shown in the dotted line of Figure 8 that would have been available had the saturable reactor 43 not been in the circuit or if only a linear reactor had been used.

Hence in the case of the circuit of Figure 6, as well as the circuits of Figures 1, 2 and 3, it is clear that the use of a non-linear reactor in accordance with my novel invention is operable first to stop a fault current or prevent rate of rise of a fault current for an appreciable time interval, and furthermore gives a signal to a current interrupting device at the very beginning of the fault to thereby initiate early operation of that current interrupting device. The combination of these two features therefore allows for the interruption of an appreciably smaller fault current than would have been interrupted in the absence of the non-linear reactor.

In the case of Figure 8, it is to be realized that the current interrupted by the circuit breaker could have been smaller if the circuit breaker operated faster or if the step current had been longer. In either case, complete current interruption would take place in the step such as at a time  $t_3$ .

Although the invention concerns itself chiefly with the properties of a saturable iron core to provide a period of low current in case of a fault, the design of the inductor within the limits of economy should be such as to emphasize and utilize its air-core inductance before and after the step to take advantage of this parameter when the iron is saturated.

Figure 10 shows a further application of my novel invention for the case of a rectifier unit consisting of two or more sections having individual D.-C. breakers in which it is essential that both rectifiers be taken off the line if either one backfires. An example of this type of application may be found in mechanical rectifiers in

which a unitary contact mechanism operates 12 contacts, six of which rectify for a first D.-C. system and the other six contacts effect rectification for a second D.-C. system.

As shown by the single line diagram of Figure 10, input A.-C. power is supplied through the A.-C. breaker 58 and is passed to the rectifier transformers shown in the dotted box 59.

In the case of Figure 10, the system of rectifier transformers comprises only a first delta-delta transformer 60 and a Y-delta transformer 61, although any number of transformers of any desired connection could be used. The individual transformers 60, 61 then energize sections 62 and 63 respectively, of the rectifying device 64.

The individual rectifying sections 62 and 63 are then connected to a common D.-C. bus 65 through the circuit interrupting devices 66 and 67, respectively, which could be provided with reverse current trip devices 68 and 69 such as described in conjunction with Figure 9.

Each of the D.-C. output leads are then provided with substantially non-linear reactors 70 and 71 in accordance with my novel invention. In this case, however, circuit interrupting device 66 has a first and second trip means 72 and 73, respectively, which could be energized by either reactor 70 or 71, respectively, and similarly, circuit interrupting device 67 has a first and second trip means 74 and 75, respectively, which could be energized by either reactor 71 or 70, respectively.

If desired, trip means 72, 73, 74 and 75 could be constructed to operate as the bucking coil 57 of Figure 9.

Hence, it is clear that upon a fault in rectifier section 62, that reactor 70 would unsaturate to thereby effect energization of both trip means 73 and 75 to thereby operate both circuit interrupting devices 66 and 67 to their circuit interrupting position. Similar remarks may be directed to a fault in rectifier section 63 with reactor 71 being unsaturated and trip means 72 and 74 being energized.

Although the application of my novel invention as described in conjunction with Figure 10 utilizes a unitary rectifier for a plurality of rectifying sections, it is clear that the same principles could be applied to isolated rectifying systems in which it is desired to take one or more systems off the line in the event of a fault in another.

My novel invention can be further applied to isolate the fault or to reduce the load on remaining rectifier units after one is subjected to a fault condition.

This is seen in Figure 11 in which rectifier transformers 76 and 77 energize the rectifiers 78 and 79, respectively, which rectifiers energize a D.-C. bus 80 through the non-linear reactors 81 and 82, respectively, and circuit interrupting devices 83 and 84, respectively.

As further shown in Figure 11, essential loads taken off the D.-C. bus 80 are energized through the circuit breakers 85, 86 and 87 whereas non-essential loads are energized through breakers 88 and 89.

A further interrupting device 90 is then provided in a position to isolate the essential loads from the non-essential loads. Circuit connections are then provided whereby voltage appearing on reactor 81 effects energization of trip means 91 and 92 of interrupting devices 83 and 90 whereas reactor 82 is connected to energize trip means 93 and 92 of interrupting devices 84 and 90 respectively.

Clearly, upon a fault on either rectifier system 78 or 79, the interrupting device corresponding to the faulted rectifier will be operated as well as the breaker 90. Hence the non-essential loads will be taken off the line and duty on the remaining rectifier will be reduced.

As seen in Figure 12, my novel invention may be so adapted as to allow simultaneous connection of two or more parallel connected D.-C. sources to a common

load even though the circuit breakers associated with each rectifier will not close at the exact same time. In the past, this condition has resulted in an extremely high energy current for the rectifier whose breaker is the first to close since this rectifier supplies all of the load current of the D.-C. load and in the event that the load is of the type that draw a high energy current, the initial current magnitude of the first connected rectifier is even higher.

Figure 12 shows three D.-C. sources, 101, 102 and 103 respectively which may be of any type such as mechanical rectifiers, mercury arc rectifiers, motor generators and so on. Each of the sources 101, 102 and 103 have the non-linear reactors 104, 105 and 106, respectively, connected in one of their D.-C. output leads and further connected in series with a switching means 107, 108 and 109 respectively.

Switching means 107, 108 and 109 are of the type which are provided with energizing coils such as 110, 111 and 112 respectively which will effect closing of their associated switching means upon energization thereof.

Energizing coils 110, 111 and 112 are seen to be connected in parallel and energizable from terminals 114 and 115 so as to effect simultaneous energization of each of the switching means or circuit breakers 107, 108 and 109.

Non-linear reactors 104, 105 and 106 are provided with D.-C. biasing windings 116, 117 and 118, respectively, which are connected in parallel and energized from any desired D.-C. source such as the battery 119 which is connected in series with a current limiting impedance 120.

The direction of the biasing current of D.-C. source 119 is such as to reverse the flux of reactors 104, 105 and 106 prior to the closing of their associated switching means 107, 108 and 109 respectively. That is to say, biasing windings 116, 117 and 118 are so energized as to require a flux change of reactors 104, 105 and 106 respectively upon initiation of D.-C. load current there-through in a forward direction.

In operation of the circuit of Figure 12, it is understood that upon energization of closing coils 110, 111 and 112 from the terminals 114 and 115, that one of the circuit breakers 107, 108 or 109 will close before the others since it is substantially impossible to provide each of breakers 107, 108 and 109 with identical closing characteristics. Assuming that breaker 107 closes first, it is seen that current may be passed through the non-linear reactor 104.

Since, however, the flux of this reactor 104 has been reversed by its biasing winding 116, reactor 104 must go through its full flux change before allowing an appreciable current to pass therethrough. Since winding 116 is connected in parallel with windings 117 and 118 it is understood that each of the other reactors 105 and 106 will commence to have their flux reversed at the same time as does reactor 104. Hence, instead of a large energy current being drawn from rectifier or D.-C. source 101, only the relatively small magnetizing current of reactor 104 will be passed.

After closure of circuit breakers 108 and 109, a similarly small current will be passed by reactors 105 and 106 and this small current will proceed to be drawn from each of the D.-C. sources 101, 102 and 103 until the associated non-linear reactors 104, 105 and 106 saturate simultaneously so as to allow load current to flow.

As may be seen in Figure 13, the system of Figure 12 may be adapted to provide automatic tripping operation as has been set forth in conjunction with the previous figures of this application. It is to be realized that many modifications of the system shown in Figure 12 will now be apparent to anyone skilled in the art.

By way of example, the biasing winding 116, 117 and

118 could be incorporated within the main current carrying winding of reactors 104, 105 and 106 respectively.

Furthermore, if D.-C. sources 101, 102 and 103 were of the mechanical rectifier type, the D.-C. bias power could be drawn if desired from the base load circuit which may be seen in copending application Serial No. 483,497, filed January 24, 1955, now Patent No. 2,782,360, and assigned to the assignee of the instant application. Although this base load power may be disconnectible after starting of the rectifier, it is to be noted that this would not interfere with the operation of the system of Figure 12 since the D.-C. bias serves only to reverse the flux of reactors 104, 105 and 106 prior to contact closure and is then no longer needed even before all of the D.-C. sources 101, 102 and 103 are connected to their common load, if oriented magnetic material without air-gap is used in reactors 104, 105 and 106.

Figure 13 in which components similar to the components of Figure 12 have been identified with similar numerals shows that the biasing windings 116, 117 and 118 each have a trip means 121, 122 and 123 respectively associated with circuit breakers 107, 108 and 109 respectively.

During the starting operation of the system of Figure 13, it is understood that the sequence of events will proceed as has been described in conjunction with Figure 12. When, however, one of the D.-C. source 101, 102 or 103 backfires or has a fault associated therewith, its current will reverse and at some point the reactor 104, 105 or 106 associated with the faulted rectifier will have its flux reversed so as to induce a signal into the trip means 121, 122 or 123 associated with the reactor having its flux reversed.

By way of example, if D.-C. source 101 has a fault associated therewith, the current flowing through reactor 104 will reverse to thereby induce a voltage in winding 116 which will cause a current flow in the trip means 121 which will effect tripping of the circuit breaker 107 in the same manner as has been previously set forth.

It is to be noted that the trip means 121, 122 and 123 should be of the type which responds to a unidirectional signal so as to prevent operation of circuit breaker 107, 108 or 109 respectively, due to power source 119 which effects an initial flux reversal of the reactors 104, 105 or 106 prior to the closure of the circuit interrupting devices 107, 108 or 109 respectively. If, for example, the circuit interrupting devices 107, 108 or 109 were provided with tripping means such as that seen in Figure 9 where the tripping means 121, 122 and 123 would correspond to the bucking coil 57 of Figure 9, then the system could be used as is shown in Figure 13 for tripping of circuit breakers 107, 108 or 109 would occur only when current in coil 121, 122 or 123, respectively, is in a particular direction and would be unaffected when the current is in a different direction.

If the tripping means 121, 122 and 123 are not inherently unidirectional, they can be made unidirectional by connecting in series with each one, a small rectifying type valve which will pass current only in the direction produced by a voltage across the reactor caused by a fault in the associated machine.

Although I have described preferred embodiments of my novel invention, many variations and modifications will now be apparent to those skilled in the art. I prefer therefore to be limited, not by the specific disclosure herein, but only by the appended claims.

I claim:

1. In a system for energizing a D.-C. load; said system comprising a first and second source of D.-C. power and a first and second switching means; said first source of D.-C. power being connected in series with said first switching means; said second source of D.-C. power being connected in series with said second switching means; said series connection of said first source of D.-C. power and said first switching means being connected in parallel with said series connection of said second source

of D.-C. power and said second switching means; said parallel connected series connections being connected in parallel with said D.-C. load; a first and second operating means for said first and second switching means respectively; said first and second operating means being operable to close their said respective first and second switching means; an energizing means for said first and second operating means; said energizing means being operable to energize said first and second operating means substantially simultaneously for substantially simultaneously closing said first and second switching means; a first and second non-linear reactor connected in series with said first and second source of D.-C. power respectively and said first and second switching means respectively; a biasing means for said first and second non-linear reactors; said biasing means being operative to saturate said first and second non-linear reactors in a first direction prior to closure of said first and second switching means; current flow through said first and second non-linear reactors unsaturating said first and second non-linear reactors after closing of said first and second switching means and thereafter saturating said first and second non-linear reactors in a direction opposite to said first direction.

2. In a system for energizing a D.-C. load; said system comprising a first and second source of D.-C. power and a first and second switching means; said first source of D.-C. power being connected in series with said first switching means; said second source of D.-C. power being connected in series with said second switching means; said series connection of said first source of D.-C. power and said first switching means being connected in parallel with said series connection of said second source of D.-C. power and said second switching means; said parallel connected series connections being connected in parallel with said D.-C. load; a first and second operating means for said first and second switching means respectively; said first and second operating means being operable to close their said respective first and second switching means; an energizing means for said first and second operating means; said energizing means being operable to energize said first and second operating means substantially simultaneously for substantially simultaneously closing said first and second switching means; a first and second non-linear reactor connected in series with said first and second source of D.-C. power respectively and said first and second switching means respectively; a biasing means for said first and second non-linear reactors; said biasing means being operative to saturate said first and second non-linear reactors in a first direction prior to closure of said first and second switching means; current flow through said first and second non-linear reactors unsaturating said first and second non-linear reactors after closing of said first and second switching means and thereafter saturating said first and second non-linear reactors in a direction opposite to said first direction; each of said first and second non-linear reactors having a respective auxiliary winding; each of said respective auxiliary windings being connected in parallel; said non-linear reactors preventing a high current overload on one of said first or second switching means if said one of said first or second switching means is closed earlier than the other.

3. In a system for energizing a D.-C. load; said system comprising a first and second source of D.-C. power and a first and second switching means; said first source of D.-C. power being connected in series with said first switching means; said second source of D.-C. power being connected in series with said second switching means; said series connection of said first source of D.-C. power and said first switching means being connected in parallel with said series connection of said second source of D.-C. power and said second switching means; said parallel connected series connections being connected in parallel with said D.-C. load; a first and

second operating means for said first and second switching means respectively; said first and second operating means being operable to close their said respective first and second switching means; an energizing means for said first and second operating means; said energizing means being operable to energize said first and second operating means substantially simultaneously for substantially simultaneously closing said first and second switching means; a first and second non-linear reactor connected in series with said first and second source of D.-C. power respectively and said first and second switching means respectively; a biasing means for said first and second non-linear reactors; said biasing means being operative to saturate said first and second non-linear reactors in a first direction prior to closure of said first and second switching means; current flow through said first and second non-linear reactors unsaturating said first and second non-linear reactors after closing said first and second switching means and thereafter saturating said first and second non-linear reactors in a direction opposite to said first direction; said first switching means having an automatic trip means connected thereto; said automatic trip means being connected to said first non-linear reactor and being energized responsive to the flow of reverse current in said first D.-C. source of power.

4. In a system for energizing a D.-C. load; said system comprising a first and second source of D.-C. power and a first and second switching means; said first source of D.-C. power being connected in series with said first switching means; said second source of D.-C. power being connected in series with said second switching means; said series connection of said first source of D.-C. power and said first switching means being connected in parallel with said series connection of said second source of D.-C. power and said second switching means; said parallel connected series connections being connected in parallel with said D.-C. load; a first and second operating means for said first and second switching means respectively; said first and second operating means being operable to close their said respective first and second switching means; an energizing means for said first and second operating means; said energizing means being operable to energize said first and second operating means substantially simultaneously for substantially simultaneously closing said first and second switching means; a first and second non-linear reactor connected in series with said first and second source of D.-C. power respectively and said first and second switching means respectively; a biasing means for said first and second non-linear reactors; said biasing means being operative to saturate said first and second non-linear reactors in a first direction prior to closure of said first and second switching means; current flow through said first and second non-linear reactors unsaturating said first and second non-linear reactors after closing of said first and second switching means and thereafter saturating said first and second non-linear reactors in a direction opposite to said first direction;

each of said first and second switching means having a respective automatic trip means connected thereto; said first and second automatic trip means being connected to said first and second non-linear reactor respectively and being energized responsive to the flow of reverse current in said first or second D.-C. sources of power respectively.

5. In a system for energizing a D.-C. load; said system comprising a first and second source of D.-C. power and a first and second switching means; said first source of D.-C. power being connected in series with said first switching means; said second source of D.-C. power being connected in series with said second switching means; said series connection of said first source of D.-C. power and said first switching means being connected in parallel with said series connection of said second source of D.-C. power and said second switching means; said parallel connected series connections being connected in parallel with said D.-C. load; a first and second operating means for said first and second switching means respectively; said first and second operating means being operable to close their said respective first and second switching means; an energizing means for said first and second operating means; said energizing means being operable to energize said first and second operating means substantially simultaneously for substantially simultaneously closing said first and second switching means; a first and second non-linear reactor connected in series with said first and second source of D.-C. power respectively and said first and second switching means respectively; a biasing means for said first and second non-linear reactors; said biasing means being operative to saturate said first and second non-linear reactors in a first direction prior to closure of said first and second switching means; current flow through said first and second non-linear reactors unsaturating said first and second non-linear reactors after closing of said first and second switching means and thereafter saturating said first and second non-linear reactors in a direction opposite to said first direction; each of said first and second non-linear reactors having a respective auxiliary winding; each of said respective auxiliary windings being connected in parallel; said non-linear reactors preventing a high current overload on one of said first or second switching means if said one of said first or second switching means is closed earlier than the other; each of said first and second switching means having a respective automatic trip means connected thereto; said first and second automatic trip means being connected to said first and second non-linear reactor respectively and being energized responsive to the flow of reverse current in said first or second D.-C. sources of power respectively.

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