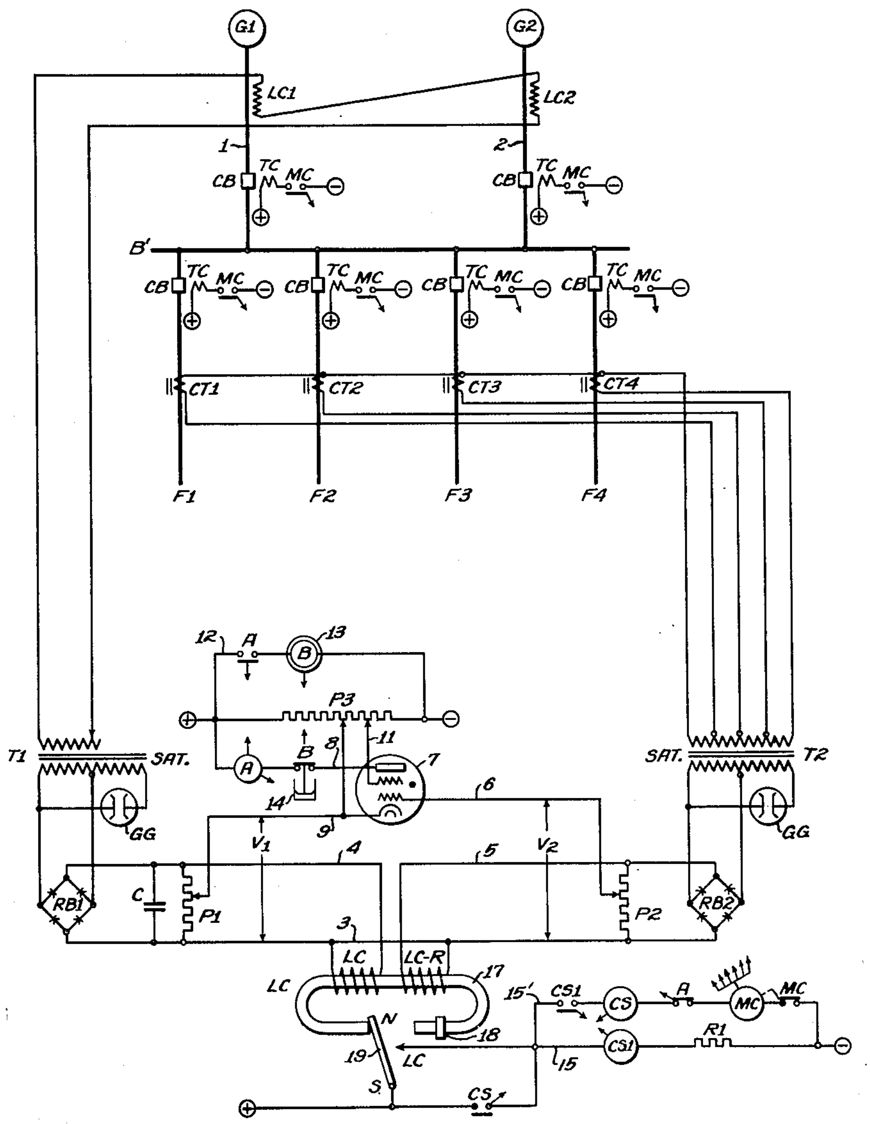
May 16, 1950 — W. K. SONNEMANN — 2,508,198

BUS-DIFFERENTIAL RELAY

Filed April 5, 1947



WITNESSES:

Robert C. Baird

INVENTOR

William K. Sonnemann.

BY O. B. Buchanan

ATTORNEY

Patented May 16, 1950 2,508,198

UNITED STATES PATENT OFFICE

2,508,198

BUS-DIFFERENTIAL RELAY

William K. Sonnemann, Roselle Park, N. J., assignor to Westinghouse Electric Corporation, East Pittsburgh, Pa., a corporation of Pennsylvania

Application April 5, 1947, Serial No. 739,559

19 Claims. (Cl. 175—294)

1

My invention relates to a new protective-relay assembly for the differential protection of multi-terminal alternating-current buses or other alternating-current equipment.

Heretofore, two principal relaying-systems have been available for the protection of multi-terminal alternating-current buses. One system has utilized ordinary line-current transformers, that is, iron-core transformers, on all of the bus-terminals, with slow-acting, differentially responsive relaying-means, energized so as to be substantially responsive, in effect, to the summated current of all of the current-transformers, this differentially responsive relaying-means being necessarily slow-acting in order to avoid errors in current-transformer performance due to asymmetrical current-components. The other available bus-differential protective-sytsem has utilized linear couplers in all of the bus-terminals, or air-core current-transformers such as are described and claimed in the Harder Patent 2,241,127, granted May 6, 1941, and the voltage-outputs of all of these linear couplers have been vectorially added, or summated, to energize a high-speed, differentially responsive, overvoltage-relay, the operation of which could be fast, because of the absence of iron-core errors due to the presence of asymmetrical fault-current components.

In both of the previously known bus-differential protective-systems, the current-responses in all of the bus-terminals have, in effect, been vectorially added, in order to produce substantially the same effect as a single, totalized relaying-current or voltage, which is theoretically zero under fault-free conditions, (assuming theoetically perfect current transforming means having no errors), and the resultant totalized current-response has been utilized to energize an overcurrent or overvoltage relay, the sensitivity of which has been limited only by the necessity for avoiding an erroneous response which would result from imperfectly matching characteristics of the various current-transforming means. The vectorial summation of the responses of all of the current-transforming means, in all of the terminals of the protected bus, has been necessary, in order to provide for the contingency of an external fault, external of the protected bus, that is, out on one of the lines (feeders or source circuits), which are connected to the several bus-terminals, being fed from currents entering the bus through any one or all of the other terminals, so that it was necessary to provide for the contingency of current-flow in either direction, in all of the bus-terminals.

2

Linear couplers add to the cost of the system, however, as they usually constitute so much extra equipment, added to the ordinary current-transformers which may be already in place, and necessarily so, for ordinary metering and relaying purposes; and the use of the linear-coupler bus-protection scheme has been limited, on this account, particularly on the many station-buses where there are a great many feeder-circuits per bus-section.

My present invention is particularly applicable to the many station-buses where there are a limited number of source-circuits per bus-section, but a great many feeder-circuits per bus-section, and where it is highly desirable to obtain instantaneous or quick-acting differential bus-protection, even though the expense of installing linear couplers in all of the feeder-terminals would be economically unjustifiable. This is particularly true for buses operating at approximately 13 kv., and lower voltages. In existing stations, current-transformers are already installed in the feeder-circuits, where they are needed for metering and for feeder-fault protection, as well as for differential bus-protection, and it is always desirable to utilize these existing current-transformers, if possible, in any bus-protected scheme, in order to reduce the cost.

My present invention is predicated upon three observations or discoveries. First, on most multi-terminal buses of the type to which my invention is particularly applicable, the load-circuit feeder-circuits contribute no appreciable amount of back-feed for a short-circuit on the bus. Second, the saturation, of an ordinary iron-core current-transformer, occurs only after a definite time-interval has elapsed after the incidence of the short-circuit, this time-interval varying from approximately one-eighth of a cycle, assuming a sixty-cycle system, up to greater values of time, depending upon the magnitude of the short-circuit current, the direct-current time-constant, the burden, and the design-constants of the transformer. Third, the installation of linear couplers in the relatively small number of source-circuits of such buses can readily be economically justified, in many cases, if such a relatively small number of linear couplers would be sufficient to insure an adequate high-speed bus-protection scheme.

It is an object of my present invention, therefore, to provide a high-speed differential bus-protection system, utilizing current-transforming elements in the terminal-leads of the protected bus, with at least some of said current-transforming elements being subject to saturation on heavy currents, in combination with means for quickly discriminating between internal and external short-circuits before the expiration of the time required for the saturable current-transforming elements to saturate, and means, responsive to such discrimination, for making said discrimination permanent for the duration of the short-circuit.

A further object of my invention is to provide such a system, utilizing linear couplers, or, in general, non-saturating current-transforming means, in the major-source terminals of the bus, and ordinary iron-core current-transformers in the load-circuit feeder-terminals of the bus, with means for separately summating the outputs of the linear couplers and the outputs of the current-transformers, plus a differentially-responsive internal-fault relay which is differentially responsive to the two summated outputs, and blocking-means, preferably selectively responsive to faults in the feeder-circuits, for blocking an erroneous delayed differential internal-fault response resulting from saturation of any current-transformer.

With the foregoing and other objects in view, my invention consists in the circuits, systems, combinations, elements, and methods of design and operation, hereinafter described and claimed, and illustrated in the accompanying drawing, the single figure of which is a diagrammatic view of circuits and apparatus embodying my invention in an illustrative form of embodiment.

In the drawing, I have shown my invention applied to the differential protection of an alternating-current bus B', which is diagrammatically represented, in what is known as a single-line diagram. Ordinarily, the bus, and its terminals, and the lines or feeders which are connected to the terminals, will consist of at least two, and usually three, conductors, according to whether the bus is a single-phase bus, or a three-phase bus. It is to be understood that the protective equipment, which is about to be described, may be associated with the bus and its terminals in any of the known manners, so as to respond to a phase-to-phase fault between two of the phase-conductors, or a ground-fault, or with a relaying-means of a type in which a single element responds to a plurality of different types of faults involving different phase-conductors or ground.

The bus B' usually has a plurality of major-source terminals, such as the terminals 1 and 2, which are connected to major power-sources for the bus, such as synchronous generators G1 and G2, respectively; although my invention is applicable, of course, when there is only one major source-circuit. The bus B' is further provided with a larger number of load-circuit feeder-terminals, such as F1, F2, F3 and F4, which are connected to load-circuits. Each of the terminals is connected to the bus B' by means of a circuit-breaker CB which is provided with a trip-coil TC.

When there are a plurality of major-source terminals, as shown at 1 and 2, they are either provided with high-quality (and therefore expensive) non-saturating iron-core current-transformers, or preferably, as shown, with non-saturable air-core current-transforming elements, such as the linear couplers LC1 and LC2, respectively, so as to eliminate the possibility of a false trip-out for an external fault on one of the major-source circuits. The secondary circuits of the linear couplers LC1 and LC2 are connected in series with each other, so as to vectorially add their current-responses, to energize the primary winding of an impedance-matching transformer T1, having taps which can be used, if necessary, for approximately matching the impedance of the secondary circuit of this transformer (which will subsequently be described), so as to be approximately the same as the total of the secondary impedances of the several linear couplers LC1 and LC2, this matched-impedance condition being the condition for obtaining the maximum energy from the linear couplers. In many cases, however, the desired minimum-trip-current setting of the fault-responsive relay (subsequently described) can be obtained without approximately matching impedances by means of tap-adjustment of the matching-transformer T1.

The several load-circuit feeder-terminals F1, F2, F3 and F4 are provided with saturable current-transforming elements, such as ordinary iron-core current-transformers CT1, CT2, CT3 and CT4, respectively. The currents delivered by these current-transformers are vectorially added, in an adjusting-transformer T2, which has different primary-winding taps for the outputs of the several current-transformers.

The two transformers T1 and T2 are both saturating-transformers. The secondary circuits of the transformers T1 and T2 energize rectifier-bridges, RB1 and RB2, respectively, which may be bridges utilizing copper-oxide rectifiers or any other suitable rectifiers. The saturable transformers T1 and T2 produce a peaked secondary voltage at high overloads, and a neon lamp or other grid-glow lamp GG is connected across the secondary-circuit of each of these transformers, to reduce these peaked-voltages, so as to protect the rectifier-bridges RB1 and RB2 against excessive voltages, as described and claimed in the Bostwick Patent 2,183,537, granted December 19, 1939.

In accordance with my present invention, the direct-current output-circuit, 3, 4, of the first rectifier-bridge RB1 is utilized to energize the operating-coil LC of a polarized linear-coupler relay LC, which has a normally open contact which is also designated by the same letters, LC.

In the drawing, the main or operating coils of the various relays are given the same letter-designation or legend as is applied to the relay as a whole, and this letter-designation or legend is also applied to all of the contacts of that relay, this being a convention which is adopted for the purpose of showing the interconnection between the various parts of the relays, in cases in which the coils and the contacts of any particular relay are separated in the drawing, after the manner of a schematic diagram or an "across-the-line" diagram. In case of a separation of the various parts of any relay, arrows or dotted lines are also used, to symbolically indicate how the various parts of each relay are connected together. The relays and switches are invariably shown in their open or deenergized positions.

In accordance with my invention, the direct-current output-circuit, 3, 5, of the second rectifier-bridge RB2 is utilized to energize a restraining-winding LC—R of the linear-coupler relay LC, so as to buck the magnetization of the operating-coil LC. The linear-coupler relay LC thus acts as a differential, internal-fault-responsive relay, for responding to internal faults, or faults on the protected bus B', as will be more fully explained hereinafter.

In accordance with my invention, the two output-voltages of the rectifier-bridges RB1 and

RB2 are utilized, in series-opposition to each other, to energize the control-grid circuit 6 of a grid-glow tube 7, or other grid-controlled tube of the sustained-discharge type, that is, a tube which will maintain a current-flow from its plate-circuit 8 to its cathode-circuit 9, once the current-flow has been started by the grid-control, until the plate-cathode circuit of the tube is externally deenergized, the grid being utilizable, as a control-means, only for the purpose of initiating, but not stopping, the tube-operation. The tube 7 thus acts as a high-speed, differential feeder-fault-responsive relay, for responding to external feeder-faults, that is, to faults on one of the feeders, F1, F2, F3 or F4, external of the protected bus B', as will be more fully explained hereinafter.

The direct-current output-voltages of the two rectifier-bridges RB1 and RB2 are made applicable, in the grid-circuit 6 of the tube 7, through two potentiometers P1 and P2, respectively, which produce the voltages V_1 and V_2, respectively. The positive terminal of the voltage V_1 is connected to the cathode-circuit 9 of the tube, so that the control-grid potential of the tube is made negative by the voltage V_1, which thus acts as a restraining voltage. The negative terminals of the two voltages V_1 and V_2 are connected together through the conductor 3. The positive terminal of the voltage V_2 is applied directly to the grid-terminal 6 of the tube, so that this voltage operates as a tube-operating voltage, for causing the main anode-cathode current to flow in the tube, when the total grid-control voltage (V_2—V_1) becomes sufficiently large or sufficiently positive.

The tube 7 is also shown as being provided with a screen-grid, having a terminal 11, which is biased from a potentiometer P3 which is energized from the positive and negative terminals (+) and (−) of any suitable direct-current voltage-source. The potentiometer P3 is provided with two taps, which are respectively connected to the cathode circuit 9 and the screen-grid circuit 11 of the tube, so that the tube-characteristics can be controlled.

In accordance with my invention, the plate-circuit 8 of the tube is utilized to energize the operating-coil A of a high-speed overvoltage-type relay A. Since the tube itself is differentially controlled, in response to the voltages V_1 and V_2 respectively, the high-speed relay A is thus a differentially-responsive relay, which responds differentially to the two output-voltages of the respective rectifier-bridges RB1 and RB2.

The high-speed differentially-responsive relay A has a make-contact A, which is utilized, in a circuit 12, to energize the operating-winding of a suitable time-delay relay B, from the direct-current buses (+) and (−). The timing or time-delay relay B has a back-contact B which is included in the anode-circuit 8 of the tube. The time-delay feature of the relay B is doubly indicated, diagrammatically, in the drawing, by means of a slug or short-circuited washer or coil 13 which is associated with the operating-coil B, and also by means of a dashpot 14 which is associated with the back-contact B, these two time-delaying indications being intended to be a symbolic or schematic representation of any time-delaying operation, whereby the relay will be slow in opening its back-contact B, and not too fast in reclosing the same, as will be subsequently pointed out.

The make-contact LC of the differential internal-fault-responsive linear-coupler relay LC is utilized, in a circuit 15, to energize the operating-coil CS1 of an auxiliary internal-fault-responsive relay CS1, from the direct-current source (+) and (−), through a resistance R1. The auxiliary internal-fault-responsive relay CS1 picks up, in something like three-quarters of a cycle, or between one-half cycle and a cycle, to close its make-contact CS1, in a branch-circuit 15' of the circuit 15, so as to be in series with the linear-coupler contact LC, and also, (in the particular embodiment illustrated), in series with the operating coil CS of a contactor-switch CS. The contactor-switch CS has a make-contact CS which is connected in shunt around the linear-coupler contact LC, so as to provide a holding-circuit for relieving the sensitive linear-coupler contact LC of any undue burden, in the event of a tripping-operation, such as will now be described. Thus, the branch-circuit 15' serially includes, in addition to the make-contact CS1 and the operating-coil CS, a back-contact A of the quick-acting relay A, the operating-coil MC of a master-contactor MC, and a back-contact MC of the same master-contactor. It will be understood, of course, that the functions of the contactor-switch CS and the master-contactor MC could have been combined into one relay, if so desired. The master-contactor MC is provided with a large number of make-contacts MC, one of said make-contacts being connected in series with each of the trip-coils, TC, of each of the circuit-breakers CB which are associated with each of the bus-terminals, 1, 2, F1, F2, F3 and F4, of the protected bus B'.

Preferably, the output-voltage of the rectifier-bridge RB1 is smoothed, and somewhat retarded in its response to changes in voltage-magnitude, by means of a shunt-connected capacitor C.

It may sometimes be desirable for the magnetic core 17 of the linear-coupler relay LC to be provided with a slug or short-circuited coil 18 for preventing or subduing the effect of pulsations of the rectified operating-current in causing possible vibrations in the polarized contact-making armature 19 of the relay.

The operation of my invention is as follows. Considering the source-circuits 1 and 2 alone, as though there were no feeder-circuits F1 to F4, it is obvious that, as far as the source-circuits are concerned, there is complete and perfectly operating high-speed differential protection, by means of the linear couplers LC1 and LC2 and the linear-coupler relay LC. Thus, any external fault which occurs on either one of the source-circuits 1 or 2 will not cause operation of the differential relay LC, because the total of the fault-currents which enter and leave the bus through the two source-circuits 1 and 2 will be zero, and the linear couplers, being non-saturable and accurate, will produce a zero summated voltage which will be applied to the impedance-matching transformer T1. The relay-system will thus be non-responsive to an external fault on either one of the source-feeders 1 and 2, and the discrimination is thus correct.

In the event of an internal fault, that is, a fault on the protected bus B', the breaker-tripping operation will be correct, and at a high speed, (within between 1 and 2 cycles) because practically all of the fault-current will be supplied from the supply-buses 1 and 2, producing a high rectified voltage across the terminals 3 and 4 of the operating-coil LC, while relatively little feed-back current will be fed into the faulted bus from the feeder-circuits F1 to F4, thus producing only a small rectified voltage in the terminals 3 and 5 of the restraining-coil LC—R of the high-speed differential relay LC.

In common with previously known linear-coupler bus-differential protective-schemes, it will be noted that my present system utilizes an auxiliary internal-fault-responsive relay CS1, which may be conveniently and deliberately designed or constructed so as to have about a three-quarter-cycle delay in its pick-up action. This much delay is desirable, in order to avoid an erroneous tripping-operation as a result of a shock-excitation of the sensitive high-speed linear-coupler relay LC, the contacts of which may be jarred closed, momentarily, as a result of a heavy jar on the switchboard-panel (not shown) on which it is mounted. The three-quarter-cycle time-delay of the auxiliary internal-fault-responsive relay CS1 also avoids an erroneous tripping-operation as a result of transient-conditions which might cause an instantaneous flicker in the summated responses of the several current-transforming elements, such as might cause the relay-contacts LC to momentarily close, instantly opening again.

In the event of an internal fault on the protected bus B′, however, the relay-contacts LC will close, and remain closed for the duration of the internal fault, even though some one or more of the feeders F1 to F4 should feed back a small percentage of the total internal-fault current. The measure of the permissible amount of such back-feed from the feeders F1 to F4 is that the current fed into the restraining-coil LC—R must not be sufficiently large to prevent the current in the operating-coil LC from operating the contacts LC; and that the voltage V_2 must not become large enough, with respect to V_1, to allow the tube 7 to become conducting. In the event of an internal fault on the bus B′, therefore, the relay-contact LC will close and remain closed, and the three-quarter-cycle time-delay of the auxiliary internal-fault-responsive relay CS1 will thus serve to make sure that the closure of the sensitive relay-contacts LC is a proper, lasting, internal-fault-responsive closure, and not a momentary flicker due to shock or transient-conditions. The slight time-delay of three-quarters of a cycle, in the energization of the trip-circuit, is quite acceptable in circuit-breaker operation.

In the event of an external fault on one of the feeder-circuits F1 to F4, say the feeder-circuit F1, the current-transformer CT1 in the faulted feeder will properly respond for at least one-eighth of a cycle, or until a material amount of saturation becomes effective in the iron core of the current-transformer. Hence, during this non-saturating time-period, the vectorial sum of all of the current-transformer secondary-currents of the feeder-circuits F1 to F4 will be equal, in effect, to the vectorial sum of all of the input-currents of the source-circuits 1 and 2, because the two saturating transformers T1 and T2 are adjusted so that this balanced condition exists. During this time-period, therefore, before material saturation becomes effective in the current-transformer CT1 of the faulted feeder F1, the differential relay LC will properly fail to respond to an external fault on the feeder F1. After a material amount of saturation becomes effective in the affected current-transformer CT1, the output of this transformer becomes smaller, and no longer properly proportional to the fault-current in the faulted feeder F1, and the sensitive differentially-responsive relay LC will usually close its contact. Thus, it will become necessary to provide means for preventing an effective relay-operation, that is, for preventing a tripping-operation of all of the circuit-breakers which are connected to the terminals of the protected bus B′.

In my apparatus, a faulty operation of the differential bus-protective relay LC, as a result of current-transformer saturation in the event of a feeder-fault, is blocked, or made ineffective, by the opening of the back-contact A of the high-speed feeder-fault-responsive relay A, the operating-time of which is less than a time equal to the time for the affected current-transformer CT1, in the faulted feeder, to saturate (thus starting the LC-relay to operate), plus the operating-time which is consumed in the closure of the differential internal-fault-responsive relay-contact LC, plus the operating-time of the auxiliary internal-fault-responsive relay CS1. Thus, there is ample time within which the back-contact A can open, and the relay A does not have to have exceptionally high-speed in its response.

The relay A is differentially controlled in response to the voltages V_2 and V_1, which are in turn responsive, respectively, to the summated current-transformer current and the summated linear-coupler voltage. The grid-glow tube 7, which energizes the relay A, may be made to recognize a feeder-fault, either through the sudden rate of increase of the summated feeder-currents, as delivered by the current-transformers CT1 to CT4, or by a sudden increase in the difference between V_2 and V_1, when V_2 and V_1 both become proportionately larger as the result of the fault-current which is drawn by the feeder-fault, or both types of response can be utilized in controlling the grid-glow tube.

A tube-response to the rate of increase of the totalized feeder-currents is obtained by reason of the filter-capacitor C which is connected in shunt-circuit relation to the voltage V_1 which is responsive to the totalized or summated linear-coupler voltages. This capacitor C draws a transient current, in response to any sudden increase in the rectified voltage of the conductors 3 and 4, thus interposing a slight delay or sluggishness in the time within which the voltage V_1 increases in response to the sudden increase in the rectified-voltage output of the rectifier-bridge RB1. Since there is no restraint on the sudden increase of the voltage V_2, which responds to the summated current-transformer outputs, the grid-control voltage (V_2—V_1) may be caused to have a momentarily positive value which is substantially greater than zero, in response to sudden feeder-current changes, even though the steady-state conditions will produce exactly balanced voltages V_1 and V_2.

On the other hand, it is possible to initially adjust the voltages V_2 and V_1, during normal fault-free conditions, so that the voltage V_2 is somewhat larger than the voltage V_1, but so that the voltage-difference (V_2—V_1) is insufficient to fire the tube 7, against the restraint of the shield-grid circuit 11, even under normal full-load conditions. Under fault-conditions, however, the difference between the two voltages V_2 and V_1 becomes larger, even though the increase in the voltage V_1 is not retarded by the capacitor C, and hence a tube-response can be obtained.

The ripple-smoothing capacitor C also has a very desirable function, in connection with the grid-circuit control of the tube 7, because it smooths out the ripples in the restraint-voltage V_1 which is applied to the grid-circuit 6 of the tube, thus reducing the sensitivity of the tube to phase-differences between the summated linear-coupler voltages and the summated current-transformer currents. The ripple-smoothing capacitor C reduces the magnitude of the dips or low-voltage points, in the restraint voltage V_1 which is applied to the tube.

In the event of a feeder-fault, therefore, the grid-glow tube 7 is caused to flash over, by the grid-control means just discussed, thus making the grid-glow tube 7 properly respond to an external fault on one of the feeders, such as F1, thus discriminating between such an external fault and an internal fault or bus-fault; and this action takes place well within the time in which saturation is likely to become noticeable, with its resultant decrease in the totalized secondary currents of the several feeder-circuit current-transformers CT1 to CT4. The feeder-fault-responsive relay A is immediately energized, as soon as the tube becomes conducting, because the back-contact B, in the plate-circuit of the tube, is closed.

The operation of the feeder-fault-responsive relay A does two things. First, it interrupts the trip-controlling circuit 15' by the opening of its back-contact A, thus preventing a faulty tripping-action, even though the internal-fault-responsive differential relay LC should falsely respond, after saturation sets in, in the fault-circuit current-transformer, such at CT1. The energization of the feeder-fault-responsive relay A also closes its make-contact A, in the circuit 12, thus energizing the operative-winding B of the time-delay relay B.

The timing-relay B responds after a suitable time-delay, which can be chosen to allow sufficient time for the duration of an external short-circuit, or for the external feeder-fault, or short-circuit on one of the feeders, such as F1, to be cleared by other protective-means (not shown); or the time-delay of the timing-relay B can be chosen to allow sufficient time for the direct-current saturation to disappear in the fault-circuit current-transformer, such as CT1.

When saturation disappears, the LC relay will resume its correct function and reset, even though the external fault still exists. This will free the relay-system, just that much more quickly, for correct operation on an internal fault, if one should occur before, or shortly after, the external fault is cleared.

The response of the timing-relay B opens its back-contact B in the plate-circuit 8 of the external-fault-responsive grid-glow tube 7, thus interrupting the flow of the plate-current. This plate-current has been flowing in the tube 7, regardless of the voltage of its control-grid circuit 6, ever since the tube was first fired. This is so, because the external-fault-responsive tube 7 is of the sustained-discharge type, in which its initial response to its grid-circuit 6 is permanent, regardless of any subsequent change in the grid-voltage. This permanent response of the tube 7 is terminated, by the opening of the back timing-relay contact 8, after a timing-relay response-time which is chosen, as previously described, so as to be longer than the duration of the short-circuit, or longer than the duration of the direct-current transformer-saturation resulting from the flow of the external-short-circuit current in the faulty-feeder current-transformer, such as CT1.

This action of the timing-relay B in interrupting the plate-circuit 8 of the external-feeder-fault grid-glow tube 7 results in a deenergization of the relay A, thus restoring the trip-controlling circuit 15' to its original condition, ready for another fault-responsive operation. The deenergization of the relay A also deenergizes the timing-relay B, but the dropout-action of this relay is slow enough to allow sufficient deionizing-time for the deionization of the space within the gas-filled tube 7, so that the tube will not immediately flash over again, but will remain in its non-conducting or unfired condition, until it again receives a sufficiently positive grid-voltage to fire the tube, as previously explained.

In the event of an internal fault on the protected bus B', since the invention is applied only to bus-systems in which the feeder-circuits F1 to F4 do not feed back a material amount of feed-back current to a bus-fault, the rectified voltage V2, which is responsive to the totalized feeder-currents as delivered by the current-transformers CT1 to CT4, will be quite small, as compared to the voltage V_1, which is responsive to the vector-sum of the very heavy source-circuit currents, as totalized by the serially connected secondaries of the linear couplers LC1 and LC2, so that the tube 7 is not fired, and hence the auxiliary feeder-fault-responsive relay A is not energized, and the back-contact A is not opened in the tripping-control circuit 15'. This permits a tripping-operation to be accomplished, in response to the closure of the internal-fault-responsive relay-contact LC and the contact CS1 of the auxilary internal-fault-responsive relay CS1. Under these internal-fault conditions, the tube-restraining voltage V_1 is so much larger than the tube-firing voltage V_2, for the reasons just explained, that the tube-blocking grid-control action occurs, with a safe margin, even with the change-delaying capacitor C present, because the action of the capacitor C, in retarding the voltage-rise in the rectified-voltage circuit 3—4, permits this voltage to respond quickly enough, to the increased source-circuit currents, to effectually block a tube-response as already described.

It will thus be understood that my improved differential bus-protecting relaying-system provides accurate and quick-acting bus-protection, responding properly to faults on the protected bus, but not responding to external faults, whether the external faults are on either the source-circuits, such as 1 and 2, or the feeder-circuits, such as F1 to F4. It is to be noted that this accurate high-speed bus-protection is produced in a relaying-system utilizing ordinary saturable current-transformers, such as CT1 to CT4, in the load-circuit feeder-terminals F1 to F4 of the protected bus, notwithstanding the fact that such high-speed protection (within 1 or 2 cycles) has not been possible in any previously known differential bus protection systems utilizing ordinary saturable current-transformers. It is to be noted, further, that the foregoing advantages are obtained by an assemblage of apparatus in which only the tube 7 has to have an operating-time less than the saturating-time of the current-transformer in the faulted feeder-circuit.

While I have illustrated my invention in a single illustrative form of embodiment, and have described its operation in respect to the illustrated form of embodiment, I wish it to be understood that various features of my invention are of generic application in other devices and circuits, and I desire that the appended claims shall be accorded the broadest construction consistent with their language.

I claim as my invention:

1. Protective relaying apparatus for differentially protecting a multi-terminal alternating-current bus having at least one or more major-source terminals which are connected to major power-sources for the bus, and a plurality of load-circuit feeder-terminals which are connected to load-circuits, a non-saturable current-transforming element or elements in the major-source terminal or terminals, and saturable current-transforming elements in the load-circuit feeder-terminals, said saturable elements being saturable on heavy currents, and said load-circuits contributing insufficient back-feed current, in general, during fault-conditions, to introduce serious saturation-errors in the relay-performance; said relaying apparatus being characterized by means for providing a separate relaying-circuit for the current or the summated currents of the non-saturable current-transforming element or elements, and for providing a separate relaying-circuit for the summated currents of the saturable current-transforming elements, a differentially responsive internal-fault-responsive relaying-means having an operating response to the relaying-circuit for the non-saturable current-transforming element or elements, and having a restraining response to the relaying-circuit for the saturable current-transforming elements, and fault-responsive blocking-means, responsive at least to feeder-faults, for operating in time to block an effective erroneous differential internal-fault response as a result of saturation of any current-transforming element.

2. The invention as defined in claim 1, characterized by said fault-responsive blocking-means including means for making its blocking-action permanent for the duration of the fault.

3. The invention as defined in claim 1, characterized by said fault-responsive blocking-means having an operating response to the relaying-circuit for the saturable current-transforming elements, before material saturation becomes effective, and having a restraining response to the relaying-circuit for the non-saturable current-transforming element or elements.

4. The invention as defined in claim 1, characterized by said fault-responsive blocking-means having an operating response to the relaying-circuit for the saturable current-transforming elements, before material saturation becomes effective, and having a restraining response to the relaying-circuit for the non-saturable current-transforming element or elements, and means for delaying any current-change in the relaying-circuit for the non-saturable current-transforming element or elements, while the current in the relaying-circuit for the saturable current-transforming elements is relatively free to change in magnitude in prompt response to the currents in the several load-circuit feeder-terminals.

5. The invention as defined in claim 1, characterized by said fault-responsive blocking-means being selectively responsive to the rate of change of the summated currents of the saturable current-transforming elements, before material saturation becomes effective.

6. The invention as defined in claim 1, characterized by said fault-responsive blocking-means comprising a quickly operative, differentially responsive, blocking relaying-means having an operative response to the relaying-circuit for the saturable current-transforming elements, before material saturation becomes effective, and having a restraining response to the relaying-circuit for the non-saturable current-transforming element or elements, in combination with auxiliary relaying-means, responsive to said quickly operative, differentially responsive, blocking relaying-means, for effecting a blocking action with respect to the differentially responsive internal-fault-responsive relaying-means.

7. The invention as defined in claim 1, characterized by said fault-responsive blocking-means comprising a quickly operative, differentially responsive, blocking relaying-means having an operative response to the relaying-circuit for the saturable current-transforming elements, before material saturation becomes effective, and having a restraining response to the relaying-circuit for the non-saturable current-transforming element or elements, and means for delaying any current-change in the relaying-circuit for the non-saturable current-transforming element or elements, while the current in the relaying-circuit for the saturable current-transforming elements is relatively free to change in magnitude in prompt response to the currents in the several load-circuit feeder-terminals, in combination with auxiliary relaying-means, responsive to said quickly operative, differentially responsive, blocking relaying-means, for effecting a blocking action with respect to the differentially responsive internal-fault-responsive relaying-means.

8. The invention as defined in claim 1, characterized by said fault-responsive blocking-means comprising a quickly operative, differentially responsive, blocking relaying-means which is selectively responsive to the rate of change of the summated currents of the saturable current-transforming elements, before material saturation becomes effective.

9. The invention as defined in claim 1, characterized by said fault-responsive blocking-means including a grid-controlled tube of the sustained-discharge type, means for supplying a restraining grid-voltage to said tube in response to the relaying-circuit for the non-saturable current-transforming element or elements, means for supplying a tube-actuating grid-voltage in response to the relaying-circuit for the saturable current-transforming elements, means responsive to a tube-operation for quickly blocking an effective response of the differentially responsive relaying-means, and time-delayed means, responsive to a tube-operation, for interrupting the tube-operation for a short while, at least long enough to deionize the tube.

10. Protective relaying apparatus for differentially protecting an alternating-current equipment using current-transforming elements in the ingoing and outgoing terminal-leads of said equipment, at least one or more of said current-transforming elements being subject to saturation on heavy currents; said relaying apparatus being characterized by a differential-current-responsive internal-fault relaying-means, energized by said current-transforming elements, for responding to internal faults within the protected equipment, and fault-responsive blocking-means, responsive at least to certain external faults, outside of the protected equipment, for operating in time to block an effective erroneous internal-fault response as a result of saturation in said current-transforming elements, in combination with an auxiliary relaying-means, responsive to said differentially responsive internal-fault re-

laying-means, for rendering the differential response effective, as a relay-operation control-means, only after the response of said auxiliary relaying-means, the blocking-means being operative prior to said response of the auxiliary relaying-means, in the event of a faulty differential internal-fault response as a result of saturation.

11. Protective relaying apparatus for differentially protecting a multi-terminal alternating-current bus having at least one or more major-source terminals which are connected to major power-sources for the bus, and a plurality of load-circuit feeder-terminals which are connected to load-circuits, a non-saturable current-transforming element or elements in the major-source terminal or terminals, and saturable current-transforming elements in the load-circuit feeder-terminals, said saturable elements being saturable on heavy currents, and said load-circuits contributing insufficient back-feed current, in general, during fault-conditions, to introduce serious saturation-errors in the relay-performance; said relaying apparatus being characterized by means for providing a separate relaying-circuit for the current or the summated currents of the non-saturable current-transforming element or elements, and for providing a separate relaying-circuit for the summated currents of the saturable current-transforming elements, a differentially responsive internal-fault-responsive relaying-means having an operating response to the relaying-circuit for the non-saturable current-transforming element or elements, and having a restraining response to the relaying-circuit for the saturable current-transforming elements, an auxiliary internal-fault relaying-means, responsive to said differentially responsive internal-fault-responsive relaying-means, for rendering the differential internal-fault response effective, as a relay operation control-means, only after the response of said auxiliary internal-fault relaying-means, and fault-responsive blocking-means, responsive at least to feeder-faults for operating in time to block said relay-operation in the event that said high-speed differentially responsive internal-fault-responsive relaying-means should erroneously respond after material saturation becomes effective in a saturable current-transforming element.

12. The invention as defined in claim 11, characterized by said fault-responsive blocking-means having an operating response to the relaying-circuit for the saturable current-transforming elements, before material saturation becomes effective, and having a restraining response to the relaying-circuit for the non-saturable current-transforming element or elements.

13. The invention as defined in claim 11, characterized by said fault-responsive blocking-means having an operating response to the relaying-circuit for the saturable current-transforming elements, before material saturation becomes effective, and having a restraining response to the relaying-circuit for the non-saturable current-transforming element or elements, and means for delaying any current-change in the relaying-circuit for the non-saturable current-transforming element or elements, while the current in the relaying-circuit for the saturable current-transforming elements is relatively free to change in magnitude in prompt response to the currents in the several load-circuit feeder-terminals.

14. The invention as defined in claim 11, characterized by said fault-responsive blocking-means being selectively responsive to the rate of change of the summated currents of the saturable current-transforming elements, before material saturation becomes effective.

15. The invention as defined in claim 11, characterized by said fault-responsive blocking-means comprising a quickly operative, differentially responsive, blocking relaying-means having an operative response to the relaying-circuit for the saturable current-transforming elements, before material saturation becomes effective, and having a restraining response to the relaying-circuit for the non-saturable current-transforming element or elements, in combination with auxiliary relaying-means, responsive to said quickly operative, differentially responsive, blocking relaying-means, for effecting a blocking action with respect to the differentially responsive internal-fault-responsive relaying-means.

16. The invention as defined in claim 11, characterized by said fault-responsive blocking-means comprising a quickly operative, differentially responsive, blocking relaying-means having an operative response to the relaying-circuit for the saturable current-transforming elements, before material saturation becomes effective, and having a restraining response to the relaying-circuit for the non-saturable current-transforming element or elements, and means for delaying any current-change in the relaying-circuit for the non-saturable current-transforming element or elements, while the current in the relaying-circuit for the saturable current-transforming elements is relatively free to change in magnitude in prompt response to the currents in the several load-circuit feeder-terminals, in combination with auxiliary relaying-means, responsive to said quickly operative, differentially responsive, blocking relaying-means, for effecting a blocking action with respect to the differentially responsive internal-fault-responsive relaying-means.

17. The invention as defined in claim 11, characterized by said fault-responsive blocking-means comprising a quickly operative, differentially responsive, blocking relaying-means which is selectively responsive to the rate of change of the summated currents of the saturable current-transforming elements, before material saturation becomes effective.

18. Protective relaying apparatus for differentially protecting an alternating-current equipment using current-transforming elements in the ingoing and outgoing terminal-leads of said equipment, at least one or more of said current-transforming elements being subject to saturation on heavy currents; said relaying apparatus being characterized by a differential-current-responsive internal-fault relaying-means, energized by said current-transforming elements, for responding to internal faults within the protected equipment, and fault-responsive blocking-means, responsive at least to certain external faults, outside of the protected equipment, for operating in time to block an effective erroneous internal-fault response as a result of saturation in said current-transforming elements, in combination with an auxiliary relaying-means, responsive to said differentially responsive internal-fault relaying-means, for rendering the differential response effective, as a relay-operation control-means, only after the response of said auxiliary relaying-means, the blocking-means being operative prior to the expiration of a time equal to about one-eighth of a cycle, plus the operating-time of the

differentially responding internal-fault relaying-means, plus the operating-time of the auxiliary relaying-means, after the occurrence of a fault-condition to which said blocking-means responds.

19. Protective relaying apparatus for differentially protecting a multi-terminal alternating-current bus having at least one or more major-source terminals which are connected to major power-sources for the bus, and a plurality of load-circuit feeder-terminals which are connected to load-circuits, a non-saturable current-transforming element or elements in the major-source terminal or terminals, and saturable current-transforming elements in the load-circuit feeder-terminals, said saturable elements being saturable on heavy currents, and said load-circuits contributing insufficient back-feed current, in general, during fault-conditions, to introduce serious saturation-errors in the relay-performance; said relaying apparatus being characterized by means for providing a separate relaying-circuit for the current or the summated currents of the non-saturable current-transforming element or elements, and for providing a separate relaying-circuit for the summated currents of the saturable current-transforming elements, a differentially responsive internal-fault-responsive relaying-means having an operating response to the relaying-circuit for the non-saturable current-transforming element or elements, and having a restraining response to the relaying-circuit for the saturable current-transforming elements, an auxiliary internal-fault relaying-means, responsive to said differentially responsive internal-fault-responsive relaying-means, for rendering the differential internal-fault response effective, as a relay-operation control-means, only after the response of said auxiliary internal-fault relaying-means, and fault-responsive blocking-means, responsive at least to feeder-faults, for blocking said relay-operation, said blocking-means being operative prior to the expiration of a time equal to about one-eighth of a cycle, plus the operating-time of the differentially responding internal-fault relaying means, plus the operating-time of the auxiliary relaying-means, after the occurrence of a fault-condition to which said blocking-means responds.

WILLIAM K. SONNEMANN.

REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

Number	Name	Date
1,927,794	Fallou	Sept. 19, 1933
1,959,053	Goldsborough	May 15, 1934
2,183,537	Bostwick	Dec. 19, 1939
2,289,149	Sonnemann	July 7, 1942