Oct. 20, 1970 F. MAYER 3,535,590

HIGH SENSITIVITY ELECTROMECHANICAL ACTUATORS

Filed Dec. 9, 1968 4 Sheets-Sheet 1

FIG. 1

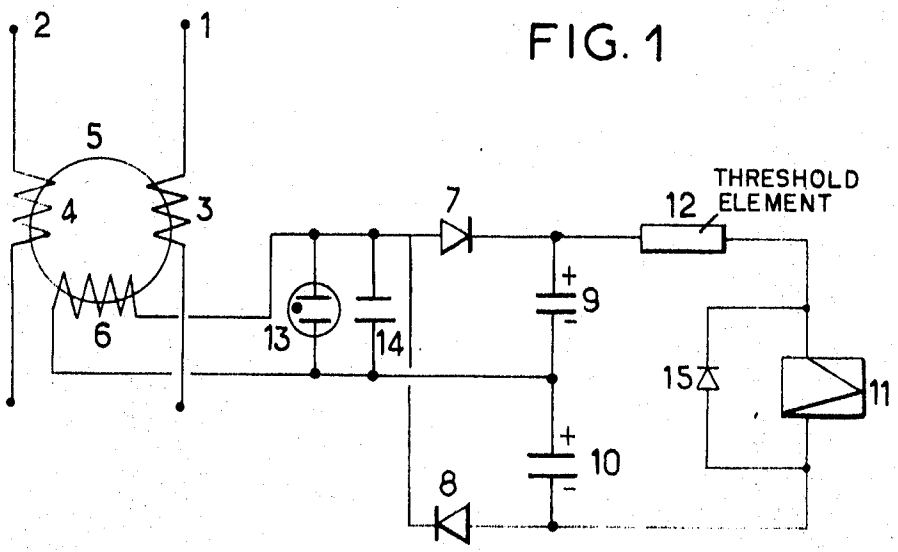
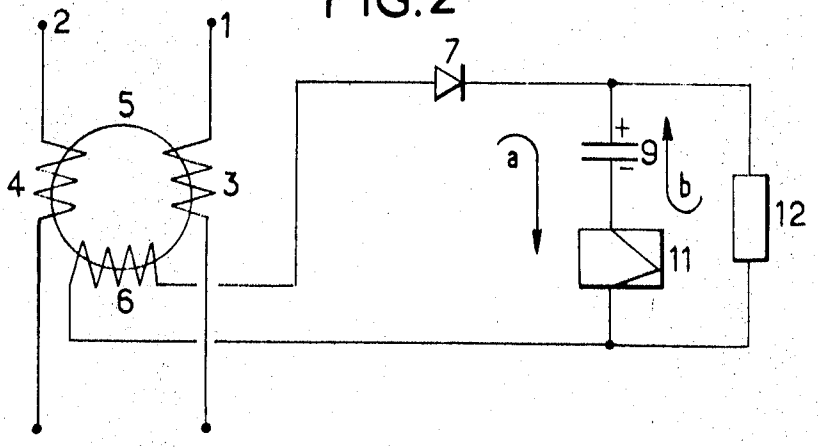


FIG. 2



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FIG. 3

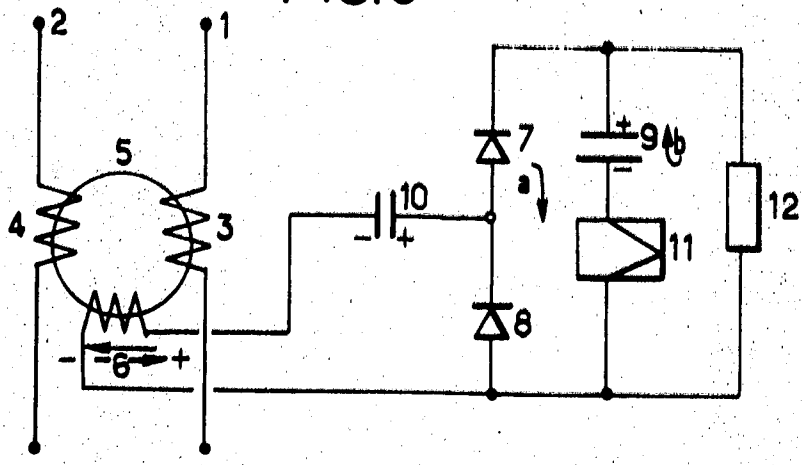
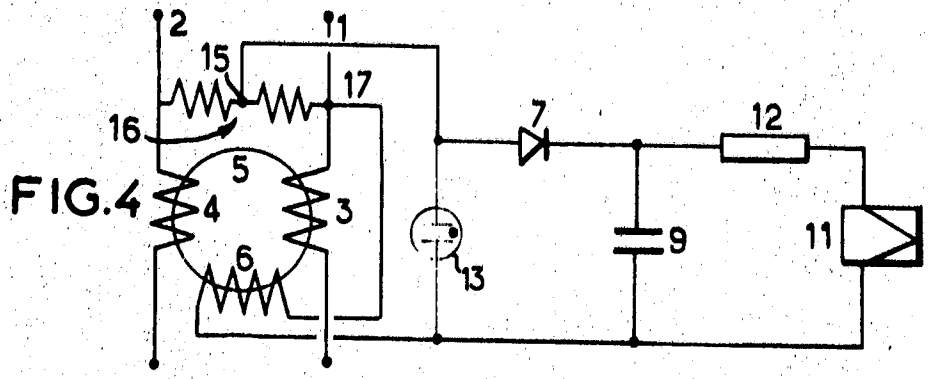


FIG. 4



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FIG. 5

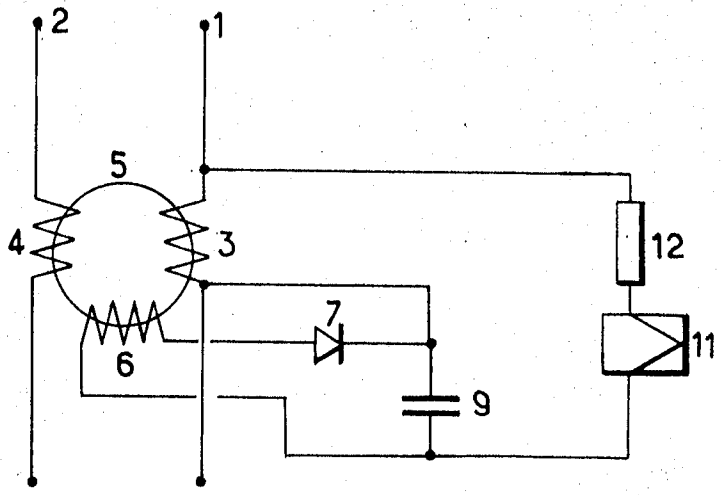


FIG. 6

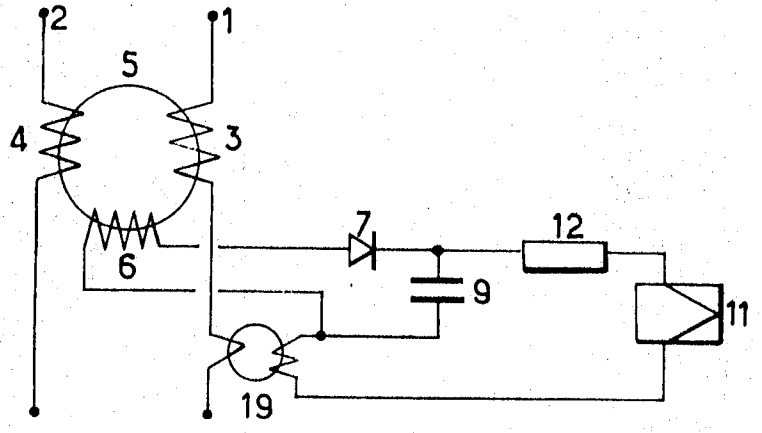
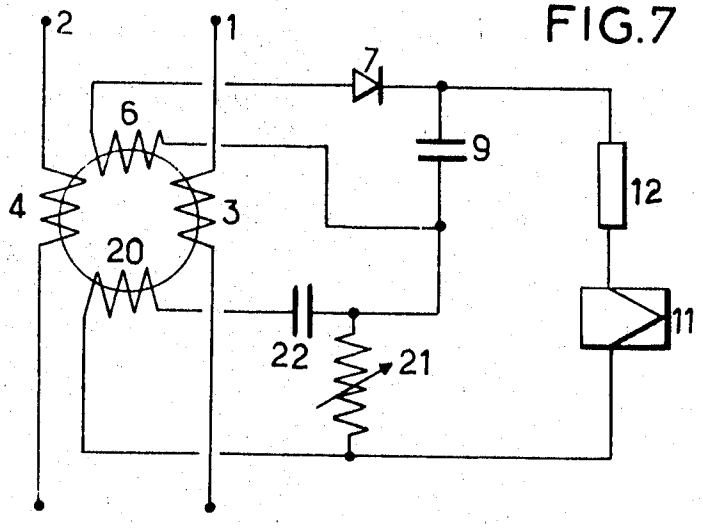


FIG. 7



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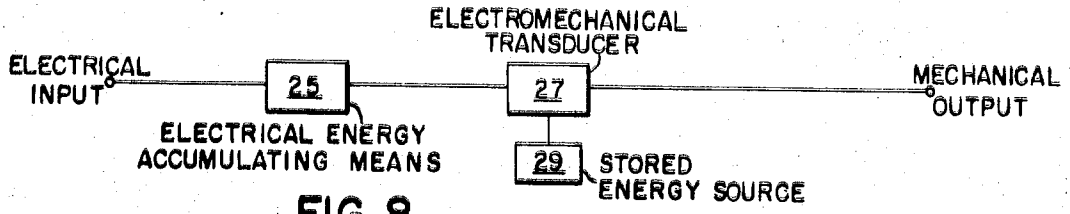


FIG.8.

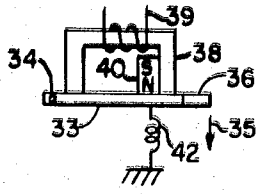


FIG.9.

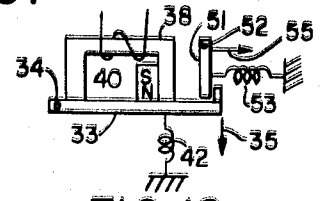


FIG.10.

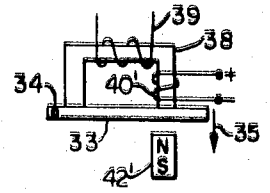


FIG.11.

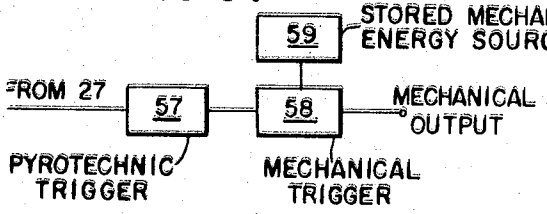


FIG.12.

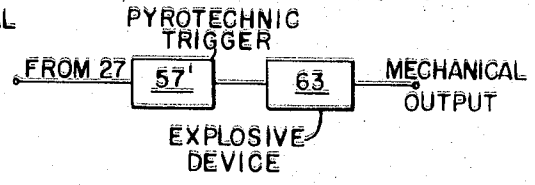


FIG.13.

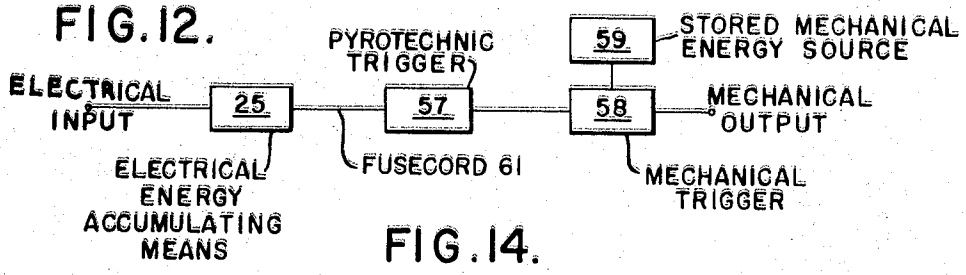


FIG.14.

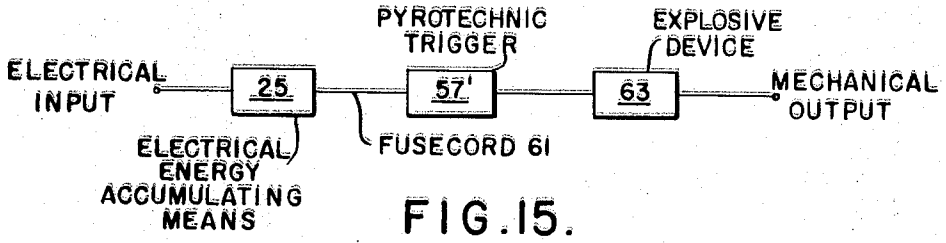


FIG.15.

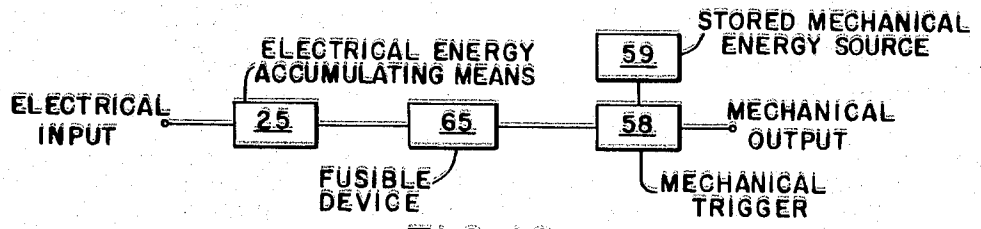


FIG.16.

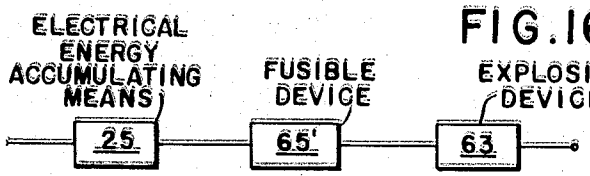


FIG.17.

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HIGH SENSITIVITY ELECTROMECHANICAL ACTUATORS

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Continuation-in-part of application Ser. No. 467,280, June 28, 1965. This application Dec. 9, 1968, Ser. No. 784,540

Int. Cl. H01h 9/20; H02h 3/28, 7/26

U.S. Cl. 317—18 19 Claims

ABSTRACT OF THE DISCLOSURE

A high sensitivity electromechanical actuator arranged to convert a low level electrical signal into a high amplitude current pulse and to apply such pulse for actuating an electromechanical transducer provided with a source of stored mechanical energy so as to provoke the release of such energy in the form of a high level mechanical signal.

CROSS REFERENCE TO RELATED APPLICATION

This is a continuation-in-part of application Ser. No. 467,280, filed on June 28, 1965, now abandoned.

BACKGROUND OF THE INVENTION

This invention relates to electrical protection devices and more especially to devices for the protection of electrical circuits against fault currents to earth.

Protective devices against the fault currents to earth comprise a differential transformer as a rule, whose primary windings are traversed by the currents in the conductors of the supply circuit which is to be protected, and a secondary winding whose induced voltage, which is a rising function of the fault current, is applied to the energizing winding of a protective relay in such manner as to cause the operation of the relay as soon as this fault current reaches a limiting value which should not be exceeded.

To the extent that personnel safety against the danger of electrocution must be assured, it has been agreed that the fault current to earth through an individual should not exceed 30 ma. It will be appreciated that the signal appearing at the secondary of the transformer then represents a very low power and that the operation of the triggering relay cannot be assured unless the relay is extremely sensitive, which explains the difficulties of construction and adjustment which are not compatible with the requirements of industrial production.

These are the reasons why other protective devices have been developed against failure or leakage currents, such as those described in the applicant's French Pat. No. 1,267,270 of June 9, 1960.

In these devices, the energising coil of the triggering relay is connected as a rule across the terminals of a storage or accumulaton element of electrc power such as a condenser, through an electronic switch which is normally in the "open" position when the voltage at its terminals is lower than a predetermined threshold, corresponding to the value considered to be acceptable for the fault current to earth, and assumes the "closed" position as soon as this voltage rises above this threshold.

This method is not however free of shortcomings. In particular in the case of a very substantial failure current, for example of the order of some hundreds of amperes, there is a risk of a deterioration of the secondary winding or of the diodes setting in, owing to the overvoltage appearing in the secondary winding, and of a demagnetization of the permanent magnet of the triggering relay employed in this apparatus, owing to the possible repetition of substantial failure currents.

SUMMARY OF THE INVENTION

The present invention has as its main object a control device for a relay intended to protect a supply circuit against fault failure currents to earth, and which eliminates the shortcomings set out above.

According to the invention there is provided a device for the protection of an electrical installation against fault currents, of the kind comprising a differential transformer for detection of a fault current, and a relay connected through a threshold electronic switch to the terminals of a storage element which is supplied from the differential transformer through a rectifier, characterized by the association of a fault detection circuit comprising the output winding of the said differential transformer and the said relay with at least one device for limiting the volatge developed in this detection circuit.

The objects according to the invention are also achieved by certain improvements in an electromechanical actuating device responsive to a low power electrical signal, which is the only external source of energy to the device, for producing a high energy mechanical output when the amplitude of the electrical signal exceeds a predetermined value, which device includes energy accumulating means connected to receive the electrical signal, to accumulate energy therefrom over a period of time, and to discharge this accumulated energy in the form of a short duration pulse. According to the improvements of the present invention, the device further includes electromechanical transducer means connected to receive such pulse from the energy accumulating means and composed of a source of stored additional energy, the transducer being arranged to undergo, in response to such pulse, an irreversible action which releases such stored energy, the device thus producing a gain in the substantially instantaneously available electric power due to the action of the energy accumulating means and a gain in the resulting mechanical energy due to the release of the stored additional energy.

The action of the transducer may be completely irreversible in that, after having been actuated, its resetting must be accomplished by the application of some external force, or it can be irreversible only for a substantially long period of time to permit the condition causing the response to be eliminated or corrected before the transducer automatically resets.

According to a particular feature of the invention, a voltage limiting device intended to protect to differential transformer and the relay against overvoltages caused by asymmetrical short-circuits, is formed by a small gas-filled tube arranged in parallel with the fault detection circuit.

According to another feature of the invention, the protective device against fault currents effects a grouping in cascade of an accumulation of energy in the form of alternating current and of another in the form of direct current, by the presence of a tuned circuit, before rectification of the leakage energy.

According to another feature of the invention, the protective device against leakage currents assured its own protection against overvoltages by judicious arrangement of its different elements.

According to another feature of the invention, it is possible to reduce the voltage required for the secondary of the differential transformer by superimposing an auxiliary voltage on the same.

Finally, according to an additional feature of the invention, it is possible to facilitate the triggering of the electric switch by means of a synchronization signal, and by virtue of this fact, even to secure the opening of the protected circuit at a definite instant of the cycle of the supply voltage of this circuit.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a circuit diagram of one embodiment of the invention.

FIG. 2 is a view similar to that of FIG. 1 of another embodiment of the invention.

FIG. 3 is a view similar to that of FIG. 1 of still another embodiment of the invention.

FIG. 4 is a view similar to that of FIG. 1 of yet another embodiment of the invention.

FIG. 5 is a view similar to that of FIG. 1 of a further embodiment of the invention.

FIG. 6 is a view similar to that of FIG. 1 of still a further embodiment of the invention.

FIG. 7 is a view similar to that of FIG. 1 of yet a further embodiment of the invention.

FIG. 8 is a block diagram of a complete device constituting one embodiment of the present invention.

FIG. 9 is a partly pictorial, partly schematic view of a preferred embodiment of one component of devices according to the invention.

FIG. 10 is a view similar to that of FIG. 9 showing another embodiment of such component.

FIG. 11 is a view similar to that of FIG. 9 showing still another embodiment of such component.

FIG. 12 is a block diagram of a portion of a device constituting another embodiment of the invention.

FIG. 13 is a view similar to that of FIG. 12 of yet another embodiment of the invention.

FIG. 14 is a view similar to that of FIG. 8 showing still another embodiment of the invention.

FIG. 15 is a view similar to that of FIG. 8 showing a further embodiment of the invention.

FIG. 16 is a view similar to that of FIG. 8 showing yet a further embodiment of the invention.

FIG. 17 is a view similar to that of FIG. 8 showing a still further embodiment of the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

In the drawings the same reference denote the same or similar parts.

In the embodiment illustrated in FIG. 1, **1** and **2** denote the conductors of a single-phase electric power distribution grid. In these conductors are respectively connected the primary windings **3** and **4** of a differential transformer **5**. This transformer includes a third winding **6** for detecting the differential flux resulting from a leakage current to earth. Each alternation of the secondary voltage is rectified by diodes **7** and **8** which are respectively connected to the secondary winding **6** so as to charge condensers **9** and **10** according to the polarities shown in the figure.

To the terminals of the electrical energy accumulator formed by the two condensers **9** and **10** is connected the energizing coil **11** of a triggering relay, polarized by a small permanent magnet, not shown in detail. The coil **11** is in series with a diode **12** of the threshold type, that is to say a diode which is normally blocked when the voltage across its terminals is lower than a predetermined threshold, and which becomes conductive when this voltage rises above this threshold, thus allowing the condensers **9** and **10** to discharge into the coil **11**, thereby causing the circuit which is to be protected to be opened by energising the said relay. A conventional diode **15** connected across the terminals of the coil **11** of the relay assures in manner known the recovery of the reactive energy at the instants of circuit interruption by the diode **12**.

The use of the voltage doubler formed by the diodes **7** and **8** and the condensers **9** and **10** in this embodiment makes it possible to reduce the voltage required at the secondary winding **6** of the differential transformer **5** for a given fault current, and thus to limit the alternating voltage resulting from a powerful failure current.

It may be recalled at this point that if this protective device should cause the supply circuit to open when a fault current to earth reaches 30 ma., it is generally accepted that it should also be adapted to do so when this current reaches higher values of up to 500 amps.

In a certain measure the second voltage resulting from a powerful leakage current may be limited by employing high-permeability materials, but whose induction remains relatively low when the circuit is saturated, for example permalloy or mu metal for the magnetic circuit of the transformer.

Finally, a limitation of the differential voltage is accomplished by connecting across the terminals of the secondary winding **6** a miniature neon tube **13** of the Ne2 type for example. For fault currents to earth which do note exceed 30 ma., the secondary voltage is effectively of the order of 15 volts as a rule, and the tube **13** does not strike. For higher failure currents, the secondary voltage may include pulses whose peak values may reach several hundreds of volts. In this case, the tube **13** strikes and the secondary voltage cannot exceed 80 to 100 volts.

It should also be noted that this neon tube may act as a warning device. In effect, if for any reason, the circuit-breaker employing this protective device has not caused the interruption of the load circuit when a relatively substantial failure current has occurred, the tube **13** lights up intermittently and thus gives warning of an earth leakage current either as a direct visual warning, or by action on a photosensitive element acting on an audible warning device for example.

In addition, the operation of the neon tube **13** may be made to serve the purpose of measuring (the frequency of the neon flashes is directly proportional to the differential current) or localising leaks to earth in the different load circuits.

Finally, in the circuit diagram of FIG. 1, there is shown a low-rating condenser **14** connected across the terminals of the secondary winding **6**. The condenser **14** matches the self-inductance of the transformer **5** to the frequency of the energy distribution grid. This also decelerates the rise of the secondary voltage in the case of powerful fault currents since its essential advantage resides in the fact that by virtue of this action, it feeds in an overvoltage with accumulation of reactive energy. With this arrangement one thus really has an accumulation of energy in cascade, namely in alternating form through the self-inductance **6** and the condenser **14**, and thereafter an accumulation of direct current by the continuous charge of the condensers **9** and **10**.

FIG. 2 also shows the conductors **1** and **2** of the distribution grid which include in series the primary windings **3** and **4** of the differential transformer **5** whose secondary winding **6** assures the detection of the differential flux. In the secondary circuit there is in series with the winding **6** a diode **7** for rectifying the secondary voltage, a "storage" condenser **9** and the energising coil of the triggering relay **11**.

The threshold diode **12** is connected across the terminals of the condenser-relay assembly in this embodiment.

In the presence of a weak fault current, the alternating voltage appearing at the terminals of the secondary winding **6** is rectified by the diode **7** and progressively charges the condenser **9**. The direction of this charging current, shown by the arrow *a*, is such that it reinforces the attraction of the displaceable armature of the relay already provided by the permanent magnet. The circuit-breaker thus remains in the closed position.

The direct voltage at the terminals of the condenser **9** rises and may reach, for an unacceptable failure current to earth, the striking threshold of the diode **12**. This latter then becomes conductive allowing the circuit comprising the elements **9**, **12**, **11** to be closed, and the condenser **9** discharges into the energizing coil of the relay **11**. The direction of the discharge current, shown by the arrow *b*, is such that its action is opposed to the permanent polarization of the relay. The armature of the relay

is then released and causes the circuit which is to be protected to open.

In the presence of a powerful failure current, for example several hundreds of amps, the same phenomena recur, but much more rapidly. It should be noted that when the diode **12** is in the conductive state and the condenser **9** has been discharged into the coil of the relay **11**, the diode "short-circuits" the relay and, owing to this fact, any supplementary current supplied by the differential transformer **5** has no further influence on the relay.

In other words, the arrangement illustrated in FIG. 2 makes it possible to eliminate the risk of demagnetization which could arise in circuits of the kind described with reference to FIG. 1.

It may be taken moreover that the rapid pulse of the charge of the condenser **9** (in the case of a powerful failure current), which acts in the sense of magnetization of the permanent polarizing magnet of the relay, acts beneficially against the ageing of this magnet.

FIG. 3 illustrates a variant of a protective device according to the invention. The principle of operation has been retained, and the storage condenser **9** in series with the coil **11** of the relay, the assembly being shunted by the diode **12**.

In this case, the advantages of this device are combined with those obtained by the presence of a voltage doubler.

The voltage doubler employed, formed by the elements **10**, **7** and **8** cannot be of the same type as that provided in FIG. 1. It is conventional however and its principle may be recalled briefly.

During one half-cycle of the voltage supplied by the secondary winding **6**, the condenser **10** is charged through the diode **8** according to the polarities shown in the figure. During the other half-cycle, the voltage supplied by the secondary winding is added to that which is already present at the terminals of the condenser **10** and charges the storage condenser **9** through the diode **7**.

In order to enhance the sensitivity of the devices and to obtain certain other advantageous characteristics, such as limitation of the overvoltages supplied by the secondary of the differential transformer in the case of strong fault currents an auxiliary voltage may be superimposed on that engendered by the failure current itself.

In FIG. 4, an electric energy accumulator condenser **9** is supplied through a diode **7** from a tapping **15** on a resistance type voltage divider **16** and from a point **17** of the conductor **1**, so that the voltage eventually appearing at the terminals of the secondary **6** is added to that tapped off the divider **16**. The energizing coil **11** of the triggering relay is connected to the terminals of the condenser **9** in series with the threshold diode **12**.

In operation, when the charges of the conductors are balanced, the condenser **9** is charged by the voltage existing between the two points **16** and **17**, the current being rectified by the diode **7**. It should be noted that this voltage is not adequate to cause the activation of the diode **12**. As soon as an imbalance of the charges appears in the conductors **1** and **2**, caused by a leakage current to earth, the voltage induced in the winding **6** is added to that supplied by the resistance **16** and causes the activation of the diode **12**. The condenser **9** is discharged suddenly into the winding **11** of the relay, thus assuring the operation of the safety devices.

It will easily be appreciated that the voltage required from the secondary of the differential transformer can be reduced, which makes it possible to reduce the number of turns forming this winding, and consequently to reduce or even eliminate the risk of deterioration in the secondary circuit.

A protective tube **13** of the kind described with reference to FIG. 1, may however be incorporated in this case as well.

In the preceding arrangement, which is naturally liable to form the basis of a variety of variants, a rectified auxiliary voltage has been employed.

In the degree to which this auxiliary voltage is periodical and linked to the frequency of the voltage of the distribution grid, certain particularly remarkable operating characteristics of the protective device are achieved.

Thus, in FIG. 5, the alternating voltage appearing at the terminals of one of the primary windings is superimposed on the direct voltage appearing at the terminals of the condenser **9** due to the presence of a leakage current to earth in the installation which is to be protected.

Owing to the low impedance of the source of alternating voltage, there is thus obtained, just at the instant at which it is needed, a voltage pulse which can cause the triggering of the diode **12**, thus making the arrangement more independent in respect of the pre-striking currents of the threshold diodes or "switching" diodes.

It is quite clear that the principle of superimposing alternating and direct voltages such as described with reference to FIG. 5 may easily be applied to arrangements employing rectifying circuits having a voltage doubler such as described with reference to FIGS. 1 and 3.

In FIG. 6, a relatively important value for the periodic voltage to be superimposed on the signal resulting from a fault current, is achieved. To this end, a small current transformer **19** having a saturated magnetic circuit is incorporated in one of the conductors of the distribution circuit, for example the conductor **1**. This transformer makes it possible to obtain brief pulses of a few volts during the falling to zero of the phase currents. The diode **12** thus strikes precisely at the instant in which the main current traversing the protective apparatus is nil. If the triggering period of the blocking mechanism is short compared to the period of the alternating voltage, it is thus certain, by this synchronization, that the circuit to be protected is broken very close to passage to zero of the current. This is very advantageous in respect of the durability of the circuit-breaker contacts.

FIG. 7 illustrates a variant of the method of synchronization of the triggering action. The saturated transformer **19** of FIG. 6 is omitted, and the synchronizing voltage is obtained from a supplementary secondary winding **20** carried by the mail differential transformer **3**.

In the case in which the period of mechanical interruption of the circuit-breaker is relatively prolonged, one may nevertheless retain the advantages of interruption of the main current on its falling near to zero. As illustrated in FIG. 7, it is sufficient to make provision for appropriate and adjustable phase shifting of the synchronizing signal, by means of a resistance capacity circuit **21**, **22**.

To simplify matters, the auxiliary synchronizing voltage may be tapped either off the terminals of one of the primary windings, or off the terminals of the secondary winding **6**, or off the terminals of a fraction of this last winding.

Although the application of the invention for the protection of single phase circuits has been described with reference to the exemplified embodiments, a device according to the invention for protection against fault currents to earth can be applied to a polyphase distribution circuit.

The circuits thus far described constitute various types of electrical energy accumulating arrangements which may be employed in combination with various types of electromechanical transducers, represented generally in FIGS. 1–7 by the element **11**, to form electromechanical actuating devices according to the invention. The electrical energy accumulating arrangements used in devices according to the invention may be of three different types: (1) direct current energy accumulators; (2) alternating current energy accumulators; and (3) combined alternating current-direct current energy accumulators.

FIGS. 2 to 7 illustrate various types of direct current energy accumulators wherein at least one diode is employed for permitting the flow only of direct current to a storage element, such as a capacitor, so as to cause energy from a succession of current pulses to be accumulated in

the storage element until the voltage thereacross reaches a value sufficient to render the threshold element connected between the storage element and the electromechanical transducer conductive, whereupon the energy which has been accumulated by the storage element is delivered in the form of a high amplitude, short duration current pulse to the electromechanical transducer.

One form of combined alternating current-direct current accumulation is illustrated in FIG. 1 wherein winding **6** and capacitor **14** form a resonant circuit so that the energy stored in the capacitor increases progressively during each successive cycle of the alternating current to which the device is to respond and the energy accumulated by the capacitor is conveyed in the form of a rectified current to the direct current accumulating elements **9** and **10**.

Finally, an alternating current accumulation could be achieved by providing a resonant circuit similar to that formed by the elements **6** and **14** of FIG. 1 and by connecting the capacitor **14** directly across the series arrangement of threshold elements **12** and electromechanical transducer **11**, whereupon the threshold element would be rendered conductive when the cyclically increasing voltage across capacitor **14** reaches a sufficiently high value.

There will now be described, with reference to FIGS. 8 to 17, the overall arrangement of electromechanical actuating devices according to the invention and various specific types of electromechanical transducers, all of which transducers are intended to be actuated by the short duration current pulse delivered by the energy accumulating means upon the breakdown of the threshold element.

FIG. 8 shows a complete actuating device in which the low level electrical signal to which the device is to respond is delivered via an electrical input of the electrical energy accumulating means **25**, which may be constituted by any of the electrical energy accumulating circuits shown in FIGS. 1 to 7 when the signal to be sensed is constituted by an alternating current. In the event that a direct current is to be sensed, only a direct current accumulation would be employed.

The output from the electrical energy accumulating means **25** is connected to the electrical input of an electromechanical transducer **27** so that the transducer will receive the high amplitude, short duration current pulse produced by means **25** upon the breakdown of its associated threshold element. The transducer **27** is combined with a source of stored energy **29** in such a manner that the response of the transducer to the current pulse from means **25** triggers the release of the energy stored by source **29**, this released energy producing the mechanical output for the device.

It will be readily appreciated that the transducer **27** can be easily arranged to control the release of stored energy which is several orders of magnitude greater than the energy contained in the pulse delivered by accumulating means **25**. Thus, the device illustrated in FIG. 8 can be arranged to produce an enormous amplification of the energy contained in the low level electrical signal applied to the input of accumulating means **25**.

This is true because the accumulating means **25** produce a substantial effective energy amplification by storing energy derived from the signal applied to the electrical input over a period of time and releasing this energy in the form of a high amplitude, short duration current pulse which has a higher instantaneous power content than the low level signal applied to its input. Then, this high amplitude, short duration pulse is applied to the electromechanical transducer so as to trigger the release of a substantially larger quantity of stored energy, which is released in the form of mechanical energy, to produce a mechanical output whose energy content can be many orders of magnitude greater than the instantaneously available energy content of the low level electrical signal to which the device is to respond.

FIGS. 9, 10 and 11 illustrate various exemplary embodiments of electromechanical transducer-stored energy source units for use in embodiments of the invention. FIG. 9 shows one embodiment in which the electromechanical transducer is constituted by a polarized relay composed of a pole piece **38**, an armature **33** pivotally mounted on a pin **34**, and a polarizing magnet **40** producing a magnetic field which is sufficient, by itself, to maintain the armature **33** in the position shown, where it contacts the faces of pole piece **38**.

The pole piece is provided with a winding **39** which is connected to receive the output from electrical energy accumulating means **25**, the winding being arranged in such a manner that the current pulse from means **25** will induce in pole piece **38** a magnetic flux which opposes that produced by magnet **40**. The stored energy source of this embodiment is constituted by a tension spring **42** connected to the armature **33** and tending to urge the armature in the direction of the arrow **35** into an open position.

Spring **42**, which can be arranged to produce a strong pulling force, i.e., to have a high potential energy, is adjusted so that the force with which it attracts armature **33** is just less than the attractive force exerted by magnet **40** when the armature is in the position shown. A slight reduction in the net magnetic attractive force exerted on armature **33** will cause the force exerted by spring **42** to become controlling so that the armature **33** will be drawn downwardly in the direction or arrow **35** and the energy stored in spring **42** will be released by being converted into the movement of a projection **36** carried by armature **33**. The projection **36** could be arranged to operate any type of mechanical output device.

The reduction in the magnetic attractive force exerted on armature **33** is effected by the application of a current pulse from the energy accumulating means **25** to the winding **39**. This arrangement is highly advantageous because a current pulse of even very short duration will be effective to permit release of the armature **33** since the armature need be permitted to move only a small distance away from the magnet **40** in order for the attractive force exerted by that magnet to be substantially reduced. Therefore, once the armature has moved but a small distance away from magnet **40**, upon the application of a current pulse to winding **39**, the spring **42** will become effective to effect the further downward movement of the armature, even if the current through winding **39** should cease.

FIG. 10 illustrates another embodiment of the present invention wherein the mechanical transducer illustrated in FIG. 9 is associated with a combination of a mechanical trigger constituted by a lever **51** mounted on a pivot **52** and a further stored energy source constituted by a tension spring **53** arranged to move the lever **51** in the direction illustrated by arrow **55**. The lever **51** is maintained in its retracted, or reset, position by a catch provided at the free end of armature **33**. This arrangement is highly advantageous because the second stored energy source **53** can be constructed to exert any arbitrarily high attractive force on the lever **51**, the magnitude of this force no having any relation to the operation of the electromechanical transducer. As a result, the lever **51** can be caused to produce any desired force when the armature **33** of the electromechanical transducer is released from its pole piece **38** and can hence be arranged to operate substantially any type of mechanical device.

FIG. 11 shows a modified version of the arrangement of FIG. 9 wherein the polarizing magnet **40** is replaced by a winding **40'** connected to receive a constant amplitude polarizing current and the stored energy source is constituted by a permanent magnet **42'** in place of the tension spring **42**. The operation of this device is identical with that of the device illustrated in FIG. 9. However, this arrangement has the advantage that the attrac-

tive force exerted by magnet **42'** will be greater when armature **33** has moved a short distance away from its pole piece than when the armature is in contact with the pole piece.

It will be readily appreciated that the electromechanical transducer and stored energy source arrangement can be constituted by many other types of triggering devices. For example, the stored energy source could be formed of a combination of a tension spring and a permanent magnet.

FIG. 12 illustrates another embodiment of the invention wherein the electromechanical transducer includes a pyrotechnic trigger **57** connected to control a mechanical trigger **58** having an associated stored mechanical energy source **59** whose stored energy is released to produce the mechanical output for the device when the mechanical trigger is tripped. The mechanical trigger **58** and source **59** can be constituted by an arrangement similar to the elements **51** and **53** illustrated in FIG. 10, for example. The pyrotechnic trigger **57** could be constituted by any known mechanically operated explosive switching device capable of holding the mechanical trigger in a reset position and of releasing this trigger when a mechanical actuating signal is received. For example, if the electromechanical transducer is constituted by a device of the type shown in FIG. 9 or 11, the pyrotechnic trigger could be of a type which is detonated by percussion.

Another embodiment of a mechanical trigger arrangement, according to the invention, is shown in FIG. 13 wherein the pyrotechnic trigger **57'** is connected to operate an explosive device **63** to produce a mechanical output in the form of an explosion. In this embodiment, the trigger **57'** could be constituted by any known type of explosive actuator. The explosive device **63** delivers its chemical energy under mechanical form. Such explosive device could be of any known type. One classical example are the explosive actuators with a mechanical rod traveling over a certain distance under heavy load, as used on rockets and artificial satellites.

Yet another embodiment of the invention is shown in FIG. 14 wherein the electromechanical transducer is constituted by a fusecord **61** controlling an arrangement **57**, **58**, and **59** similar to that shown in FIG. 12. In this embodiment, the pyrotechnic trigger **57** is detonated by the fusecord **61**, the fusecord being ignitable by the heat energy or electrical energy generated by the current pulse from accumulating means **25**.

FIG. 15 shows yet another embodiment wherein the electromechanical transducer is constituted by a fusecord **61** connected to accumulating means **25** and an arrangement of a pyrotechnic trigger **57'** and explosive device **63** similar in structure and operation to the arrangement shown in FIG. 13.

FIG. 16 shows an embodiment wherein the electromechanical transducer is constituted by a fusible device connected to be actuated by the output from means **25** so as to trigger the operation of a mechanical trigger **58** provided with a stored mechanical energy source **59**. The fusible device could be constituted, for example, by a thin metallic fuse wire which melts when traversed by the current pulse from means **25**. Devices of this type are known as "single shot switching devices" mostly for military applications.

The combination of such a fusible device with electrical energy accumulating means of the type employed in the practice of the present invention is highly advantageous since it leads to an additional "amplification" of the electromechanical action triggered by the low level electrical input. The electrical energy accumulating means **25** acts to convert the energy content of the initial low level electrical signal, having an amplitude of I_1 for example, and flowing to the accumulating means for a period of t_1, into a pulse having a higher amplitude I_2 and a shorter duration t_2, with I_1t_1 being substantially equal to I_2t_2.

Thus, while this accumulation does not involve an increase in the total energy delivered by the electrical input signal, it does cause this energy to be concentrated into a short duration output pulse having a high amplitude. However, since the thermal effect of the current delivered to the fusible device is proportional to I^2t, where t is the duration of the current delivered ot the fusible device, the output pulse delivered from the electrical energy accumulating means will have a substantially greater melting effect on the fusible device than would the low level input signal if it were delivered directly to such device. For example, if a low level input signal having an amplitude of 1 amp and a duration of one second were concentrated by the electrical accumulating means into a pulse having an amplitude of 10 amps and a duration of 0.1 second, the melting effect of the output pulse would be ten times as great as that of the initial low level input signal.

FIG. 17 shows one further embodiment of the invention wherein the electrical energy accumulating means **25** are connected to control an electromechanical transducer constituted by a fusible device **65'** and an explosive device **63**. In this embodiment, the fusible device **65'** could be constituted by a squib, for example.

A squib contains an electrical heating wire or fuse embedded in an explosive powder—the whole being contained for instance in the head of a bolt. The actuation of the squib knocks the head of the bolt away and liberates mechanical pieces screwed together. Applications of such devices are well known in rockets and satellites, for separating the different stages.

It may thus be seen that the present invention permits the achievement of enormous power gains between an extremely low level electrical input signal and a very high level mechanical output signal, these gains being achieved in devices which do not require any external auxiliary electrical power source since all of the operating power for such devices is derived directly and solely from the low level electrical signal to which they are to respond.

Devices according to the invention effect, firstly, an electrical signal amplification, without an accompanying energy gain, by the accumulation, over a period of time, of the energy content of the low level electrical input signal and the subsequent release of the accumulated energy during a substantially shorter period of time. Thus, the energy counter of the low level signal having a small amplitude I_1 and a relatively long duration t_1 can be converted into a pulse having a substantially higher amplitude I_2 and a correspondingly shorter duration t_2. If this pulse is delivered to an electromechanical transducer requiring a high level electrical input but having a short response time, corresponding to t_2, the result is an effective power gain having a ratio of t_1/t_2.

If the output pulse produced by the electrical energy accumulating means is to produce an electromagnetic action in the electromechanical transducer, its effect will be determined by the value, in ampere-turns, of the magnetic potential which it produces and the input portion of the electromechanical transducer will always have a certain self-inductance L in addition to a resistance R. Since the output from the electrical energy accumulating means always has a very short duration, the rate of rise of the output pulse in the electromechanical transducer is very important, as is the speed of its mechanical response.

Therefore, the electromechanical transducer is preferably selected so that, from an electrical point of view, the ratio of its self-inductance to its resistance (L/R) will be as small as possible. This can be achieved, for example, by employing suitable types of attraction relays, saturated magnetic circuits, and windings having special forms. It is also desirable, for the same reasons, that the mechanical portion of the electromechanical transducer require as small an actuating force as possible.

In addition, because of the nature of the high amplitude signal produced by the electrical energy accumulating

means, it is highly desirable that the action of the electromechanical transducer be irreversible, i.e., that it automatically complete its movement to, and remain in, its actuated state after it has been triggered.

Moreover, it will be readily appreciated that the shorter the response time of the electromechanical transducer, the greater can be the amplitude gain which the electrical energy accumulating means can be designed to produce. Thus, release-type relays of the kind shown in FIGS. 9, 10 and 11 can be advantageously employed in embodiments of the present invention, precisely because of their short response times and the fact that their action is irreversible, despite their relatively high L/R ratio. However, short response times and an irreversible action can also be achieved by locking relays of the attraction type.

The same considerations apply to the selection of the value of the mechanical energy stored in the spring or permanent magnet which normally attracts the relay armature when a release-type relay is employed.

It should also be appreciated that the electrical discharge circuit will automatically adapt to the input of the actuator, which may be a relay, a fusible wire, etc. For example, a relay which can operate at any voltage between 0 and 20 volts, will receive a discharge voltage of 20 volts.

The mechanical gain in embodiments of the invention is effected by the triggering or release of the energy previously stored in a spring which is stretched when the electromechanical transducer is set, or in a relay armature which has been moved away from a permanent magnet when the relay is set, or in any type of triggering mechanism which is reset before the start of operation, or in an element restrained by a fusible wire which is connected to release the element upon melting, etc.

In other embodiments of the invention, a high level explosive gain is achieved when the pulse from the electrical energy accumulating means is employed to trigger a relatively large explosion through the intermediary of a small thermal, electrical or mechanical energy discharge.

The discharge of the electrical energy accumulating condenser into an electromechanical transducer such as a relay is a single pulse of quasi-sinusoidal shape (damped resonant system). On the other hand, when the sensitivity of a relay is considered with regard to pulses of a same energy but of different instantaneous powers (pulses of a duration inversely proportional to their amplitude) a maximum sensitivity is found for a given value of the pulse width, where the excitation is just strong enough for releasing the armature and where its duration is sufficient for this movement to be irreversible. The parameters conditioning such optimum condition are the mass of the armature, the strength of the spring, etc.

Obviously one important teaching of the invention is the use of an actuating pulse and of a relay response which are matched to each other so as to provide optimum operating conditions.

The same remark applies to any other type of electromechanical transducers such as for example the fusible devices in which case also appropriate matching leads to some similar types of optimum "amplification."

The electromechanical transducer could be constituted by, in addition to a relay, a torque motor, or a piezoelectric or piezomagnetic transducer, such as a ferroelectric bimetallic strip; or still a stepping relay having an automatical zero resetting mechanism (actuated by a spring for example) to provide a reversible action for actuating a switch for example.

When the electromechanical transducer is constituted by an attraction-type relay, means can be provided either to maintain it in its open position, such means being constituted by a spring, a permanent magnet, or a combination of the two, or to urge it into its closed position, for example by means of a permanent magnet positioned to attract the relay armature but only effective after the armature has begun to move toward its closed position.

To cite one specific example of the invention, the embodiment shown in FIG. 7 could be arranged so that the electrical energy accumulating means is constituted by a self-excited vibratory generator followed by an alternating current accumulator, tuned to the resonant frequency of the vibrator, and a direct current accumulator, while the device **65'** could be constituted by a small squib and the device **63** by a mine. Thus, such an apparatus could be employed to trigger, without the aid of any auxiliary external power source, a mine upon the occurrence of a very small vibration in the vicinity of the apparatus.

It will be understood that the above description of the present application is susceptible to various modifications, changes and adaptations.

What is claimed is:

1. A device for the protection of an electrical installation against fault currents, of the kind comprising a differential transformer for detection of a fault current, and a relay connected through a threshold electronic switch to the terminals of a storage element which is supplied from the differential transformer through a rectifier, character by the association of a fault detection circuit comprising the output winding of the said differential transformer and the said relay, with at least one device for limiting the voltage developed in this detection circuit, and wherein a source of a synchronization signal is connected in series with the storage element, said source being adapted to facilitate the triggering of the electronic threshold switch.

2. A device according to claim **1**, in which the synchronization signal source is a winding on the differential transformer.

3. A device according to claim **1**, wherein the said source is a small saturable current transformer which is arranged on one of the conductors of the supply.

4. A device according to claim **1**, wherein a phase shift circuit of the resistance capacity type is associated with the synchronization signal source.

5. A device for protecting an electrical circuit against fault currents to ground, said device comprising, in combination:

- a differential transformer for detection of such a fault current;
- a capacitor connected to the output of said differential transformer for tuning the output winding of said transformer to the frequency of the electrical circuit supply system;
- an electrical storage element;
- a rectifier connected to supply electrical energy from said transformer to said storage element;
- a threshold electronic switch connected to said storage element; and
- a triggering relay composed of a movable armature, a source of stored energy urging said armature into an actuated position, biasing means normally maintaining said armature in its deactuated position, and input means connected across said storage element through said switch for nullifying the influence of said biasing means and thus causing the release of energy from said source to move said armature to its actuated position by the sudden discharge of the energy in said storage element through said relay when said switch is caused to conduct by the occurrence of a fault current exceeding the threshold value of said switch.

6. A device for protecting an electrical circuit against fault currents to ground, said device comprising, in combination:

- a differential transformer for detection of such a fault current;
- an electrical storage element;
- a rectifier connected to supply electrical energy from said transformer to said storage element;
- a threshold electronic switch connected to said storage element; and

a triggering relay connected across said storage element through said switch for being actuated by the sudden discharge of the energy in said storage element through said relay when said switch is caused to conduct by the occurence of a fault current exceeding the threshold value of said switch;

said storage element and said relay being connected in series to form a circuit branch and said electronic switch being connected in parallel with said branch so that said branch is traversed in one direction by the charging current and in the opposite direction by the discharge current from said storage element.

7. A device for protecting an electrical circuit against fault currents to ground, said device comprising, in combination:

a differential transformer for detection of such a fault current;

an electrical storage element;

a rectified connected to supply electrical energy from said transformer to said storage element;

a threshold electronic switch connected to said storage element; and

a triggering relay connected across said storage element through said switch for being actuated by the sudden discharge of the energy in said storage element through said relay when said swtich is caused to conduct by the occurrence of a fault current exceeding the threshold value of said switch;

wherein the voltage applied through said rectifier to said storage element is constituted by the superimposition of the fault voltage supplied by said differential transformer on an auxiliary voltage tapped from the terminals of the input to said transformer through a voltage divider.

8. In an electromechanical actuating device responsive to a low power electrical signal, which is the only external source of energy to the device, for producing a high energy mechanical output when the amplitude of the electrical signal exceeds a predetermined value, which device includes energy accumulating means connected to receive the electrical signal, to accumulate energy therefrom over a period of time, and to discharge the accumulated energy in the form of a short duration pulse, the improvement wherein said device further includes electromechanical transducer means connected to receive such pulse from said energy accumulating means and comprising a source of stored additional energy, said transducer being arranged to undergo, in response to such pulse, an irreversible action which releases such stored additional energy, said device thus producing a gain in the substantially instantaneously available electric power due to the action of said energy accumulating means and a gain in the resulting mechanical energy due to the release of the stored additional energy.

9. An arrangement as defined in claim **8** wherein said transducer comprises a normally closed, release-type relay normally magnetically biased into its closed position and provided with a winding connected to receive the energy discharged from said energy accumulating means and to convert such energy into a magnetic force which opposes the biasing applied to said relay, and said source of stored additional energy is operatively associated with said relay for urging it into its opened position, the force applied by said source having such a value as to be capable of urging said relay into its open condition only when said relay winding receives the energy discharged from said accumulating means.

10. An arrangement as defined in claim **9** wherein said source of stored additional energy is constituted by a tension spring connected to the armature of said relay.

11. An arrangement as defined in claim **9** wherein said source of stored additional energy is constituted by a permanent magnet positioned to attract the armature of said relay.

12. An arrangement as defined in claim **8** further comprising a mechanical trigger connected to be actuated by the release of energy from said source of stored additional energy, and a source of stored mechanical energy operatively associated with said mechanical trigger in such a way that its stored mechanical energy is released when said mechanical trigger is actuated.

13. An arrangement as defined in claim **12** further comprising a pyrotechnic trigger connected between said electromechanical transducer and said mechanical trigger and arranged to actuate said mechanical trigger in response to the release of energy from said source of stored additional energy.

14. An arrangement as defined in claim **8** further comprising a pyrotechnic trigger connected to the output of said electromechanical transducer and an explosive device connected to said pyrotechnic trigger, said pyrotechnic trigger detonating said explosive device in response to the release of energy from said source.

15. An arrangement as defined in claim **8** wherein said electromechanical transducer comprises: a fusecord connected to said energy accumulating means to be ignited by the discharge of accumulated energy therefrom; a pyrotechnic trigger having its input connected to said fusecord for being detonated when the entire fusecord has been ignited; a mechanical trigger connected to said pyrotechnic trigger to be actuated upon detonation of said pyrotechnic trigger; and a source of stored mechanical energy operatively associated with said mechanical trigger for causing said mechanical trigger to provoke the release of stored mechanical energy therefrom when said mechanical trigger is actuated.

16. An arrangement as defined in claim **8** wherein said electromechanical transducer comprises a fusecord connected to said energy accumulating means to be ignited by the discharge of accumulated energy therefrom, a pyrotechnic trigger connected to said fusecord to be detonated when the entire fusecord has been ignited; and an explosive device connected to said pyrotechnic trigger to be detonated upon the detonation of said trigger.

17. An arrangement as defined in claim **8** wherein said electromechanical transducer comprises: a fusible device connected to said energy accumulating means to be melted by the accumulated energy discharged therefrom; a mechanical trigger connected to said fusible device to be actuated upon the melting of said fusible device; and a source of stored mechanical energy operatively associated with said mechanical trigger so as to cause the mechanical energy stored in said mechanical energy source to be released upon the actuation of said trigger.

18. An arrangement as defined in claim **8** wherein said electromechanical transducer comprises a fusible device connected to said energy accumulating means to be melted by the accumulated energy discharged by said means and an explosive device connected to said fusible device to be detonated by the melting of said fusible device.

19. A method for actuating an electromechanical transducer including a source of stored additional energy, comprising: applying a low power electrical signal as the only external source of energy for the transducer, to energy accumulating means; causing said energy accumulating means to accumulate energy from the signal over a period of time; causing said energy accumulating means to subsequently discharge the accumulated energy, in the form of a short duration pulse after a predetermined quantity of energy has been accumulated; applying such pulse to said electromechanical transducer; causing said transducer to undergo, in response to such pulse, an irreversible action; and releasing, upon the occurrence of the irreversible action, such stored additional energy for producing a gain in the substantially instantaneously available electric power due to the action of said energy accumulating means and a gain in the resulting mechanical energy due to the release of the stored additional

energy, whereby a high energy mechanical output is produced when the amplitude of the electrical signal exceeds a predetermined value.

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