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(54) Title: FAULT CURRENT AND DIFFERENTIAL CURRENT DETECTION SYSTEM CAPABLE OF PREVENTING SPURIOUS TRIGGERING OF A PROTECTION SYSTEM DUE TO TRANSIENT INTERFERENCE PULSES
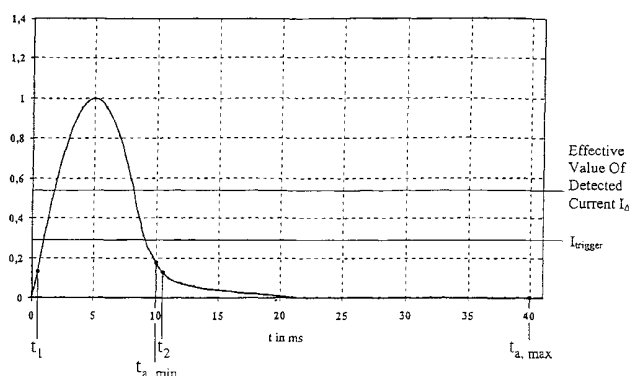
(57) Abstract: A fault or differential current detection system is provided. The detection system detects a fault or differential current generated on a conductive path supplying power to an electric device and prevents the fault or differential current from being supplied to the electric device. The detection system comprises a detector, a switch, and a controller. The detector detects a detected current generated on the conductive path and outputs a corresponding detection signal. The controller inputs the detection signal and determines if the detected current is greater than or equal to a first predetermined current threshold based on the detection signal. Then, the controller refrains from outputting a control signal to the switch for a predetermined delay period after the detected current becomes greater than or equal to the first predetermined current threshold. Then, the controller determines if the detected current is greater than or equal to a second predetermined current threshold when the predetermined delay period is over. After the detected current becomes greater than or equal to the second predetermined currend threshold, the controller determines if the detected current is a fault or differential current. When the detected current is a fault or differential current, the controller outputs the control signal to the switch to instruct the switch to isolate the fault or differential current from the electric device. A software program executed by the controller is also provided.

FAULT CURRENT AND DIFFERENTIAL CURRENT DETECTION SYSTEM CAPABLE OF PREVENTING SPURIOUS TRIGGERING OF A PROTECTION SYSTEM DUE TO TRANSIENT INTERFERENCE PULSES

FIELD OF THE INVENTION

The present invention relates to a detection system that detects fault currents

and differential currents that are supplied to an electric device and triggers a

protection switch to prevent such currents from being supplied to the electric device.

5   More particularly, the present invention relates to a detection system that triggers the

protection switch when harmful fault currents and differential currents are detected

and that does not erroneously trigger the protection switch when harmless transient

interference pulses are detected. In addition, the present invention relates to a method

performed by the detection system and a software program for implementing the

10   method.

BACKGROUND OF THE INVENTION

In many applications, electrical currents are supplied to one or more electric

devices to provide power for the devices. For example, electrical currents are

supplied from a power company to one or more electrical outlets in a residential

15   home, and a user can connect an electric device to an outlet to supply power to the

device. If the electric device malfunctions or is mishandled by the user, a potentially

dangerous situation may arise. For example, if the user contacts a portion of the

electric device that receives electrical currents from the power company, the electrical

current will pass through the user to the ground and may cause the user's heart to

20   suffer from a cardiac arrest. Also, if the portion of the electric device that receives

electrical currents is improperly grounded due to faulty insulation, a large amount of

current will be supplied to the electric device and may start a fire in the user's home.

The additional surge of current that is supplied to the user's home when the electric

device malfunctions or is mishandled is known as a fault current.

In order to prevent fire in the user's home or to prevent the user from being

5 harmed, a circuit breaker has been developed that detects fault currents and that

blocks the supply of electrical current to the one or more electrical outlets in the

user's home if the detected fault currents exceed certain levels. Fig. 5 shows an

example of such a circuit breaker 1, which comprises a sum-current transformer 2, a

power supply 4, triggering circuit 5, a triggering relay 6, a switching mechanism 7,

10 and a switch 8.

The electric currents are supplied from the power company to the user's home

via a conductor network LN, and the network LN includes three active conductors L_1,

L_2, and L_3 and a neutral or ground conductor N. The conductor network LN is

wrapped around a core 3 of the sum-current transformer 2 to form a primary winding

15 N1 of the transformer 2. Also, a secondary winding N2 is wrapped around the core 3

of the transformer 2, and the triggering circuit 5 is connected to the winding N2.

Specifically, the triggering circuit 5 is connected across the output terminals of the

winding N2, and the triggering relay 6 is connected across the output terminals of the

circuit 5. The triggering relay 6 controls the switching mechanism 7 to selectively

20 open the switch 8, and the switch 8 is provided in the path of the conductor network

LN between the power company and the electrical device.

When the electric device in the user's home is operating or being handled

under normal conditions, no fault currents exist. As a result, the vector sum of the

currents flowing through the core 3 via the conductor network LN is zero. However,

25 if a fault current I_f is generated, the vector sum of the currents is not zero, and a

voltage U_e is generated across the secondary winding N2. The characteristics of the

voltage U_e correspond to the characteristics of the fault current I_f, and the triggering

circuit 5 generates an output voltage U_a based on the input voltage U_e. The output

voltage U_a causes an operating current I_a to flow through the triggering relay 6. When

5   the fault current I_f exceeds a triggering current $I_{trigger}$, the triggering circuit 5 triggers

the relay 6. The triggering of the relay 6 causes the switching mechanism 7 to open

the switch 8 to block the supply of current from the power company to at least one

outlet in the user's home.

Since the value of residual operating current I_a is based on the value of the

10   fault current I_f, the relay 6 triggers when the fault current I_f increases to a point that

causes the current I_a to flow. Accordingly, when the user contacts a conductive

portion of an electric device and causes a large fault current I_f to be generated, the

relay 6 triggers, and switching mechanism 7 opens the switch 8. As a result, the

dangerous fault current I_f is no longer supplied to the user and will not harm the user.

15   Similarly, if the insulation in the electric device is faulty and a large fault current I_f is

generated, the relay 6 triggers so that the switching mechanism 7 opens the switch 8.

Thus, the dangerous fault current I_f is no longer supplied to the electric device, and

any possibility of the electric device starting a fire is eliminated.

However, since the circuit breaker 1 shown in Fig. 5 is implemented via

20   hardware circuitry, the circuit breaker 1 is often activated when dangerous fault

currents are not present, and thus, the circuit breaker 1 unnecessarily interrupts the

operation of the electric device. For example, when one or more electric components

connected to the conductor network LN are initially turned on, transient interference

pulses are generated that have large amplitudes but last for only a short period of time.

25   For example, as shown in Fig. 1, when the electric components are turned on,

transient interference pulses typically occur from the time t=0 (i.e. t_0) to the time t=10

(i.e. $t_{a, min}$).

When such pulses (and similar pulses) are generated, the triggering circuit 5

outputs a current I_a that triggers the relay 6, and the switching mechanism 7 causes the

5   switch to prevent power from being supplied to the electric device. However, by the

time the relay 6 triggers, the transient interference pulses no longer exist, and thus,

circuit breaker 1 unnecessarily blocks the supply of the electrical power to the electric

device. As a result, the operation of the electric device is unnecessarily stopped.

In an attempt to overcome the above problem, the hardware of the circuit

10   breaker 1 has been redesigned to try to prevent it from triggering between the times t_0

and $t_{a, min}$. However, the ability to successfully redesign the circuit breaker 1 to

suppress the times at which it will trigger is limited because such hardware

modification is expensive and complicated. For example, the additional circuitry

needed to prevent the circuit breaker 1 from triggering at certain times adversely

15   affects the values of the triggering times at which the circuit breaker 1 needs to trigger

when a fault current is detected. In addition, the time periods during which the circuit

breaker 1 should trigger (or not trigger) vary based on the specific applications under

which the circuit breaker 1 is to operate and vary based on the different standards

adopted by different countries. Since hardware circuitry is used to control the times

20   when the circuit breaker 1 will trigger or not trigger, modifying the circuit breaker 1

so that it can operate under different applications and according to the standards of

different countries is very time consuming and difficult.

SUMMARY OF THE INVENTION

One object of the present invention is to provide a fault or differential current detection system that accurately triggers when harmful fault currents and differential currents are detected and that does not erroneously trigger when harmless transient

5   interference pulses are detected.

Another object of the present invention is to provide a fault or differential current detection system that can be easily mass-produced and that can be easily modified to work in many different environments.

In order to achieve the above and other objects, a fault or differential current

10   detection software program is provided. The software program is contained in a computer readable medium and includes instructions to instruct a controller to perform a routine comprising: (a) inputting a detection signal corresponding to an abnormal current generated on a conductor; (b) determining if said abnormal current is greater than or equal to a first predetermined current based on said detection signal;

15   (c) refraining from outputting a control signal for a predetermined delay period after said abnormal current is greater than or equal to said first predetermined current; (d) determining if said abnormal current is greater than or equal to a second predetermined current after said predetermined delay period is over; (e) determining if said abnormal current is a fault current after said abnormal current is greater than or

20   equal to said second predetermined current; and (f) when said abnormal current is said fault current, outputting said control signal at least indirectly to a switch to instruct said switch to isolate said fault current from an electric device connected to said conductor.

In order to further achieve the above and other objects, another fault current

25   detection software program is provided. This software program is also contained in a

computer readable medium and includes instructions to instruct a controller to

perform a routine comprising: (a) placing said controller in a sleep mode; (b)

inputting a detection signal corresponding to an abnormal current generated on a

conductor; (c) determining if said abnormal current is equal to or greater than a first

5   predetermined current based on said detection signal; (d) changing an operational

mode of said controller from said sleep mode to an active mode after said abnormal

current becomes greater than or equal to said first predetermined current; (e)

measuring an effective value of said abnormal current after said abnormal current

becomes greater than or equal to said first predetermined current; (f) refraining from

10   outputting a control signal while said operational mode of the said controller is

changing in said step (c) and said effective value is being measured in said step (e);

(g) determining if said effective value of said abnormal current is greater than or equal

to a second predetermined current after said effective value of said abnormal current

is measured in step (e); (h) determining if said abnormal current is a fault current after

15   said abnormal current becomes greater than or equal to said second predetermined

current; and (i) when said abnormal current is said fault current, outputting said

control signal at least indirectly to a switch to instruct said switch to isolate said fault

current from an electric device connected to said conductor.

In order to yet further achieve the above and other objects, a fault current

20   detection system is provided. The detection system detects a fault current generated

on a conductive path supplying power to an electric device and prevents the fault

current from being supplied to the electric device. The fault current detection system

comprises: a detector that detects an abnormal current generated on said conductive

path and outputs a corresponding detection signal; a switch that is provided in said

25   conductive path that selectively isolates said electric device from said conductive

path; and a controller that inputs said detection signal and determines if said abnormal

current is greater than or equal to a first predetermined current based on said detection

signal, wherein said controller refrains from outputting a control signal for a

predetermined delay period after said abnormal current becomes greater than or equal

5   to said first predetermined current, wherein said controller determines if said

abnormal current is greater than or equal to a second predetermined current after said

predetermined delay period is over, wherein said controller determines if said

abnormal current is a fault current after said abnormal current becomes equal to or

greater than said second predetermined current, and wherein, when said abnormal

10   current is said fault current, said controller outputs said control signal at least

indirectly to said switch to instruct said switch to isolate said fault current from said

electric device.

        In order to even further achieve the above and other objects, another fault

current detection system is provided. The detection system detects a fault current

15   generated on a conductive path supplying power to an electric device and prevents the

fault current from being supplied to the electric device. The fault current detection

system comprises: a detector that detects an abnormal current generated on said

conductive path and outputs a corresponding detection signal; a switch that is

provided in said conductive path that selectively isolates said electric device from said

20   conductive path; and a controller that is placed in a sleep mode and inputs a detection

signal corresponding to an abnormal current generated on said conductive path,

wherein said controller determines if said abnormal current is greater than or equal to

a first predetermined current based on said detection signal, wherein said controller

changes an operational mode from said sleep mode to an active mode after said

25   abnormal current becomes greater than or equal to said first predetermined current,

wherein said controller measures an effective value of said abnormal current after said

abnormal current becomes greater than or equal to said first predetermined current,

wherein said controller refrains from outputting a control signal while said operational

mode of the said controller is changing from said sleep mode to said active mode and

5   while said effective value is being measured, wherein said controller determines if

said effective value of said abnormal current is greater than or equal to a second

predetermined current after said effective value of said abnormal current is measured,

wherein said controller determines if said abnormal current is a fault current after said

abnormal current becomes greater than or equal to said second predetermined current,

10   and wherein, when said abnormal current is said fault current, said controller outputs

said control signal at least indirectly to said switch to instruct said switch to isolate

said fault current from an electric device connected to said conductive path.

BRIEF DESCRIPTION OF THE DRAWINGS

The above and other objectives and advantages of the present invention will

15   become more apparent by describing in detail preferred embodiments thereof with

reference to the attached drawings in which:

Fig. 1 is an example of a graphical representation of the generation of a

transient interference pulse;

Fig. 2 is an example of a graphical representation of the generation of a

20   harmful fault or differential current after a transient interference pulse is generated;

Fig. 3 is an example of a software routine performed by the detection system

according to an illustrative embodiment of the present invention;

Fig. 4 is an example of a block diagram of the structure of a fault current

detection system according to an illustrative embodiment of the present invention; and

Fig. 5 is a block diagram of a circuit breaker that is implemented via hardware

and that prevents power from being supplied to an electric device when a fault current

is detected.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

5   The following description of the preferred embodiments discloses specific

configurations, components, and process steps. However, the preferred embodiments

are merely examples of the present invention, and thus, the specific features described

below are merely used to more easily describe such embodiments and to provide an

overall understanding of the present invention. Accordingly, one skilled in the art

10   will readily recognize that the present invention is not limited to the specific

embodiments described below. Furthermore, the descriptions of various

configurations, components, and steps of the present invention that are known to one

skilled in the art are omitted for the sake of clarity and brevity.

The present invention relates to a detection system that triggers and prevents a

15   harmful fault or differential current from being supplied to an electric device and that

does not trigger when a transient interference pulse is generated. An example of the

structure of a detection system in accordance with an illustrative embodiment of the

present invention is shown in Fig. 4. As shown in the figure, the detection system

comprises a sum current transformer 20, a controller 30, and a switch 40. A

20   conductor network 10 forms a primary winding of the sum current transformer 20 and

is connected to an electric device via the switch 40. The configuration of and

interconnections among the conductor network 10, sum current transformer 20, and

switch 40 are preferably similar to those of the corresponding components shown in

Fig. 5 and will not be discussed in greater detail for the sake of brevity.

The controller 30 receives a detection signal from the sum current transformer 20, and the characteristics of the detection signal correspond to characteristics of fault currents I_f and/or transient interference pulses that are generated on the conductor network 10. The controller 30 filters out the portions of the detection signal that

5 correspond to the transient interference pulses and analyzes the remaining portions of the detection signal to determine if any fault currents I_f are generated in the conductor network 10. If a fault current I_f does exist, the controller 30 determines if it is severe. If the fault current I_f is severe, the controller 30 outputs a control signal to the switch 40 to instruct the switch 40 to block the supply of the fault current I_f to the electric

10 device. To more fully understand the advantages and other aspects of the present invention, a brief description of the generation of transient interference pulses and harmful fault and differential currents will be described in conjunction with Figs. 1 and 2.

Fig. 1 is a graphical representation of the generation of a transient interference

15 pulse that is generated when one or more electrical components connected to or embodied in the electric device are initially turned on. As shown in the figure, when one or more components are initially turned on at time t = 0 (i.e. t_0), a transient interference pulse is often generated sometime between time t_0 and time $t_{a, min}$ (e.g. t = 10 ms). When the interference pulse is generated between the times t_0 and $t_{a, min}$, the

20 controller 30 does not output a control signal to open the switch 40, and thus, the operation of the electric device is not interrupted. Furthermore, since a harmful fault current or differential current does not occur after the time $t_{a, min}$ in the example shown in Fig. 1, the controller 30 does not output a control signal to the switch 40 after the time $t_{a, min}$.

25 Fig. 2 is a graphical representation of the generation of a harmful fault or

differential current. As shown in the figure, the fault or differential current is generated between the time t_0 and the time $t_{a,\,max}$. Furthermore, in the present embodiment, the detection system preferably detects the fault or differential current before the time $t_{a,\,max}$ (e.g. t = 40 ms) to prevent the fault or differential current from

5   beginning to harm a user that is operating the device or to prevent the device from starting a fire.

Based on the two scenarios described above in conjunction with Figs. 1 and 2, the controller 30 does not trigger (i.e. output the control signal to the switch 40) during the time period when transient interference pulses are typically generated but

10   does trigger before any fault currents cause harm. In particular, the controller 30 does not trigger between the times t_0 and $t_{a,\,min}$ but does trigger between the times $t_{a,\,min}$ and $t_{a,\,max}$.

In a preferred embodiment, the operation of the controller 30 is controlled via a software program. The software program may be supplied to the controller 30 via a

15   read only memory ("ROM"), a random access memory ("RAM"), a floppy disk, a hard disk, an optical disk, a carrier wave (e.g. a carrier wave transmitted via the internet, a vertical blanking interval of a television signal, etc.), or any other computer readable medium. An illustrative example of the software routine executed by the controller 30 is represented by the flow chart shown in Fig. 3.

20   As shown in the figure, the controller 30 is initially in a "sleep mode" or "power down" (step S300). In the sleep mode, certain subsystems (e.g. analog-to-digital converters, input/output systems, etc.) of the controller 30 are turned off in order conserve energy. While in the sleep mode, the controller 30 determines if an instantaneous value of a detected current I_Δ (i.e. a fault current, differential current,

25   transient interference pulse, etc.) is greater than or equal to a predetermined fraction A

of a rated residual current (or nominal fault current) $I_{\Delta n}$ (step S305). In other words,

the controller 30 determines if the following relationship is satisfied:

$$I_\Delta \geq A * I_{\Delta n} \quad (1)$$

The nominal fault current $I_{\Delta n}$ corresponds to the sensitivity of the detection system

5   (i.e. corresponds to the smallest fault current I_f that will cause the controller 30 to

output the control signal to the switch 40) and is selected based on the standards of the

electrical system in which the detection system is incorporated. Also, the parameter

A is preferably a fraction having a value from 0.3 to 0.5. If the instantaneous value of

the detected current I_Δ is less than the predetermined fraction A of the nominal fault

10   current $I_{\Delta n}$, the controller 30 remains in the sleep or power down mode (step S300).

On the other hand, if the instantaneous value of the detected current I_Δ is

greater than or equal to the predetermined fraction A of the nominal fault current $I_{\Delta n}$,

the controller 30 enters an active mode, in which the controller 30 activates all of its

subsystems (e.g. analog-to-digital converters, input/output systems, etc.) (step S310).

15   A minimum idle time period t_{idle}, during which the controller 30 is idle, is required for

the controller 30 to transition from the sleep mode or power mode to the active mode.

. Furthermore, in a preferred embodiment, a user can adjust one or more parameters in

the software routine to increase the duration of the idle time period t_{idle} during which

the controller 30 is idle.

20   An example of when the controller 30 transitions from the sleep mode to the

active mode is shown in Figs. 1 and 2. Specifically, after various components

connected to the electric device turn on at time t_0, the instantaneous value of the

detected current I_Δ begins to rise. Then, when the value of the detected current I_Δ

equals the predetermined fraction A of the nominal fault current $I_{\Delta n}$ at the time t_1, the

controller 30 becomes active.

Afterwards, the controller 30 sets a first loop counter parameter Z equal to

zero (step S315) and executes a first measurement routine during which the controller

30 measures and calculates the effective value of the detected current I_Δ (step S320).

Suitable algorithms for determining the effective value of the detected current I_Δ are

well known to one skilled in the art upon reading the specification, and therefore, they

will not be described for the sake of brevity. Also, in the present embodiment, a

minimum calculation time period t_{calc} is required for the controller 30 to measure and

calculate the effective value of the detected current I_Δ. Furthermore, in a preferred

embodiment, the user can adjust one or more parameters in the software routine to

increase the duration of the calculation time period t_{calc} during which the controller 30

is executing the first measurement routine.

The total amount of time for the controller 30 to (1) enter the active mode and

(2) measure and calculate the effective value of the detected current I_Δ is considered to

be the total delay time period t_{delay}. In other words, the total delay time period t_{delay}

equals the sum of the idle time period t_{idle} and the calculation time period t_{calc} as

represented in the following equation:

$$t_{delay} = t_{idle} + t_{calc} \qquad (2)$$

If the total delay time period t_{delay} is set such that the period t_{delay} ends at or after the

time $t_{a,\,min}$ (Figs. 1 and 2), the controller 30 will not trigger and will not output a

control signal to the switch 40 in response to a transient interference pulse that is

generated before the time $t_{a,\,min}$. (The time $t_{a,\,min}$ is the minimal trigger time before

which the circuit breaker cannot trigger). In other words, the time period between the

time t_0 and $t_{a,min}$ is the time period in which the system cannot trigger. In particular,

the transient interference pulses typically have time durations of several milliseconds and typically occur between the times t_0 and $t_{a,min}$. Thus, if the period t_{delay} ends at or after the time $t_{a,min}$, the controller 30 is still transitioning from the sleep or power down mode to the active mode and is calculating the effective value of the detected current I_Δ when the transient interference pulses occur. Thus, the controller 30 is busy performing such tasks when the transient interference pulses are generated and does trigger in response to such pulses. Furthermore, since the user can easily change the delay period t_{delay} by simply changing various parameters in the software routine, the detection system can be easily modified and adapted to various electric devices, standards, and situations having different periods during which transient interference pulses occur.

An example of the relative timing of the times and periods described above are shown in Figs. 1 and 2. Specifically, at the time t_0, various components connected to the electric device are turned on, and transient interference currents may occur between the times t_0 and $t_{a,min}$. As shown in Figs. 1, a transient interference pulse (i.e. the detected current I_Δ) increases from the time t_0, and at t_1, the instantaneous value of the detected current I_Δ equals the predetermined fraction A of the nominal fault current $I_{\Delta n}$. Thus, at time t_1, the controller 30 begins to transition from the sleep mode to the active mode and performs the first measurement routine to calculate the effective value of the detected current I_Δ during the delay period t_{delay} (steps S305, S310, and S320 (Fig. 3)). By adjusting the parameters of the software routine, the delay period t_{delay} can be adjusted such that the controller 30 finishes calculating the effective value of the detected current I_Δ in step S320 at time t_2. In other words, the period t_{delay} is set to equal the difference between the time t_2 and the time t_1. Thus, before the time t_2, the controller 30 does not trigger and does not output a control

signal to the switch. After the time t_2, the period t_{delay} has ended, and the controller 30

is able to trigger. Accordingly, the controller 30 does not trigger in response to the

transient interference pulses that occur between the times t_0 and $t_{a,min}$. Furthermore,

while the controller 30 is calculating the effective value of the detected current I_Δ, it

refrains from outputting the calculated effective value until the time t_2.

After the time t_2 has passed and the controller 30 has calculated the effective

value of the detected current I_Δ in step S320, it determines whether or not the effective

value of the detected current I_Δ is greater than a second predetermined fraction B of

the nominal fault current $I_{\Delta n}$ (step S325). In other words, at the time t_2, the controller

30 determines if the following relationship is satisfied:

$$I_{\Delta rms} \geq B * I_{\Delta n} \quad (3)$$

The parameter B is preferably a fraction having a value from 0.3 to 0.5 and may or

may not equal the parameter A mentioned previously. As long as the effective value

of the detected current I_Δ is less than the fraction B of the nominal fault current $I_{\Delta n}$ (as

in the situation shown in Fig. 1), the first measurement routine performed in step S320

is repeated a predetermined number of times. Specifically, if the effective value of

the detected current I_Δ does not satisfy relationship (3), the controller 30 increments

the first loop counter parameter Z by one (step S330) and determines if the parameter

Z equals a predetermined number Y (step S335). The predetermined number Y

preferably equals an integer between 1 and 30 and is a parameter that can be selected

by the user. If the first loop counter parameter Z does not equal the predetermined

number Y, the controller 30 performs the first measurement routine again to update

the calculation of the effective value of the detected current I_Δ (step S320) and

determines if the updated effective value satisfies relationship (3) above (step S325).

If the effective value of the detected current I_Δ never satisfies relationship (3) when the first measurement routine is repeated for the predetermined number Y of times, the parameter Z equals the predetermined number Y (step S335), and the controller 30 again enters the sleep or power down mode (step S300).

On the other hand, if the effective value of the detected current I_Δ is greater than the fraction B of the nominal fault current $I_{\Delta n}$ (step S325), the controller 30 determines that a harmful fault current or differential current potentially exists, resets a second loop counter parameter W to zero (step S340), and performs a second measurement routine (step S345). In the second measurement routine, the controller 30 calculates the effective value $I_{\Delta rms}$, the peak values $-\hat{I}_\Delta$ and $+\hat{I}_\Delta$, the period $T_{I\Delta}$, and/or the frequency $f_{I\Delta}$ of the detected current I_Δ. Suitable algorithms for determining the above values are well known to one skilled in the art upon reading the specification, and therefore, they will not be described for the sake of brevity.

Afterwards, the controller 30 performs an evaluation routine based on the calculated values to determine which type of fault current has occurred and the severity of the fault current (step S350). (An example of an evaluation routine is described in the U.S. Patent Application which was invented by the inventors of the present application, was filed on the same day as the present application, and is entitled "SOFTWARE-CONTROLLED EVALUATION OF FAULT CURRENTS FOR PROTECTION AND MONITORING SYSTEMS". The disclosure of this concurrently filed application is hereby incorporated into the present application by reference.) Based on the evaluation routine, the controller 30 determines whether or not to trigger and output the control signal to the switch 40 (step S355). If triggering is required, the controller 30 outputs the control signal to the switch 40 (step S358) and returns to the sleep or power down mode (step S300).

On the other hand, if the controller 30 determines that triggering is not required (step S355), the second measurement routine (step S345) and the evaluation routine (step S350) are repeated a predetermined number X of times. Specifically, the controller 30 increments the second loop counting parameter W by one (step S360) and determines if the parameter W equals a predetermined number X (step S370). The predetermined number X preferably equals an integer between 1 and 50 that can be selected by the user. If the parameter W does not equal the predetermined number X, the controller 30 performs the second measurement routine again to update the calculations of the effective value $I_{\Delta rms}$, peak values $-\hat{I}_\Delta$ and $+\hat{I}_\Delta$, period $T_{I\Delta}$, and/or frequency $f_{I\Delta}$ of the detected current I_Δ (step S345). Then, the controller 30 performs the evaluation routine again (step S350). If the controller 30 is never triggered when the second measurement routine and evaluation routine are repeated for the predetermined number X of times, the second loop counting parameter W equals the predetermined number X (step S370), and the controller 30 again enters the sleep mode or power down mode (step S300).

As explained above, if the effective value of the detected current I_Δ is less than a fraction B of the nominal fault current $I_{\Delta n}$ (step S325) the controller 30 repeats the first measurement routine (step S320) and comparison operation (step S325) a predetermined number of times. As a result, the controller 30 is capable of determining if a harmful fault current or differential current occurs shortly after a transient interference pulse. Similarly, if the controller 30 has not triggered after performing the evaluation routine (step S350), the controller 30 repeats the second measurement routine (step S345) and the evaluation routine (step S350) a predetermined number of times. Consequently, the controller 30 is able to detect a cyclical fault current or differential current that only periodically exceeds the

triggering threshold level required for the controller 30 to output the control signal to

the switch 40.

The illustrative embodiment of the detection system described above triggers

when a harmful fault or differential current is detected. Furthermore, the detection

5   system is designed so that it refrains from triggering in response to transient

interference pulses without degrading its ability to detect harmful currents. In

addition, since many of the operations performed by the detection system are based on

parameters that are selected by a user, the detection system can be easily modified to

be compatible with many different types of electric devices operating under many

10   different types of standards.

The previous description of the preferred embodiments is provided to enable a

person skilled in the art to make and use the present invention. Moreover, various

modifications to these embodiments will be readily apparent to those skilled in the art,

and the generic principles and specific examples defined herein may be applied to

15   other embodiments without the use of inventive faculty. For instance, the above

examples refer to parameters that have specific values or ranges of values and refer to

procedures that detect specific types of currents. However, the present invention is

not limited to such parameters having such values and is not limited to the detection

of such currents. Therefore, the present invention is not intended to be limited to the

20   embodiments described herein but is to be accorded the widest scope as defined by

the limitations of the claims and equivalents thereof.

What is claimed is:

1.   A fault or differential current detection software program contained in
a computer readable medium, wherein the fault or differential current detection
software program includes instructions to instruct a controller to perform a routine
comprising:

5   (a)   determining if a detected current generated on a conductor is greater
than or equal to a first predetermined current threshold based on a detection signal
corresponding to said detected current;

(b)   refraining from outputting a control signal for a predetermined delay
period after said detected current is greater than or equal to said first predetermined
10   threshold;

(c)   determining if said detected current is greater than or equal to a second
predetermined current threshold after said predetermined delay period is over;

(d)   determining if said detected current is a fault or differential current
after said detected current is greater than or equal to said second predetermined
15   current threshold; and

(e)   when said detected current is said fault or differential current,
outputting said control signal at least indirectly to a switch to instruct said switch to
isolate said fault current from an electric device connected to said conductor.

2.   The fault or differential current detection software program as claimed
in claim 1, wherein said predetermined delay period is adjustable by a user of said
software program.

3.   The fault or differential current detection software program as claimed in claim 1, wherein the routine further comprises:

(f)   placing the controller in a sleep or power down mode, and

wherein said step (b) comprises:

5   (b1)   changing an operational mode of said controller from said sleep or power down mode to an active mode,

wherein a predetermined idle period elapses when said operational mode changes from said sleep mode to said active mode,

wherein said predetermined idle period constitutes at least a portion of said 10   predetermined delay period, and

wherein said controller refrains from outputting said control signal during said predetermined idle period.

4.   The fault or differential current detection software program as claimed in claim 1, wherein said step (b) comprises:

(b1)   measuring an effective value of said detected current,

wherein a predetermined measurement period elapses when said effective 5   value of said detected current is measured,

wherein said predetermined measurement period constitutes at least a portion of said predetermined delay period, and

wherein said controller refrains from outputting said control signal during said predetermined measurement period.

5.   The fault or differential current detection software program as claimed in claim 1, wherein the routine further comprises:

(f)   placing said controller in a sleep or power down mode, and

wherein said step (b) comprises:

(b1)   changing an operational mode of said controller from said sleep or

power down mode to an active mode; and

(b2)   measuring an effective value of said detected current,

wherein a predetermined idle period elapses when said operational mode

changes from said sleep mode to said active mode,

wherein a predetermined measurement period elapses when said effective

value of said detected current is measured,

wherein said predetermined idle period and said predetermined measurement

period constitute at least a portion of said predetermined delay period, and

wherein said controller refrains from outputting said control signal during said

predetermined idle period and said predetermined measurement period.

6.   The fault or differential current detection software program as claimed

in claim 5, wherein at least one of said predetermined idle period and said

predetermined measurement period is adjustable by a user of said software program.

7.   The fault or differential current detection software program as claimed

in claim 1, wherein said predetermined delay period expires after a period during

which transient interference pulses are generated on said conductor.

8.   The fault or differential current detection software program as claimed

in claim 4, wherein said step (c) comprises:

(c1)   determining if said effective value of said detected current is greater

than or equal to said second predetermined current threshold after said predetermined

5   delay period is over; and

(c2)   repeating said steps (b1) and (c1) if said effective value of said

detected current is less than said second predetermined current value.

9.   The fault or differential current detection software program as claimed

in claim 8, wherein said step (c2) repeats said steps (b1) and (c1) a predetermined

number of times if said effective value of said detected current is less than said second

predetermined current threshold.

10.   The fault or differential current detection software program as claimed

in claim 1, wherein said step (d) comprises:

(d1)   measuring at least one characteristic of said detected current;

(d2)   determining if said detected current is said fault or differential current

5   based on said at least one characteristic; and

(d3)   repeating said steps (d1) and (d2) if said detected current is determined

not to be said fault or differential current.

11.   The fault or differential current detection software program as claimed

in claim 10, wherein said step (d3) repeats said steps (d1) and (d2) a predetermined

number of times if said detected current is determined not to be said fault or

differential current.

12. A fault or differential current detection software program contained in a computer readable medium, wherein the fault or differential current detection software program includes instructions to instruct a controller to perform a routine comprising:

5   (a)   placing said controller in a sleep or power down mode;

(b)   determining if a detected current generated on a conductor is greater than or equal to a first predetermined current threshold based on a detection signal corresponding to said detected current;

(c)   changing an operational mode of said controller from said sleep or

10   power down mode to an active mode after said detected current becomes greater than . or equal to said first predetermined current threshold;

(d)   measuring an effective value of said detected current after said detected current becomes greater than or equal to said first predetermined current threshold;

15   (e)   refraining from outputting a control signal while said operational mode of the said controller is changing in said step (c) and said effective value is being measured in said step (d);

(f)   determining if said effective value of said detected current is greater than or equal to a second predetermined current threshold after said effective value of

20   said detected current is measured in step (d);

(g)   determining if said detected current is a fault or differential current after said detected current becomes greater than or equal to said second predetermined current threshold; and

(h)   when said detected current is said fault or differential current,

25   outputting said control signal at least indirectly to a switch to instruct said switch to

isolate said fault or differential current from an electric device connected to said

conductor.

13.   The fault or differential current detection software program as claimed

in claim 12, wherein said step (f) comprises:

(f1)   determining if said effective value of said detected current is greater

than or equal to said second predetermined current threshold;

5   (f2).   repeating said steps (d) and (f1) if said detected current is less than said

second predetermined current threshold.

14.   The fault or differential current detection software program as claimed

in claim 13, wherein step (f2) comprises:

(f2a)   repeating said steps (d) and (f1) a predetermined number of times if

said effective value of said detected current is less than said second predetermined

5   current threshold; and

(f2b)   placing said controller in said sleep or power down mode after said

steps (d) and (f1) have been repeated for said predetermined number of times.

15.   The fault or differential current detection software program as claimed

in claim 12, wherein said step (g) comprises:

(g1)   measuring at least one characteristic of said detected current;

(g2)   determining if said detected current is said fault or differential current

5   based on said at least one characteristic; and

(g3)   repeating said steps (g1) and (g2) if said abnormal current is

determined not to be said fault or differential current.

16.   The fault or differential current detection software program as claimed in claim 15, wherein step (g3) comprises:

(g3a)   repeating said steps (g1) and (g2) a predetermined number of times if said detected current is not said fault or differential current; and

5   (g3b)   placing said controller in said sleep or power down mode after said steps (g1) and (g2) have been repeated for said predetermined number of times.

17.   The fault or differential current detection software program as claimed in claim 12, wherein a predetermined idle period elapses when said operational mode changes from said sleep or power down mode to said active mode in said step (c),

wherein a predetermined measurement period elapses when said effective

5   value of said detected current is measured in said step (d), and

wherein said predetermined idle period and said predetermined measurement period constitute at least a portion of a predetermined delay period.

18.   The fault or differential current detection software program as claimed in claim 17, wherein at least one of said predetermined measurement period and said predetermined idle period is adjustable by a user of said software program.

19.   The fault or differential current detection software program as claimed in claim 18, wherein said predetermined delay period expires after a period during which transient interference pulses are generated on said conductor.

20.   A fault or differential current detection system that detects a fault or

differential current generated on a conductive path supplying power to an electric

device and that prevents the fault or differential current from being supplied to the

electric device, wherein the fault or differential current detection system comprises:

5   a detector that detects a detected current generated on said conductive path and

outputs a corresponding detection signal;

        a switch that is provided in said conductive path that selectively isolates said

electric device from said conductive path; and

        a controller that inputs said detection signal and determines if said detected

10   current is greater than or equal to a first predetermined current threshold based on said

detection signal,

        wherein said controller refrains from outputting a control signal for a

predetermined delay period after said detected current becomes greater than or equal

to said first predetermined current threshold,

15   wherein said controller determines if said detected current is greater than or

equal to a second predetermined current threshold after said predetermined delay

period is over;

        wherein said controller determines if said detected current is a fault or

differential current after said detected current becomes greater than or equal to said

20   second predetermined current threshold, and

        wherein, when said detected current is said fault or differential current, said

controller outputs said control signal at least indirectly to said switch to instruct said

switch to isolate said fault or differential current from said electric device.

21.   The fault or differential current detection system as claimed in claim

20, wherein said predetermined delay period is adjustable by a user.

22.   The fault or differential current detection system as claimed in claim

20, wherein said controller is placed in a sleep or power down mode, and

       wherein said controller changes an operational mode from said sleep or power

down mode to an active mode after said detected current becomes greater than or

5   equal to said first predetermined current threshold,

       wherein a predetermined idle period elapses when said operational mode

changes from said sleep or power down mode to said active mode,

       wherein said predetermined idle period constitutes at least a portion of said

predetermined delay period, and

10   wherein said controller refrains from outputting said control signal during said

predetermined idle period.

23.   The fault or differential current detection system as claimed in claim

20, wherein said controller measures an effective value of said detected current after

said detected current is greater than or equal to said first predetermined current

threshold,

5   wherein a predetermined measurement period elapses when said effective

value of said detected current is measured,

       wherein said predetermined measurement period constitutes at least a portion

of said predetermined delay period, and

       wherein said controller refrains from outputting said control signal during said

10   predetermined measurement period.

24.   The fault or differential current detection system as claimed in claim

20, wherein said controller is placed in a sleep or power down mode,

wherein said controller changes an operational mode from said sleep or power

down mode to an active mode after said detected current is greater than or equal to

5   said first predetermined current threshold,

wherein said controller measures an effective value of said detected current

after said detected current is greater than or equal to said first predetermined current

threshold,

wherein a predetermined idle period elapses when said operational mode

10   changes from said sleep or power down mode to said active mode,

wherein a predetermined measurement period elapses when said effective

value of said detected current is measured,

wherein said predetermined idle period and said predetermined measurement

period constitute at least a portion of said predetermined delay period, and

15   wherein said controller refrains from outputting said control signal during said

predetermined idle period and said predetermined measurement period.

25.   The fault or differential current detection system as claimed in claim

24, wherein at least one of said predetermined idle period and said predetermined

measurement period is adjustable by a user.

26.   The fault or differential current detection system as claimed in claim

20, wherein said predetermined delay period expires after a period during which

transient interference pulses are generated on said conductive path.

27. The fault or differential current detection system as claimed in claim 23, wherein, when said effective value of said abnormal current is less than said second predetermined current threshold, said controller repeatedly measures said effective value of said detected current and repeatedly determines if said effective

5   value of said detected current is greater than or equal to said second predetermined current threshold.

28. The fault or differential current detection system as claimed in claim 27, wherein, when said effective value is less than said second predetermined current threshold, said controller repeatedly measures said effective value and repeatedly determines if said effective value is greater than or equal to said second

5   predetermined current threshold for a predetermined number of times.

29. The fault or differential current detection system as claimed in claim 20, wherein said controller measures at least one characteristic of said detected current after said detected current becomes greater than or equal to said second predetermined current threshold,

5   wherein said controller determines if said detected current is said fault or differential current based on said at least one characteristic, and

        wherein said controller repeatedly measures said at least one characteristic and repeatedly determines if said detected current is said fault or differential current if said detected current has not previously been determined to be said fault or

10 differential current.

30.   The fault or differential current detection system as claimed in claim

29, wherein, if said detected current has not previously been determined to be said

fault or differential current, said controller repeatedly measures said at least one

characteristic and repeatedly determines if said detected current is said fault or

5   differential current a predetermined number of times.

31.   A fault or differential current detection system that detects a fault or

differential current generated on a conductive path supplying power to an electric

device and that prevents the fault or differential current from being supplied to the

electric device, wherein the fault or differential current detection system comprises:

5   a detector that detects a detected current generated on said conductive path and

outputs a corresponding detection signal;

a switch that is provided in said conductive path that selectively isolates said

electric device from said conductive path; and

a controller that is placed in a sleep or power down mode and inputs a

10   detection signal corresponding to said detected current generated on said conductive

path,

wherein said controller determines if said detected current is greater than or

equal to a first predetermined current threshold based on said detection signal,

wherein said controller changes an operational mode from said sleep or power

15   down mode to an active mode after said detected current becomes greater than or

equal to said first predetermined current threshold,

wherein said controller measures an effective value of said detected current

after said detected current becomes greater than or equal to said first predetermined

current threshold,

20   wherein said controller refrains from outputting a control signal while said

operational mode of the said controller is changing from said sleep or power down

mode to said active mode and while said effective value is being measured,

        wherein said controller determines if said effective value of said detected

current is greater than or equal to a second predetermined current threshold after said

25   effective value of said detected current is measured,

        wherein said controller determines if said detected current is a fault or

differential current after said detected current becomes greater than or equal to said

second predetermined current threshold, and

        wherein, when said detected current is said fault or differential current, said

30   controller outputs said control signal at least indirectly to said switch to instruct said

switch to isolate said fault or differential current from an electric device connected to

said conductive path.

        32.   The fault or differential current detection system as claimed in claim

31, wherein, if said detected current is less than said second predetermined current

threshold, said controller repeatedly measures said effective value of said detected

current and repeatedly determines if said effective value of said detected current is

5   greater than or equal to said second predetermined current threshold.

        33.   The fault or differential current detection system as claimed in claim

32, wherein when said detected current is less than said second predetermined current

threshold, said controller repeatedly measures said effective value and repeatedly

determines if said effective value is greater than or equal to said second

5   predetermined current threshold a predetermined number of times, and

wherein, after said controller has repeatedly measured said effective value and

has repeatedly determined if said effective value is greater than or equal to said

second predetermined current threshold a predetermined number of times, said

controller is placed in said sleep or power down mode.

34.   The fault or differential current detection system as claimed in claim

31, wherein said controller measures at least one characteristic of said detected

current after said detected current becomes greater than or equal to said second

predetermined current threshold,

5   wherein said controller determines if said detected current is said fault or

differential current based on said at least one characteristic, and

wherein, when said detected current is determined not to be said fault or

differential current, said controller repeatedly measures said at least one characteristic

and determines if said detected current is said fault or differential current based on

10   said at least one characteristic.

35.   The fault or differential current detection system as claimed in claim

34, wherein, when said detected current is determined not to be said fault or

differential current, said controller repeatedly measures said at least one characteristic

and determines if said detected current is said fault or differential current based on

5   said at least one characteristic for a predetermined number of times, and

wherein, after said controller has repeatedly measured said at least one

characteristic and has determined if said detected current is said fault or differential

current based on said at least one characteristic for a predetermined number of times,

said controller is placed in said sleep or power down mode.

36.   The fault or differential current detection system as claimed in claim

31, wherein a predetermined idle period elapses when said controller changes said

operational mode changes from said sleep or power down mode to said active mode,

wherein a predetermined measurement period elapses when said controller

5   measures said effective value of said detected current after said detected current

becomes greater than or equal to said first predetermined current threshold, and

wherein said predetermined idle period and said predetermined measurement

period constitute at least a portion of a predetermined delay period.

37.   The fault or differential current detection system as claimed in claim

36, wherein at least one of said predetermined measurement period and said

predetermined idle period is adjustable by a user.

38.   The fault or differential current detection system as claimed in claim

37, wherein said predetermined delay period expires after a period during which

transient interference pulses are generated on said conductive path.

39.   A fault or differential current detection software program contained in

a computer readable medium, wherein the fault or differential current detection

software program includes instructions to instruct a controller to perform a routine

comprising:

5   (a)   determining if an instantaneous value of a current generated on a

conductor is greater than or equal to a first predetermined current threshold;

(b)   when said instantaneous value of said current is greater than or equal to

said first predetermined current threshold, determining an effective value of said

current;

10   (c)   determining if said effective value of said current is greater than or

equal to a second predetermined current threshold; and

(d)   when said effective value of said current is greater than or equal to said

second predetermined current threshold, determining if said current is a fault or

differential current.

40.   The fault or differential current detection software program as claimed

in claim 39, wherein said step (d) comprises:

(d1)   when said effective value of said current is greater than or equal to said

second predetermined threshold, determining if said current is a fault or differential

5   current;

(d2)   when said effective value of said current is less than said second

predetermined threshold, updating said effective value of said current and repeating

said steps (d1) and (d2) until said effective value of said current is greater than or

equal to said second predetermined threshold or until said steps (d1) and (d2) have

10   been repeated a first predetermined number of times.

41.   The fault or differential current detection software program as claimed

in claim 40, wherein said step (d1) comprises:

(d1a)   when said current is determined to be a fault or differential current,

outputting a control signal; and

5   (d1b)   when said current is determined not to be a fault or differential current,

updating said effective value of said current and repeating said steps (d1a) and (d1b)

until said current is determined to be a fault current or until said steps (d1a) and (d1b)

have been repeated a second predetermined number of times.

42.   The fault or differential current detection software program as claimed

in claim 41, wherein at least one of said first predetermined current threshold, said

second predetermined current threshold, said first predetermined number of times, and

said second predetermined number of times can be selected by a user of the software

5   program.

43.   The fault or differential current detection software program as claimed

in claim 42, wherein all of said first predetermined current threshold, said second

predetermined current threshold, said first predetermined number of times, and said

second predetermined number of times can be selected by a user of the software
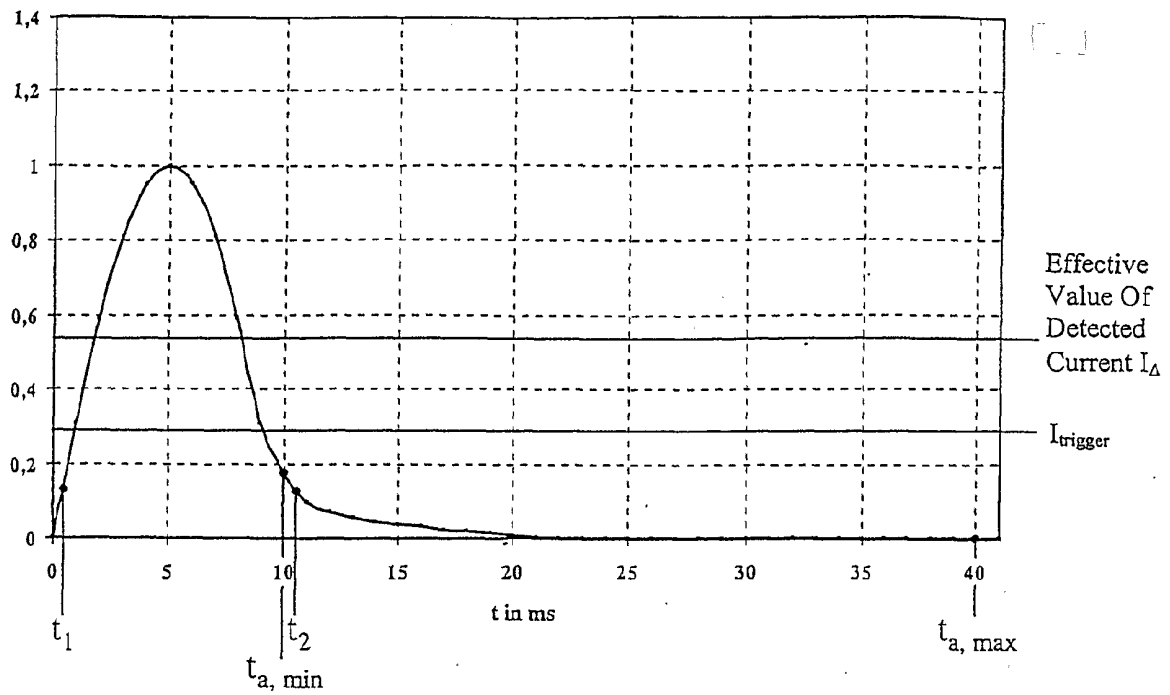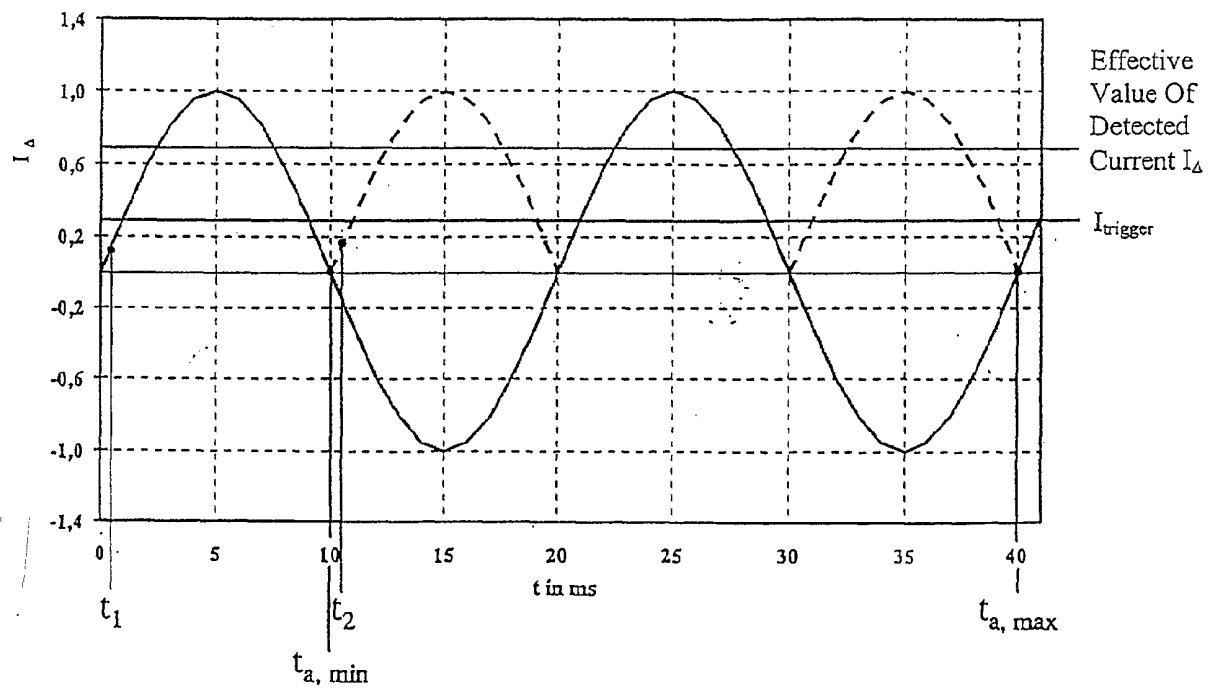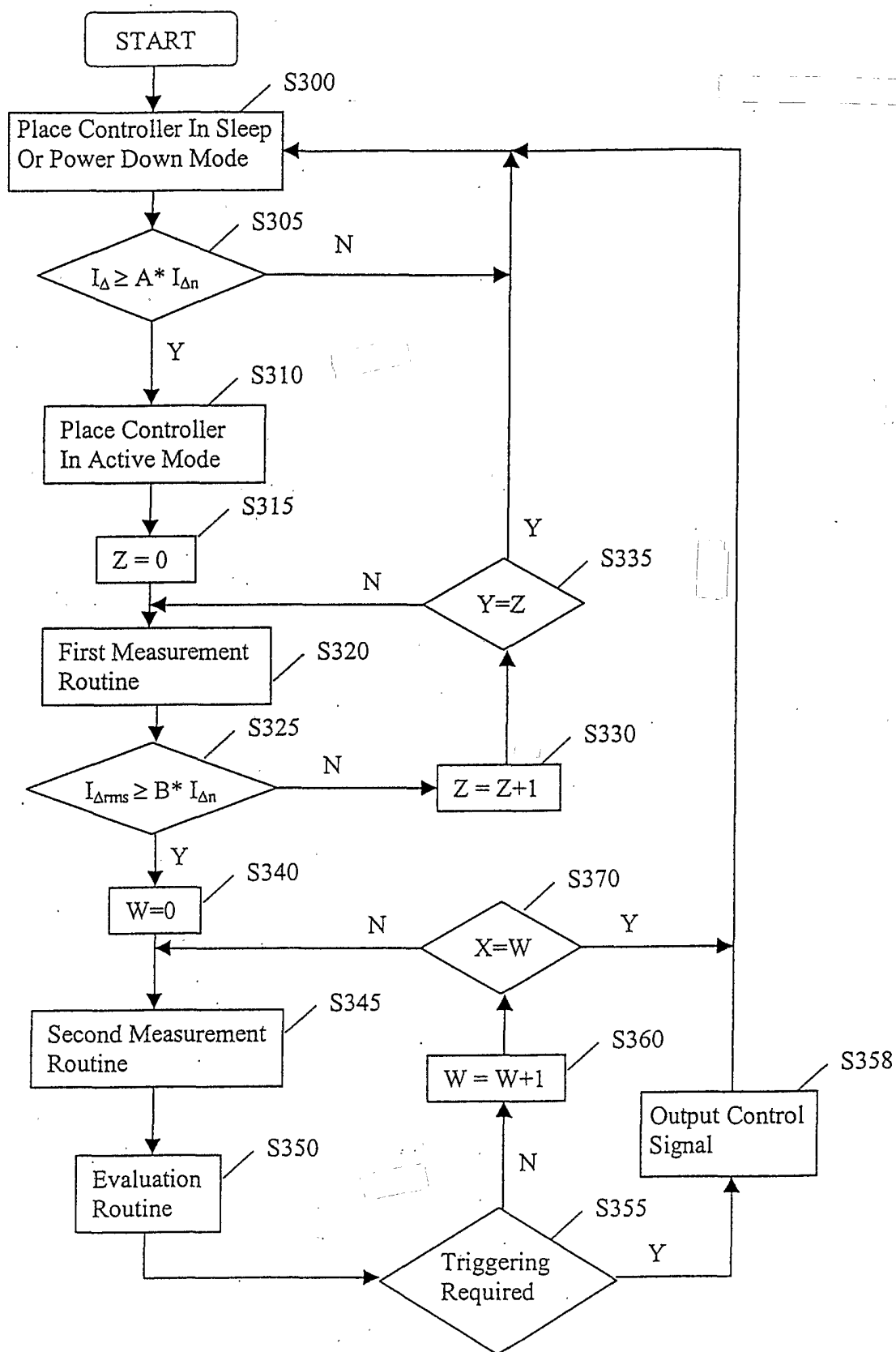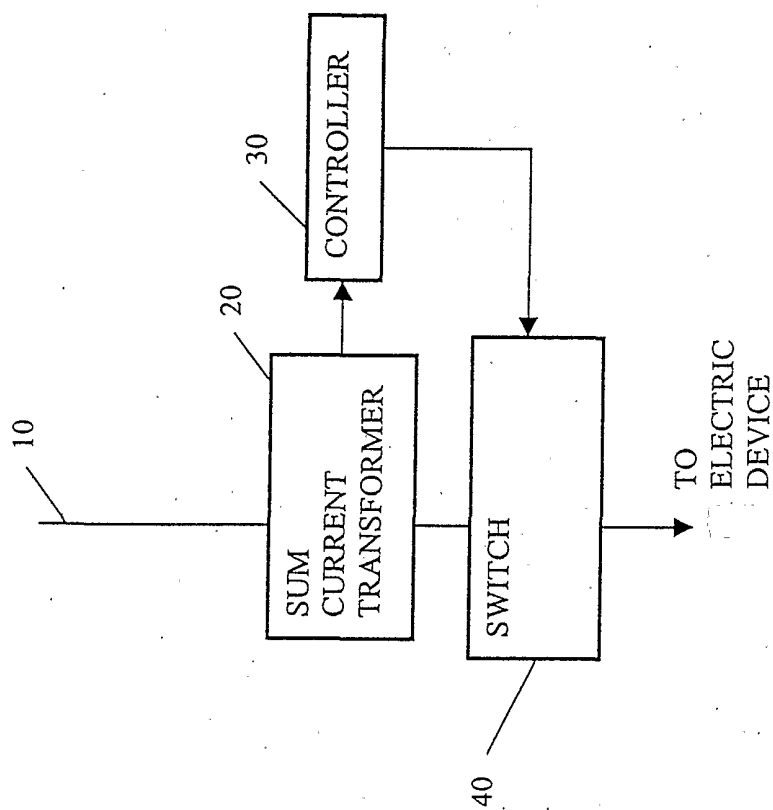
5   program.

FIG. 1

FIG. 2

START

S300

Place Controller In Sleep
Or Power Down Mode

S305

$I_\Delta \geq A * I_{\Delta n}$ — N

Y

S310

Place Controller
In Active Mode

S315

$Z = 0$

S335

Y=Z — Y

N

First Measurement
Routine — S320

S325

$I_{\Delta rms} \geq B * I_{\Delta n}$ — N — $Z = Z+1$ — S330

Y

$W=0$ — S340

X=W — S370 — Y

N

Second Measurement
Routine — S345

$W = W+1$ — S360

Evaluation
Routine — S350

Output Control
Signal — S358

Triggering
Required — S355 — Y

N

FIG. 3

SUM CURRENT TRANSFORMER

CONTROLLER

SWITCH

TO ELECTRIC DEVICE

10

20

30

40

FIG. 4

FIG. 5