CLAIMS

What is claimed is:

1. A method in a control apparatus of protecting a branch circuit in a Direct Current, DC, distribution system, said method comprising:

determining that a fault condition exists in the DC distribution system;

calculating, for each of a plurality of calculation intervals, a pseudo energy value, the pseudo energy value being based at least in part on a difference between branch current measurements and/or estimates of successive calculation intervals that have been increased by an exponential power, the exponential power being variable as a function of time;

accumulating a running sum of the calculated pseudo energy values while the fault condition persists; and

tripping a protection element for the branch circuit responsive to the accumulated running sum of the calculated pseudo energy values reaching a defined pseudo energy threshold.

2. The method of claim 1, wherein determining the difference between a branch current measurement and/or estimate comprises:

determining a difference between a present calculation interval, as raised by the exponential power, the exponential power being an *n*-th power, and a branch current measurement or estimate for a preceding calculation interval, as raised to the *n*-th power, wherein n is equal to or greater than two;

multiplying the difference between the present and preceding calculation intervals by an elapsed time between the present calculation interval and the preceding calculation interval, to obtain the pseudo energy value for the present calculation interval; and

adding the pseudo energy value for the present calculation interval to the running sum.

3. The method of claim 1, further comprising reducing a sampling rate used for sampling the branch current, based on using a branch current estimate rather than a branch current measurement for calculation of the pseudo energy values in at least some calculation intervals over which the pseudo energy values are accumulated.

4. The method of claim 1, wherein the defined pseudo energy threshold is set according to a location of the branch circuit within the electrical structure of the DC distribution system.

5. The method of claim 1, wherein the defined pseudo energy threshold is one among a plurality of defined pseudo energy thresholds corresponding to different load values, and wherein the method further comprises choosing which defined pseudo energy threshold to use for tripping the protection element, from among the plurality of defined pseudo energy thresholds, based on selecting the defined pseudo energy threshold that best matches a pre-fault load condition of the branch circuit.

6. The method of claim 1, wherein determining that the fault condition exists comprises detecting the fault condition from a branch circuit voltage or current, or from a derivative of the branch circuit voltage or current.

7. The method of claim 1, further comprising determining whether the fault condition persists, wherein determining whether the fault condition persists comprises repeatedly determining at least one of:

whether or not a branch current is above a current threshold used for fault detection; and

whether or not a branch voltage is below a voltage threshold used for fault detection.

8. The method of claim 1, further comprising resetting the protection element responsive to at least one of: receiving a control input at the control apparatus, determining that the fault condition no longer exists, and determining that the fault condition no longer exists in combination with determining that a defined period of time has elapsed since tripping the protection element.

9. A method in a control apparatus of protecting a branch circuit in a Direct Current, DC, distribution system, said method comprising:

determining that a fault condition exists in the DC distribution system;

accumulating pseudo energy values while the fault condition persists, based on repeatedly sampling current for the branch circuit; and

tripping a protection element for the branch circuit responsive to the accumulated pseudo energy values reaching a defined pseudo energy threshold; wherein

accumulating the pseudo energy values while the fault condition persists includes computing each pseudo energy value based on branch current measurements or estimates raised to an exponential power of n equals 2 or greater, and wherein the method further includes varying the exponential power as a function of time, based on using a higher exponential power during an initial time period following the determination that the fault condition exists, and using a lower exponential power during a subsequent time period.

10. A control apparatus configured to protect a branch circuit in a Direct Current, DC, distribution system, said control apparatus comprising:

an interface circuit configured to obtain local measurements for the branch circuit;

a processing circuit configured to:

determine that a fault condition exists in the DC distribution system;

calculate, for each of a plurality of calculation intervals, a pseudo energy value that is based at least in part on a difference between branch current measurements and/or estimates of successive calculation intervals that have been increased by an exponential power, the exponential power being variable as a function of time;

accumulate a running sum of the calculated pseudo energy values while the fault condition persists; and

trip a protection element for the branch circuit responsive to the accumulated pseudo energy values reaching a defined pseudo energy threshold.

11. The control apparatus of claim 10, wherein the control apparatus is configured to protect two or more branch circuits in the DC distribution system, each branch circuit having a respective protection element and being associated with a respectively defined pseudo energy threshold, and, correspondingly, wherein the interface circuit is configured to obtain measurements for each of the two or more branch circuits and the processing circuit is configured to independently accumulate pseudo energy values for each of the two or more branch circuits and to independently trip the respective protection element of any given one of the two or more branch circuits, responsive to the accumulated pseudo energy values for the given branch circuit reaching the defined pseudo energy threshold of the given branch circuit.

12. The control apparatus of claim 10, wherein the processing circuit is configured to accumulate pseudo energy values based on being configured to accumulate the pseudo energy values over successive calculation intervals, including being configured to:

determine a difference between a branch current measurement or estimate for a present calculation interval, as raised by the exponential power to an *n*-th power, and a branch current measurement or estimate for a preceding calculation interval, as raised to the n-th power, wherein n is equal to or greater than two;

multiply the difference by an elapsed time between the present calculation interval and the preceding calculation interval, to obtain the pseudo energy value for the present calculation interval; and

add the pseudo energy value for the present calculation interval to the running sum.

13. The control apparatus of claim 10, wherein the processing circuit is configured to reduce a sampling rate used for sampling the branch current, based on using a branch current estimate rather than a branch current measurement for calculation of the pseudo energy value in at least some calculation intervals over which the pseudo energy values are accumulated.

14. The control apparatus of claim 10, wherein the defined pseudo energy threshold is set according to a location of the branch circuit within the electrical structure of the DC distribution system.

15. The control apparatus of claim 10, wherein the defined pseudo energy threshold is one among a plurality of defined pseudo energy thresholds corresponding to different load values, and wherein the processing circuit is configured to choose which defined pseudo energy threshold to use for tripping the protection element, from among the plurality of defined pseudo energy thresholds, based on selecting the defined pseudo energy threshold that best matches a pre-fault load condition of the branch circuit.

16. The control apparatus of claim 10, wherein the processing circuit is configured to determine that the fault condition exists, based on being configured to detect the fault condition from a branch circuit voltage or current or from a derivative of the branch circuit voltage or current.

17. The control apparatus of claim 10, wherein the processing circuit is configured to determine whether the fault condition persists, based on being configured to repeatedly determine at least one of:

whether or not a branch current is above a current threshold used for fault detection; and

whether or not a branch voltage is below a voltage threshold used for fault detection.

18. The control apparatus of claim 10, wherein the processing circuit is configured to reset the protection element responsive to at least one of: a control input received at the control apparatus, a determination that the fault condition no longer exists, and a determination that the fault condition no longer exists in combination with a determination that a defined period of time has elapsed since tripping the protection element.

19. The control apparatus of claim 10, wherein the control apparatus and the protection element are integrated together as a protection device.

20. A control apparatus configured to protect a branch circuit in a Direct Current, DC, distribution system, said control apparatus comprising:

an interface circuit configured to obtain local measurements for the branch circuit;

a processing circuit configured to:

determine that a fault condition exists in the DC distribution system;

accumulate pseudo energy values while the fault condition persists, based on repeatedly sampling current for the branch circuit; and

trip a protection element for the branch circuit responsive to the accumulated pseudo energy values reaching a defined pseudo energy threshold; wherein, to accumulate the pseudo energy values while the fault condition persists, the processing circuit is configured to:

compute each pseudo energy value based on branch current measurements or estimates raised to an exponential power of n equals 2 or greater; and

vary the exponential power as a function of time, based on using a higher exponential power during an initial time period following the determination that the fault condition exists, and using a lower exponential power during a subsequent time period.