Claims

1. A high-voltage DC (HVDC) power system comprising:

a plurality of sending-end (SE) modules coupled in electrical series and divided into at least two groups that each operate independently with respect to an electrical ground;

a plurality of receiving-end (RE) power converter modules electrically coupled to said plurality of SE modules, the plurality of RE power converter modules comprising:

a fast ground-fault detection and control device;

a receiving-end front-end DC-DC converter controller; and

an output current damping control comprising a receiving-end current measuring loop; and

at least two SE control systems, each SE control system of said at least two SE control systems configured to regulate each group of said at least two groups to facilitate maintaining a substantially zero amp ground current, wherein said fast ground-fault detection and control device is configured to simultaneously transmit a fault signal to at least one SE control system of said at least two SE control systems.

2. The system of claim 1, wherein said HVDC power system further comprises a bipolar configuration having an earth ground and two opposite polarity transmission cables supplying said RE power converter modules from said SE modules.

3. The system of claim 1, wherein said HVDC power system further comprises a bipolar configuration having a low impedance metallic wire return and two opposite polarity transmission cables supplying said RE power converter modules from said SE modules.

4. The system of claim 1, wherein said HVDC power system further comprises a monopolar configuration having two transmission cables in electrical parallel supplying said RE power converter modules from said SE modules and at least one of a low impedance metallic wire return and an earth ground.

5. The system of claim 1, wherein said plurality of receiving-end (RE) power converter modules further comprises one or more ground fault detector devices implemented in each terminal of a switchyard configuration to facilitate identification of a ground fault location.

6. The system of claim 1, wherein said receiving-end current measuring loop comprises:

a high-pass-filter configured to eliminate a direct current component of the current; and

a regulator configured to generate a corresponding duty-cycle signal configured to modify the duty cycle of a first stage DC-DC converter of the RE power converter modules.

7. The system of claim 1, wherein said receiving-end front-end DC-DC converter controller comprises:

a receiving-end front-end DC-DC converter;

a receiving-end front-end DC-DC controller; and

a current reference circuit configured to generate a current reference signal based on a ratio of electrical power through said receiving-end front-end DC-DC converter, a voltage across an output of said receiving-end front-end DC-DC converter, and a reference voltage.

8. A method of high voltage DC (HVDC) power system control and protection, said method comprising:

coupling a plurality of loads to a receiving end (RE) power distribution system, the RE power distribution system configured as a plurality of monopole distribution systems configured to operate independently with respect to a ground, each load of the plurality of loads coupled to a branch of the RE power distribution system through a respective load distribution cable and a respective RE load power conversion module;

measuring a first current of the load at an inlet of the associated load distribution cable;

measuring a second current of the load at an inlet of the associated RE load power conversion module;

detecting a ground fault in the branch;

closing a bypass switch across conductors of the load distribution cable associated with the branch to bypass load current from the branch;

ramping down current in an associated monopole distribution system;

opening a ground fault isolation switch when the monopole distribution system current is approximately zero; and

ramping the current in the associated monopole distribution system to supply other loads in the monopole distribution system while the ground fault affected branch is isolated.

9. The method of claim 8, wherein detecting a ground fault in the branch comprises:

comparing a residual common mode current of the first and second currents to a threshold; and

determining a ground fault and location based on the comparison.

10. The method of claim 8, wherein ramping down current in an associated monopole distribution system comprises ramping down the output of a monopole system of a sending end power distribution system.

11. The method of claim 8, wherein opening a ground fault isolation switch when the monopole distribution system current is approximately zero comprises opening a ground fault isolation switch upstream of the load distribution cable to isolate the respective load distribution cable and the respective RE load power conversion module from the RE power distribution system.

12. The method of claim 8, wherein opening a ground fault isolation switch when the monopole distribution system current is approximately zero comprises opening a ground fault isolation switch upstream of the respective RE load power conversion module to isolate the respective RE load power conversion module from the RE power distribution system.

13. The method of claim 8, further comprising coupling a plurality of sending-end (SE) modules in electrical series and divided into at least two groups that each operate independently with respect to an electrical ground.

14. The method of claim 8, further comprising automatically adjusting a terminal voltage of the RE load power conversion module to damp current oscillations and spikes.

15. The method of claim 14, further comprising measuring a receiving-end current using a high-pass-filter configured to eliminate a direct current component of the current and a regulator configured to generate a corresponding duty-cycle signal.

16. The method of claim 8, further comprising:

coupling the receiving end (RE) power distribution system to a plurality of sending-end (SE) modules coupled together in electrical series and divided into at least two groups that each operate independently with respect to an electrical ground using a pair of opposite polarity transmission cables; and

operating the HVDC power system in a bipolar mode where current through the HVDC power system is balanced such that an approximately zero amp current flows through a system ground connection.

17. The method of claim 8, further comprising coupling a system ground connection between the receiving end (RE) power distribution system and the plurality of sending-end (SE) modules through earth.

18. The method of claim 8, further comprising coupling a system ground connection between the receiving end (RE) power distribution system and the plurality of sending-end (SE) modules through a low-impedance wired connection.

19. A subsea receiving end (RE) assembly of a high-voltage DC (HVDC) power system, said assembly comprising:

a plurality of receiving-end (RE) power converter module branches coupled in electrical series and comprising an associated load segment comprising an RE power converter module, a load, a load distribution cable, and load segment distribution protective devices, each RE power converter module branch of said plurality of RE power converter module branches supplying a respective load with three-phase alternating current (AC) power for each branch of loads, said associated load segment comprising:

a fast ground-fault detection system comprising:

a first current sensor configured to measure load current entering said load distribution cable;

a second current sensor configured to measure load current entering said RE power converter module downstream from said load distribution cable;

a ground fault detector configured to compare a residual common mode current measured by said first and second current sensors to a threshold and generate a ground fault command; and

a load isolation device configured to isolate a ground fault from the HVDC power system based on the generated ground fault command, wherein the HVDC power system includes a sending-end (SE) system, said ground fault detector further configured to simultaneously transmit a fault signal to an SE controller, said SE controller configured to ramp down an output current of the faulted side of the SE system.

20. The system of claim 1, wherein each SE control system of said at least two SE control systems comprises:

a first measurement system coupled to one group of said at least two groups and configured to measure an electrical current and a voltage with respect to the electrical ground, wherein each RE power converter module of the plurality of RE power converter modules comprises a load distribution cable.

21. The system of claim 20, wherein said fast ground fault detection and control device comprises:

a first current sensor configured to measure load current entering said load distribution cable;

a second current sensor configured to measure load current entering said RE power converter module downstream from said load distribution cable;

at least one ground fault detector configured to compare a residual common mode current measured by said first and second current sensors to a threshold and generate a ground fault command; and

a load isolation device configured to isolate a ground fault from said HVDC power system based on the generated ground fault command.