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(54) **Title**: METHOD AND APPARATUS FOR PROTECTING POWER SYSTEMS FROM EXTRAORDINARY ELECTROMAGNETIC PULSES

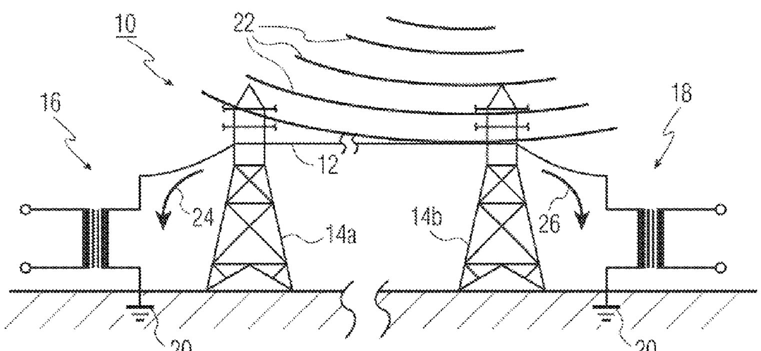

FIG. 1B

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(57) **Abstract**: One form of the invention provides a method and apparatus for preventing an extraordinary electromagnetic pulse from reaching and rendering inoperative an electrical component of an electrical power system, wherein the component is located in a conductive path of the system that receives the pulse. The method and apparatus comprises the steps or means for detecting the presence of the pulse in the conductive path prior to the pulse reaching and rendering inoperative the electrical component. The pulse is diverted around the electrical component with a low inductance, high current capacity circuit relative to the electrical component before the pulse can reach and render the electrical component inoperative. The foregoing invention may beneficially utilize a high-speed current shunt comprising a flat conductive metal strap having a defined current-measuring region, a tapered parallel-plate transmission-line matching transformer attached to the current-measuring region and an output via a coaxial cable.

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AMENDED CLAIMS

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1. A method for preventing an extraordinary electromagnetic pulse from reaching and rendering inoperative a magnetic-winding containing electrical component of an electrical power system, which component is located in a conductive path of said system that receives said pulse, the method comprising the steps of:

   a) detecting the presence of said pulse in said conductive path prior to the pulse reaching and rendering inoperative said electrical component; and

   b) diverting said pulse around the electrical component by creation of a low inductance, high current capacity short-circuit relative to the electrical component, so as to thereby collapse the magnetic field in said winding before the pulse can reach and render the electrical component inoperative.

2. The method of claim 1, wherein said conductive path further includes a second electrical component and further comprising:

   a) detecting the presence of said pulse in said conductive path prior to the pulse reaching and rendering inoperative the second electrical component; and

   b) diverting said pulse around the second electrical component by creation of a second low inductance, high current capacity short-circuit relative to the second electrical component before the pulse can reach and render the second electrical component inoperative.

3. The method of claim 1 or 2, wherein said first-mentioned and said second electrical components respectively comprise an electrical transformer or an electrical generator.

4. The method of claim 1 or 2, wherein said detecting comprises detecting an overvoltage condition in said conductive path arising from said pulse travelling in said power system towards earth ground.

5. The method of claim 1 or 2, wherein said detecting comprises detecting an overcurrent condition arising from said pulse traveling from earth ground towards said electrical component.

6. The method of claim 1 or 2, wherein said detecting and said diverting occur in less than 500 picoseconds.

7. (cancelled)

8. The method of claim 7, wherein:

a) the low inductance circuit comprises a bidirectional high-voltage cold-cathode field-emission vacuum electron tube including cylindrical inner electrode encircled by a first cylindrical grid, in turn encircled by a second cylindrical grid, in turn encircled by a cylindrical outer electrode; the inner and outer electrodes and the first and second grids sharing a common main axis;

b) the inner and outer cylindrical electrodes respectively functioning bidirectionally, as either a field-emission cathode or an anode, depending on the instantaneous polarity of the signal applied across said electrodes;

c) the radial spacing from the inner electrode to the first grid is such as to create therebetween a circular waveguide supporting the transverse electromagnetic mode; and the spacing between the second grid and the outer electrode is such as to create therebetween a circular waveguide supporting the transverse electromagnetic mode;

d) the radial spacing between the first grid and the second grid is sufficient to prevent flashover between the first and second grids at an intended operating voltage; and

e) said switch being mounted in a reentrant tube socket comprising a pair of conductive top-hat shaped sockets, each with a cylindrically shaped portion mainly closed at one end and an open end encircled by a rim portion, the open ends facing each other and the rim portions serving as electrodes for said switch.

9. (cancelled)

10. The method of claim 2, further comprising the step of isolating said electrical component subsequent to onset of said diverting, after a predetermined period of time no more than two cycles of line voltage applied to the electrical component.

11. The method of claim 10, wherein the step of isolating is initiated from sensing overcurrent as a result of a GIC in said conductive path.

12. The method of claim 10, wherein the step of isolating is initiated from sensing overvoltage as a result of an NEMP or NNEMP in said conductive path.

13. The method of claim 1 or 2, wherein:

a) said low inductance circuit comprises a switch mounted on a self-supporting conductor formed from an elongated, conductive, stainless steel core covered with a conformal conductive chrome sheathing layer, which in turn is covered by a conformal conductive copper sheathing layer; and

b) one end of said self-supporting conductor is connected to earth ground.

14. The method of claim 13, wherein the copper conductive sheathing is covered by a conformal corrosion-resistant dielectric protective layer.

15. The method of claim 13, wherein a cross-section of the self-supporting conductor along a main dimension defines a flat rectangular solid with radiused edges along said main dimension.

16. Apparatus for preventing an extraordinary electromagnetic pulse from reaching and rendering inoperative a magnetic-winding containing component of an electrical power system, which component is located in a conductive path of said system that receives said pulse, the apparatus comprising:

a) means for detecting the presence of said pulse in said conductive path prior to the pulse reaching and rendering inoperative said electrical component; and

b) means for diverting said pulse around the electrical component by creation of a low inductance, high current capacity short-circuit relative to the electrical component before the pulse can reach and render the electrical component inoperative.

17. The apparatus of claim 16, wherein said conductive path further includes a second electrical component and further comprising:

a) means for detecting the presence of said pulse in said conductive path prior to the pulse reaching and rendering inoperative the second electrical component; and

b) means for diverting said pulse around the second electrical component by creation of a second low inductance, high current capacity short-circuit relative to the second electrical component before the pulse can reach and render the second electrical component inoperative.

18. The apparatus of claim 16 or 17, wherein said first-mentioned and said second electrical components respectively comprise an electrical transformer or an electrical generator.

19. The apparatus of claim 16 or 17, wherein said means for detecting comprises means for detecting an overvoltage condition in said conductive path arising from said pulse travelling in said power system towards earth ground.

20. The apparatus of claim 16 or 17, wherein said means for detecting comprises means for detecting an overcurrent condition arising from said pulse traveling from earth ground towards said electrical component.

21. The apparatus of claim 16 or 17, wherein said detecting and said diverting occurring in less than 500 picoseconds.

22. The apparatus of claim 16 or 17, wherein said low inductance circuit is bidirectional.

23. The apparatus of claim 22, wherein:

a) the low inductance circuit comprises a bidirectional high-voltage cold-cathode field-emission vacuum electron tube including cylindrical inner electrode encircled by a first cylindrical grid, in turn encircled by a second cylindrical grid, in turn encircled by a cylindrical outer electrode; the inner and outer electrodes and the first and second grids sharing a common main axis;

b) the inner and outer cylindrical electrodes respectively functioning bidirectionally, as either a field-emission cathode or an anode, depending on the instantaneous polarity of the signal applied across said electrodes;

c) the radial spacing from the inner electrode to the first grid is such as to create therebetween a circular waveguide supporting the transverse electromagnetic mode; and the spacing between the second grid and the outer electrode is such as to create therebetween a circular waveguide supporting the transverse electromagnetic mode;

d) the radial spacing between the first grid and the second grid is sufficient to prevent flashover between the first and second grids at an intended operating voltage; and

e) said switch being mounted in a reentrant tube socket comprising a pair of conductive top-hat shaped sockets, each with a cylindrically shaped portion mainly closed at one end and an open end encircled by a rim portion, the open ends facing each other and the rim portions serving as electrodes for said switch.

24. (cancelled)

25. The apparatus of claim 17, further comprising means for isolating said electrical component from a circuit comprising said first and second low inductance, high current capacity circuits, subsequent to onset of said diverting, after a predetermined period of time no more than two cycles of line voltage applied to the electrical component.

26. The apparatus of claim 25, wherein the means for isolating is responsive to overcurrent being sensed as a result of a GIC pulse in said conductive path.

27. The apparatus of claim 25, wherein the means for isolating is responsive to overvoltage being sensed as a result of an NEMP or NNEMP in said conductive path.

28. The apparatus of claim 16 or 17, wherein:

a) said low inductance circuit comprises a switch mounted on a self-supporting conductor formed from an elongated, conductive, stainless steel core covered with a conformal conductive chrome sheathing layer, which in turn is covered by a conformal conductive copper sheathing layer; and

b) one end of said self-supporting conductor is connected to earth ground.

29. The apparatus of claim 28, wherein the copper conductive sheathing is covered by a conformal corrosion-resistant dielectric protective layer.

30. The apparatus of claim 28, wherein a cross-section of the self-supporting conductor along a main dimension defines a flat rectangular solid with radiused edges along said main dimension.

31. A high-speed current shunt, comprising:

a) a flat conductive metal strap having a first and a second electrode at each end of said strap for connection to an external circuit for receiving current through the strap; said strap having a defined current-measuring region extending from a first linear position to a second linear position along the length of the strap; and

b) a tapered parallel-plate transmission-line impedance-matching transformer, comprising:

i) first and second plates tapered in shape and having a wide end and a narrow end, relative to one another; each tapered plate having a length approximately 10 times that of width of said metal strap;

ii) said first plate being attached at its wide end to said first linear position of the defined measuring region by a solder and said second plate being attached at its wide end to said second linear position of the defined measuring region by a solder; and

iii) a coaxial cable with a center conductor being attached by a solder to the narrow end of the first plate, and a shield being attached by a solder to the narrow end of the second plate.

32. The shunt of claim 31, wherein said solders have a conductivity at least as high as that of silver solder with a silver content exceeding 5 percent by mass.

33. The shunt of claim 31, wherein the conductive metal strap has a conductivity at least as high as that of commercial grade copper with a copper content of at least 94 percent by mass.

34. The shunt of claim 31, further comprising a first electrical insulation under said first plate extending from a juncture of said strap and said wide end of the first plate to beyond said narrow end of the first plate and into a slot extending along a longitudinal length under and approximately parallel to the center conductor of the coaxial cable.

35. The shunt of claim 31, further comprising a second electrical insulation under said second plate extending from a juncture of said strap and said wide end of the second plate in the direction towards the coaxial cable, not less than one-half of the length of the second plate.

36. The shunt of claim 31, wherein the width of each of the tapered plates is approximately equal to the width of the flat metal strap.

37. The shunt of claim 31, wherein the impedance of the coaxial cable is 50-ohms.

38. The shunt of claim 31, wherein the diameter of the coaxial cable is at least 12.77 mm.

39. A bidirectional high-voltage cold-cathode field-emission bi-directional vacuum electron tube, comprising:

a) a cylindrical inner electrode encircled by a first cylindrical grid, in turn encircled by a second cylindrical grid, in turn encircled by a cylindrical outer electrode; the inner and outer electrodes and the first and second grids sharing a common main axis;

b) the inner and outer cylindrical electrodes respectively functioning bidirectionally, as either a field emission cathode or an anode, depending on the instantaneous polarity of the signal applied across said electrodes;

c) the radial spacing from the inner electrode to the first grid is such as to create therebetween a circular waveguide supporting the transverse electromagnetic mode; and the spacing between the second grid and the outer electrode is such as to create therebetween a circular waveguide supporting the transverse electromagnetic mode; and

d) the radial spacing between the first grid and the second grid is sufficient to prevent flashover between the first and second grids at an intended operating voltage.

40. The combination of the electron tube of claim 39 and a reentrant electron tube socket for said tube; the reentrant tube socket comprising a pair of conductive top-hat shaped sockets, each with a cylindrically shaped portion mainly closed at one end and an open end encircled by a rim portion, the open ends facing each other and the rim portions serving as electrodes for said switch.

41. A method for preventing an extraordinary electromagnetic pulse from reaching and rendering inoperative an electrical component of an electrical power system that is normally at a DC voltage, which component is located in a conductive path of said system that receives said pulse, the method comprising the steps of:

a) detecting the presence of said pulse in said conductive path prior to the pulse reaching and rendering inoperative said electrical component; and

b) diverting said pulse around the electrical component by creation of a unidirectional low inductance, high current capacity short-circuit relative to the electrical component, before the pulse can reach and render the electrical component inoperative.

42. (new) Apparatus for preventing an extraordinary electromagnetic pulse from reaching and rendering inoperative an electrical component of an electrical power system that is normally at a DC voltage, which component is located in a conductive path of said system that receives said pulse, the method comprising the steps of:

a) detecting the presence of said pulse in said conductive path prior to the pulse reaching and rendering inoperative said electrical component; and

b) diverting said pulse around the electrical component by creation of a unidirectional low inductance, high current capacity short-circuit relative to the electrical component, before the pulse can reach and render the electrical component inoperative;.