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(54) **PROTECTION ARRANGEMENT FOR A TRANSFORMER**

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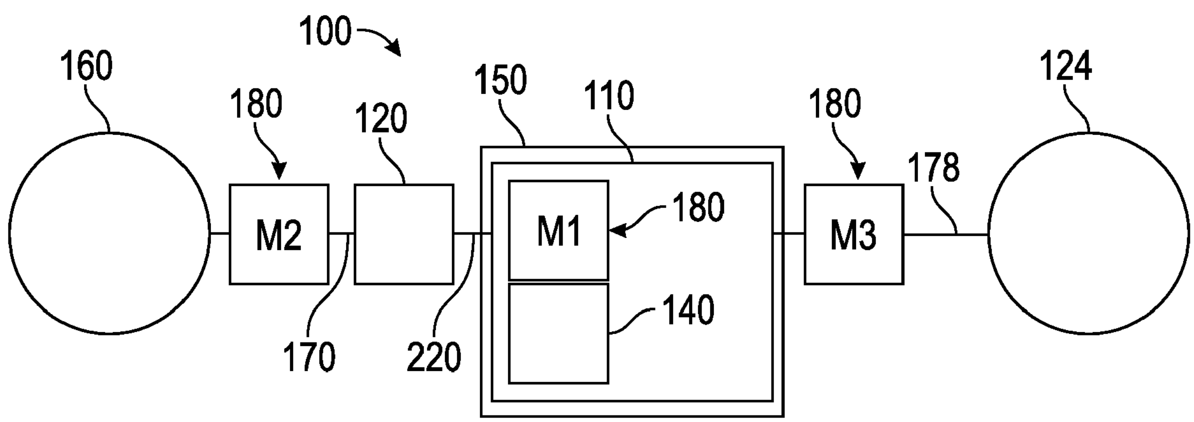
(57) **ABSTRACT**

A protection arrangement for a transformer includes at least one fault interrupter configured to be coupled to at least one winding of the transformer, to protect the transformer from over-current faults, and a voltage protector configured to be coupled to the at least one winding, to protect the transformer from transient over-voltage events caused by the at least one fault interrupter.



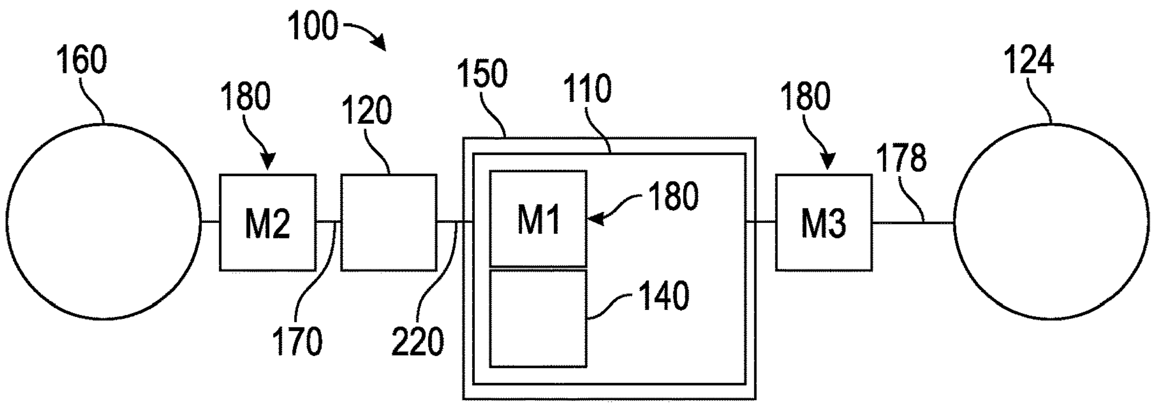


FIG. 1A

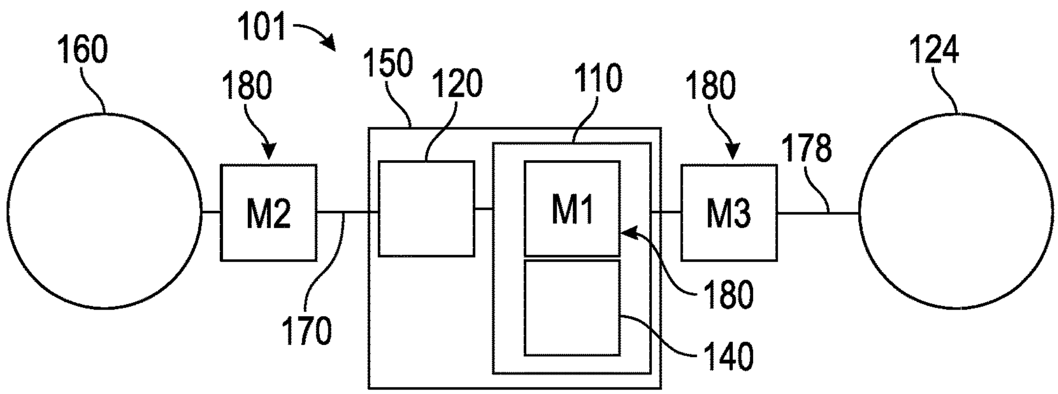


FIG. 1B

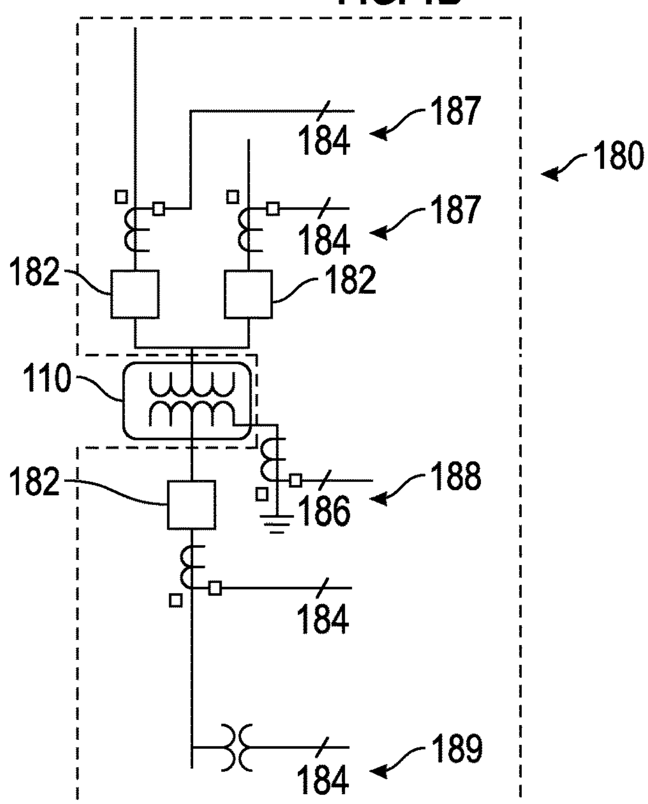


FIG. 2

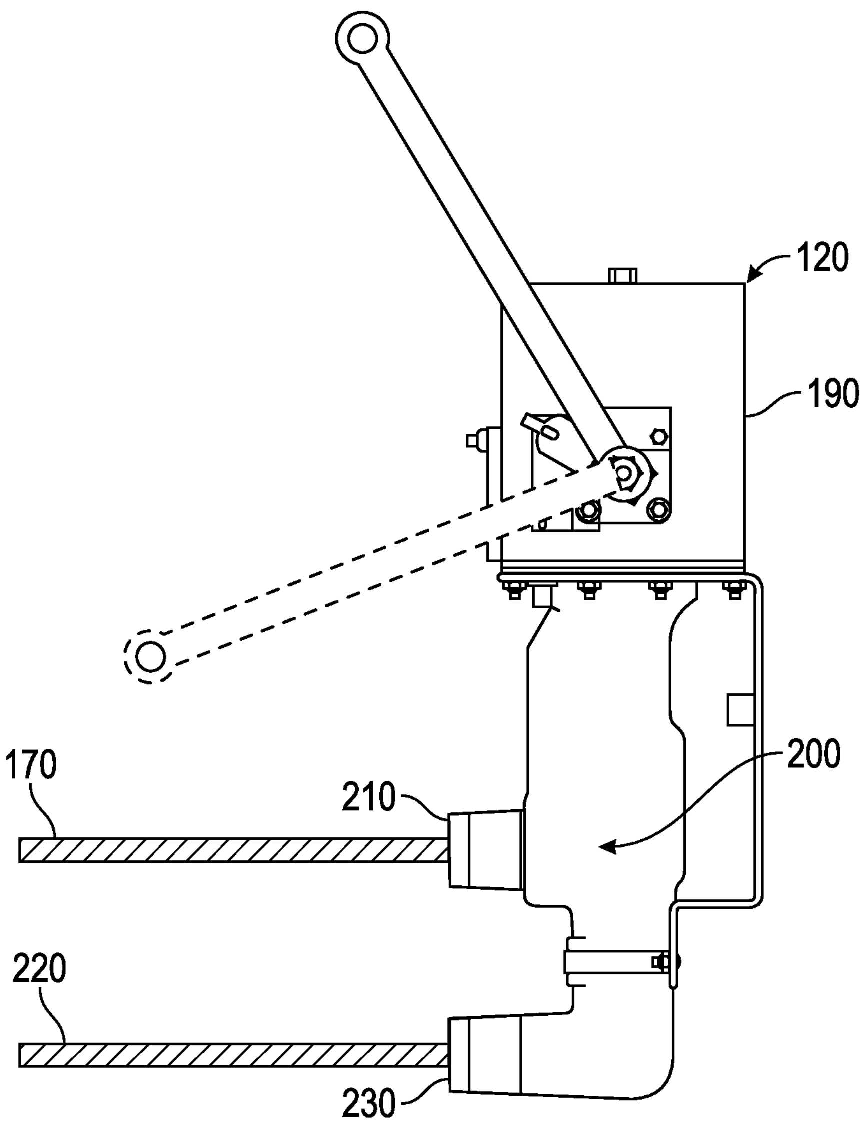


FIG. 3A

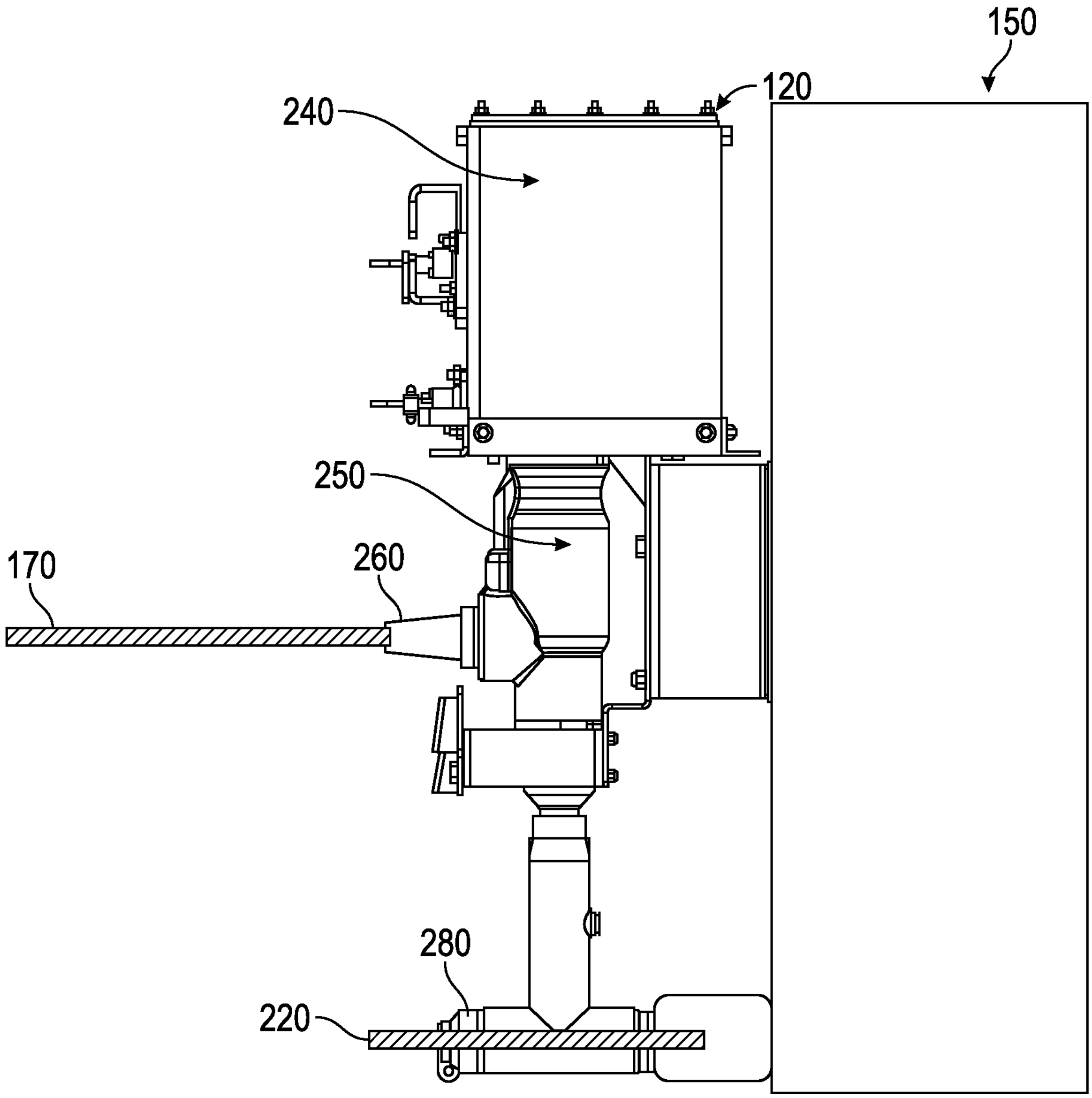


FIG. 3B

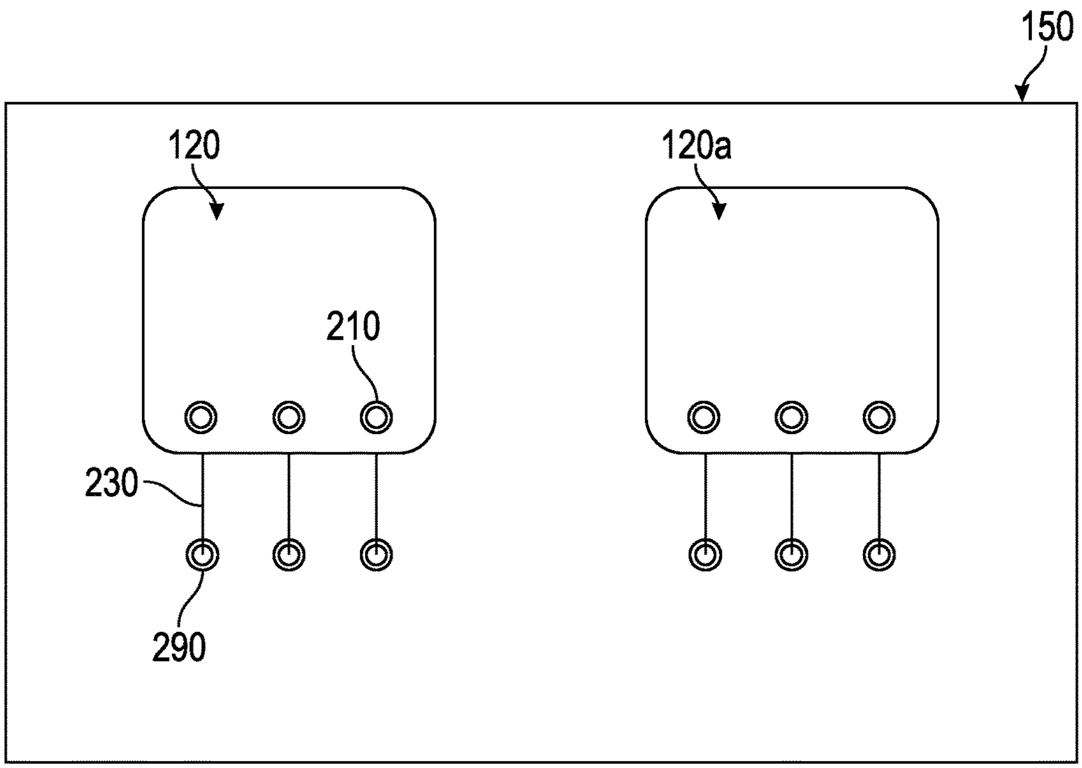

150
120
120a
210
230
290

FIG. 4

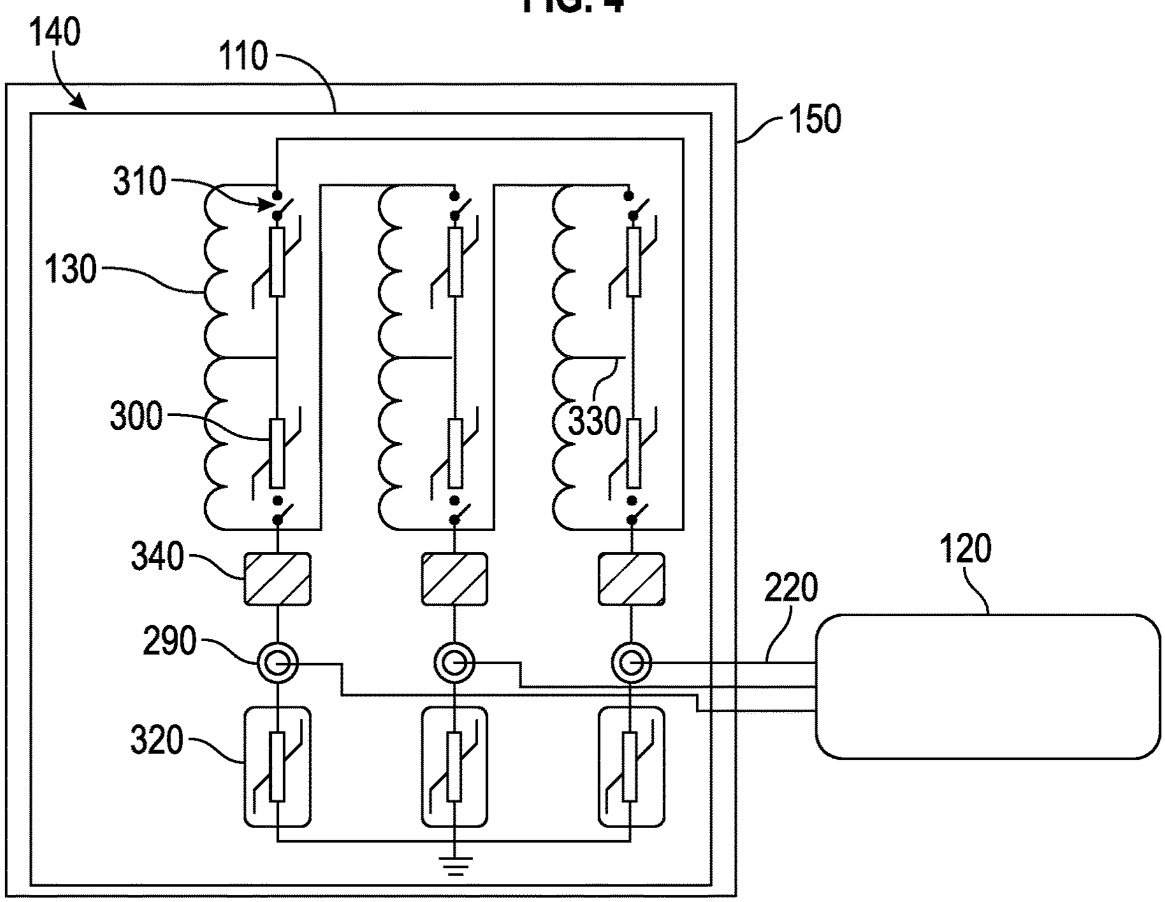

140
110
150
310
130
300
330
340
290
320
220
120

FIG. 5

PROTECTION ARRANGEMENT FOR A TRANSFORMER

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application is a 35 U.S.C. § 371 national stage application of PCT International Application No. PCT/EP2022/073631 filed on Aug. 24, 2022, the disclosures and content of which are incorporated by reference herein in their entireties.

TECHNICAL FIELD

[0002] The embodiments described herein are generally directed to transformer assembly protection systems.

BACKGROUND

[0003] In miniature distributor substation ("Mini Sub") solution, a transformer and a fault interrupter are close coupled. Without suitable protection, voltage across windings at disconnection of an inductive load, interruption of load currents, interruption of short-circuit currents, any one or more at different and/or same time, is likely to exceed transformer basic insulation level ("BIL") for certain conditions of breaker operation, putting the transformer at risk of premature failure. The interrupter cuts current before it reaches 0. The energy accumulated in the circuit may lead to multiple fast voltage transients observed along windings and across ground insulation. Breaking operation brings the most severe (duration, amplitudes) transients. The aforementioned close coupling exposes transformer active part to damage from transients, damaging a winding as well as insulation of a transformer arrangement.

SUMMARY

[0004] Accordingly, an aspect of the disclosure involves a protection arrangement for a transformer that includes at least one fault interrupter configured to be coupled to at least one winding of the transformer, to protect the transformer from over-current faults, and a voltage protector configured to be coupled to the at least one winding, to protect the transformer from transient over-voltage events caused by the fault interrupter.

BRIEF DESCRIPTION OF THE DRAWINGS

[0005] The details of the present disclosure, both as to its structure and operation, may be gleaned in part by study of the accompanying drawings, in which like reference numerals refer to like parts, and in which:

[0006] FIGS. **1**A-B are simplified schematics of embodiments of a protection arrangement for a transformer;

[0007] FIG. **2** is a simplified schematic of an embodiment of a monitoring system of the protection arrangement for mainly monitoring the fault interrupter of FIGS. **1**A-**1**B;

[0008] FIGS. **3**A-B are side elevational views of embodiments of fault interrupters of the protection arrangement for a transformer of FIGS. **1**A-**1**B;

[0009] FIG. **4** is a simplified schematic of a pair of fault interrupters of the protection arrangement for a transformer of FIGS. **1**A-**1**B, in the case of a dual source; and

[0010] FIG. **5** is a simplified schematic of an embodiment of a voltage protector of the protection arrangement for a transformer of FIGS. **1**A-**1**B.

DETAILED DESCRIPTION

[0011] With reference to FIGS. **1**A-B, embodiments of a protection arrangement **100**, **101** for a transformer **110** will be described. The protection arrangement **100**, **101** includes at least one fault interrupter **120** configured to be coupled to at least one (e.g., primary winding(s)) **130** of the transformer **110**, to protect the transformer **110** from over-current faults, and a voltage protector **140** configured to be coupled to the at least one winding **130**, to protect the transformer **110** from transient over-voltage events caused by the fault interrupter **120**, as described further below and in greater detail in conjunction with FIG. **5**. In one embodiment (not shown), the fault interrupter **120** and/or the voltage protector **140** are/is coupled to more than one winding **130**, for example, but not by way of limitation, with a three-phase transformer. In another embodiment, the fault interrupter **120** and/or the voltage protector **140** are/is coupled to all windings **130**. In a further embodiment (not shown), the fault interrupter **120** and/or the voltage protector **140** are/is coupled to a single winding **130**, for example, but not by way of limitation, with a single-phase transformer. The transformer **110** identified in FIG. **1**A is the active part (e.g., windings, core, internal connections) having the voltage protector **140**.

[0012] In the event of current fault, over-voltage event, or combined current fault and over-voltage event, the protection arrangement **100**, **101** will disconnect the transformer winding(s) **130**. This reduces or eliminates damage to the transformer winding(s) **130** and insulation arrangement, and further reduces or eliminates the effect of additional forces that could come from an earth fault event or line fault event. The transformer **110** includes the primary winding **130** and a secondary winding (not shown). In one embodiment, the transformer **110** is a liquid-immersed (e.g., mineral oil, ester oil) transformer, but may also be a dry transformer. The transformer **110** may include a pad-mounted transformer, a ground-mounted transformer, a substation transformer, a Network transformer, or a Generator Step Up transformer. The active part of transformer **110** is enclosed within an enclosure (e.g., tank body) **150**.

[0013] A source **160**, such as a high-voltage side of an external network, supplies power to the transformer **110** via input cables **170**. The transformed power is received by a load **124** via output cable(s) **178**. The fault interrupter **120** may disconnect the transformer **110** from the source **160** at rated conditions or may be used to switch between sources.

[0014] One or more monitoring system(s) **180**, located inside and/or outside of the transformer enclosure **150**, monitors the protection arrangement **100**, **101** everywhere. The monitoring system(s) **180** monitor one or more conditions in the protection arrangement **100**, **101** to determine at least one of the over-current faults and the over-voltage events. In an embodiment, the monitoring system(s) **180** include at least a first monitoring system **M1** located inside of the enclosure **150** housing the transformer **110** and a second monitoring system **M2** located outside of the enclosure **150** housing the transformer **110**. The monitoring system(s) **180** include one or more sensors and/or one or more relays. The monitoring system(s) **180** include one or more current transformers configured to measure both phase and ground current (e.g., measures primary current, secondary current, difference between two to determine if transformer **110** is operating properly) in the one or more lines, and/or one or more potential transformers that measure voltage in the one or more lines. A third monitoring system

M3 is coupled to another winding (e.g., secondary winding). The monitoring system(s) **180** treats the fault interrupter **120** to have desired operation and signaling.

[0015] As shown in FIG. **2**, an embodiment of the monitoring system **180** for mainly monitoring the fault interrupter **120** will be described. The monitoring system **180** includes auxiliary contacts **182** for signaling input, connector/disconnector switches **184**, connector/disconnector switch **186**, current transformers **187** for monitoring input, neural paths **188** each with a current transformer and grounding, and potential transformers **189** for monitoring input.

[0016] With reference to FIGS. **1**A-B, and **3**A-B, the fault interrupter **120** is coupled to the transformer **110** to protect the transformer **110** from over-current faults. For example, but not by way of limitation, the fault interrupter **120** is coupled to the transformer **110** by the fault interrupter **120** being connected to transformer bushings (directly in FIG. **3**B, through cable in FIG. **3**A) and the transformer bushings being connected with the winding(s)) **130** internally.

[0017] In one embodiment, the fault interrupter **120** is a medium-voltage fault interrupter **120**. As used herein, "medium voltage" includes, for example, up to 36 kV. In another embodiment, the fault interrupter **120** is a high-voltage fault interrupter **120**. As used herein, "high voltage" includes, for example, greater than 36 kV. In the embodiment shown, the fault interrupter **120** is externally mounted to the enclosure **150** of the transformer **110**, but in an alternative embodiment of the protection arrangement **101**, as shown in FIG. **1**B, the fault interrupter **120** is internally mounted, inside the enclosure **150** of the transformer **110**. The fault interrupter **120** includes an epoxy encapsulated fault interrupter switch with an integral magnetic actuator. Alternatively, the fault interrupter **120** may be spring-operated.

[0018] In the embodiment of the fault interrupter **120** shown in FIG. **3**A, which is a flexible jumper connection between transformer bushing and fault interrupter **120**, the fault interrupter **120** is a vacuum fault interrupter enclosed in a housing **190**, outside of the enclosure **150** of the transformer **110**. A vacuum bottle **200** is coupled to the housing **190**. Input cable **170** is coupled to the vacuum bottle **200** via interface connection **210**. Interconnection **220** is coupled to the vacuum bottle **200** via interface connection **230**.

[0019] FIG. **3**B illustrates another embodiment of the fault interrupter **120**, which shows a direct connection between transformer bushing and fault interrupter **120** (no flexible jumper as in FIG. **3**A) and where the fault interrupter **120** is a vacuum fault interrupter enclosed in a housing **240**, outside of the enclosure **150** of the transformer **110**. A vacuum bottle **250** is coupled to the housing **240**. Input cable **170** is coupled to the vacuum bottle **250** via interface connection **260**. Interconnection **220** is coupled to the vacuum bottle **250** via connection **280**, which is a fault interrupter connection with the transformer bushing.

[0020] FIG. **4** illustrates another embodiment of the fault interrupter **120**, where a second fault interrupter **120*a*** is mounted externally to the enclosure **150** of the transformer **110** in the case of a dual/second source. Also shown in FIG. **4**, interface connections **210**, **230** and primary side transformer bushings **290** are provided.

[0021] With reference to FIG. **5**, which shows the high-voltage side of the transformer **110**, the voltage protector **140** will now be described in more detail. In the embodiment shown, the voltage protector **140**, which is located inside the enclosure **150**, is coupled to the primary winding **130** to protect the transformer **110** from transient over-voltage events caused by the fault interrupter **120**. In alternative embodiments, the voltage protector **140** is located outside the enclosure **150** or located outside and inside the enclosure **150**. In the embodiment shown in FIG. **5**, The voltage protector **140** includes metal oxide ("MO") varistors **300** and switches **310** integrated with the primary winding **130** along with surge arrestors **320** disposed between the primary side transformer bushings **290** in the enclosure **150** and ground.

[0022] The combination of the MO varistors **300** and switches **310** may provide a very efficient way to clamp the voltage along the primary winding **130** during transient over-voltage events to reduce or prevent damage to the transformer **110** and control transient over-voltages to a pre-defined limit, which depends on the transformer primary connected system voltage, the basic insulation level of the transformer insulation system, the power system configuration, and the combination of the components configured in power system, that is safe for the transformer **110**. The surge arrestors **320** achieve combination of phase-to-phase and phase-to-ground protection of the transformer **110**, but primarily provide phase-to-earth protection of the transformer **110**. The MO varistors **300** and switches **310** are connected to the primary winding **130** at winding tap **330** to protect the primary winding **130**. The MO varistors **300** primarily provide phase-to-phase protection of the transformer **110**. Extra current protectors **340** such as, not limited to, fuses, surge counters, may be provided.

[0023] The protection arrangement **100**, **101** for a transformer **110** is advantageous because with a higher number of switching operations, without a suitable protection, there is a higher risk of premature failure of transformer insulation due to uncontrolled switching transient over voltages Accordingly, it is essential to equip the transformer **110** (e.g., of a mini sub solution) with the voltage protector **140** to provide transient voltage protection.

[0024] The above description of the disclosed embodiments is provided to enable any person skilled in the art to make or use the subject matter. Various modifications to these embodiments will be readily apparent to those skilled in the art, and the general principles described herein can be applied to other embodiments without departing from the spirit or scope of the subject matter. Thus, it is to be understood that the description and drawings presented herein represent embodiments of the subject matter and are therefore representative of the subject matter which is broadly contemplated by the present subject matter. It is further understood that the scope of the present subject matter fully encompasses other embodiments that may become obvious to those skilled in the art and that the scope of the present subject matter is accordingly not limited.

[0025] Combinations, described herein, such as "at least one of A, B, or C," "one or more of A, B, or C," "at least one of A, B, and C," "one or more of A, B, and C," and "A, B, C, or any combination thereof" include any combination of A, B, and/or C, and may include multiples of A, multiples of B, or multiples of C. Specifically, combinations such as "at least one of A, B, or C," "one or more of A, B, or C," "at least one of A, B, and C," "one or more of A, B, and C," and "A, B, C, or any combination thereof" may be A only, B only, C only, A and B, A and C, B and C, or A and B and C, and any such combination may contain one or more members of its constituents A, B, and/or C. For example, a combination of A and B may comprise one A and multiple B's, multiple A's and one B, or multiple A's and multiple B's.

1-18. (canceled)

19. A protection arrangement for a transformer, comprising:

at least one fault interrupter configured to be coupled to at least one winding of the transformer, to protect the transformer from over-current faults; and

a voltage protector configured to be coupled to the at least one winding, to protect the transformer from transient over-voltage events caused by the at least one fault interrupter,

wherein the voltage protector is configured to clamp the voltage along the at least one winding to reduce damage to the transformer.

20. The protection arrangement of claim **19**, wherein the at least one fault interrupter is located outside of an enclosure housing the transformer.

21. The protection arrangement of claim **19**, wherein the at least one fault interrupter is located inside of an enclosure housing the transformer.

22. The protection arrangement of claim **19**, wherein the at least one fault interrupter includes a pair of fault interrupters configured to be coupled with a respective pair of sources.

23. The protection arrangement of claim **19**, wherein the voltage protector is located inside of an enclosure housing the transformer.

24. The protection arrangement of claim **19**, wherein the voltage protector includes at least one of metal oxide varistors and at least one of surge arresters as winding arresters.

25. The protection arrangement of claim **19**, further comprising one or more monitoring systems to monitor one or more conditions in the protection arrangement to determine at least one of the over-current faults and the over-voltage events.

26. The protection arrangement according to claim **25**, wherein the one or more monitoring systems include a first monitoring system located inside of an enclosure housing the transformer and a second monitoring system located outside of the enclosure housing the transformer.

27. The protection arrangement according to claim **25**, wherein the one or more monitoring systems include one or more relays.

28. The protection arrangement according to claim **25**, wherein the one or more monitoring systems include one or more sensors.

29. The protection arrangement according to claim **25**, wherein the one or more monitoring systems is configured to monitor current to ground.

30. The protection arrangement according to claim **25**, wherein the one or more monitoring systems is configured to monitor current from an external network to the protection arrangement.

31. The protection arrangement according to claim **25**, wherein the protection arrangement includes one or more lines, and the one or more monitoring systems include one or more current transformers (CT) configured to measure current in the one or more lines.

32. The protection arrangement according to claim **25**, wherein the protection arrangement transformer includes one or more lines, and the one or more monitoring systems include one or more potential transformers (PT) that measure voltage in the one or more lines.

33. The protection arrangement according to claim **25**, wherein at least one of the one or more monitoring systems is coupled to another winding.

34. The protection arrangement of claim **19**, wherein the transformer is a liquid-immersed transformer.

35. The protection arrangement of claim **19**, wherein the transformer is a dry transformer.

36. The protection arrangement of claim **19**, wherein the at least one fault interrupter is a medium-voltage interrupter.

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