Claims

1. An apparatus for detecting electrical leakage and partial discharge on a power line, comprising: a residual current sensor configured to monitor current imbalance in the power line; a partial discharge sensor configured to detect high-frequency discharge events associated with the power line; a fluxgate magnetometer configured to sense low-frequency or substantially DC magnetic drift indicative of slowly varying leakage current; and a processing unit operatively coupled to the sensors, the processing unit being configured to combine outputs of the residual current sensor, the partial discharge sensor, and the fluxgate magnetometer to compute a fused leakage index (Lx) indicative of a fault condition, and to generate a fault indication when the leakage index exceeds a predetermined threshold.

2. The apparatus of claim 1, wherein the processing unit comprises a filtering algorithm or Kalman filter configured to track slow changes in the fluxgate magnetometer signal, thereby enabling detection of current drift at frequencies on the order of one millihertz or lower.

3. The apparatus of claim 1, wherein the residual current sensor is a Rogowski coil arranged around one or more conductors of the power line, and wherein the apparatus further comprises a calibration signal source configured to inject a periodic pilot signal of approximately 1 kHz into the Rogowski coil or an associated test winding, the processing unit being further configured to measure the Rogowski coil's response to the pilot signal and automatically adjust calibration parameters of the residual current sensor based on the measured response, thereby self-calibrating the sensor during operation.

4. The apparatus of claim 1, wherein the processing unit comprises an FPGA (field-programmable gate array) or dedicated logic configured to generate a phase-resolved partial discharge (PRPD) pattern from signals of the partial discharge sensor and to compress the PRPD data in real-time for transmission over a low-bandwidth wireless network, such that essential features of partial discharge activity are retained within a reduced-size data representation.

5. The apparatus of claim 1, further comprising one or more environmental sensors selected from the group consisting of a humidity sensor and a temperature sensor, wherein the processing unit is configured to adjust the leakage index threshold or to apply an environmental weighting factor to the computed leakage index based on environmental conditions measured by said one or more environmental sensors, thereby compensating for environmental influences on leakage current or partial discharge activity.

6. The apparatus of claim 1, further comprising a dual-source power supply system including: a line-powered energy harvester configured to draw operating power from electromagnetic fields of the power line; a solar energy harvester (solar panel) mounted

on the apparatus; and a rechargeable lithium iron phosphate ($LiFePO_4$) battery connected to supply power to the apparatus, wherein the dual-source power supply is configured such that energy from the line-powered harvester and the solar harvester jointly charge the battery and power the apparatus, and the battery provides failover power to maintain continuous operation of the apparatus during periods when the power line is de-energized or when harvested power is insufficient.

7. The apparatus of claim 1, wherein the residual-current sensor and processing unit are provided on a retrofit daughter board that electrically interfaces with an existing residual-current transmitter while re-using the transmitter's enclosure, radio transceiver, and power-harvesting subsystem.
8. The apparatus of claim 1, wherein the residual-current sensor, partial-discharge sensor, and processing unit are provided on a field-installable daughter-board configured to plug into an existing residual-current transmitter, the daughter-board receiving operating power and data connectivity from the transmitter while re-using the transmitter's enclosure, wireless transceiver, and power-harvesting subsystem.