The PCS2000 Solutions (PCS) Open Phase Detection System (OPD System) is designed to identify open phase conditions on the General Design Criteria (GDC) 17 offsite power supplies to nuclear power plants. The system covers open conditions that could occur on the direct feed from the transmission system and inside the station service transformer, including bushing connections, internal jumpers, no-load tap changer and transformer winding connections. Measurement capabilities of the system range from as low as 10% of no-load excitation current (Figure 1) up to transformer full load (Figure 2), transformer inrush (Figure 3), and fault current levels (Figures 4 & 5). The system can be applied to any transformer winding or core configuration, including but not limited to wye-grounded high-side, delta high-side, two winding, three winding, autotransformer, core form, shell form, and single phase. The system can also be applied to generator step-up and unit auxiliary transformer combinations where used as credited offsite power sources. The system can specifically identify which phase or phases are involved in open phase conditions as seen in Figure 6. In addition to identifying transmission-side open phase conditions, the PCS OPD system is coordinated to protect critical plant loads and protective devices from damaging negative sequence heating effects caused by open phase conditions.

The OPD system uses specifically-designed, window-type current sensors on the high voltage bushings of the power transformer to monitor open phase conditions. A single sensor set provides measurement from no-load excitation to load current levels. The sensors are sized based on power transformer characteristics and configuration.

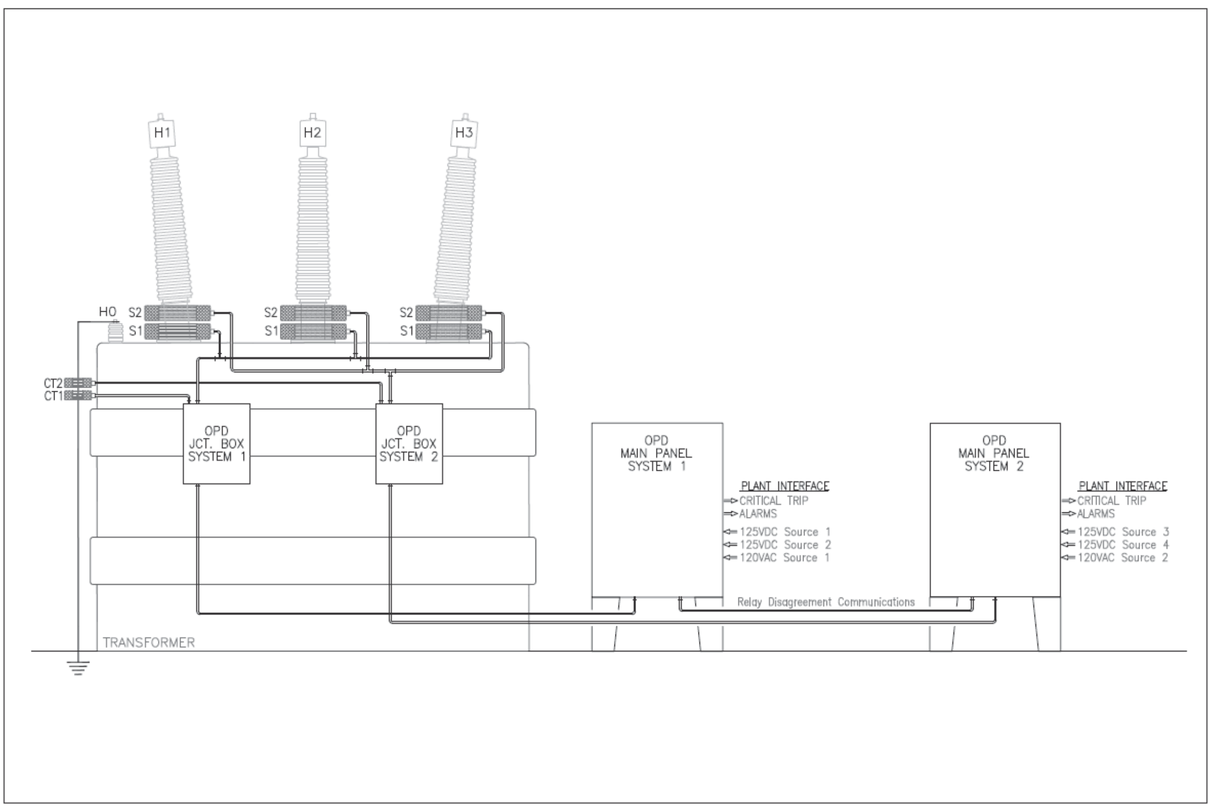
High-end, EHV transmission grade microprocessor-based protective relays are used to monitor transformer high-side current magnitudes, phase angles, sequence components and waveform to identify open phase conditions on the high-voltage supply system, the transformer high-side winding and its associated components. A custom-designed program written with user programmable analog algorithms, variables, and logic is used to identify open phase conditions that could cause damage to plant loads or undesired actuation of plant protective devices. The adaptive algorithm covers varying transformer load and transmission unbalanced conditions.

The OPD system is equipped with data logging that continuously monitors power system quantities, decision making quantities, and OPD system component health. The continuously logged data includes transformer excitation/load current, neutral current, sequence components, and harmonic content. This set of data can be used to self-report and alarm by exception. A satellite synchronized clock is used to provide a high accuracy time reference to OPD system components through industry standard IRIG clock interfaces. This enables the individual relays to time-synchronize events and perform Synchrophasor measurements so that the monitored quantities can be correlated with transmission system and plant disturbances.

The OPD system can be equipped with additional sensors to include transformer low-side equipment such as voltage regulators, cables, circuit breakers, and switchgear buses.

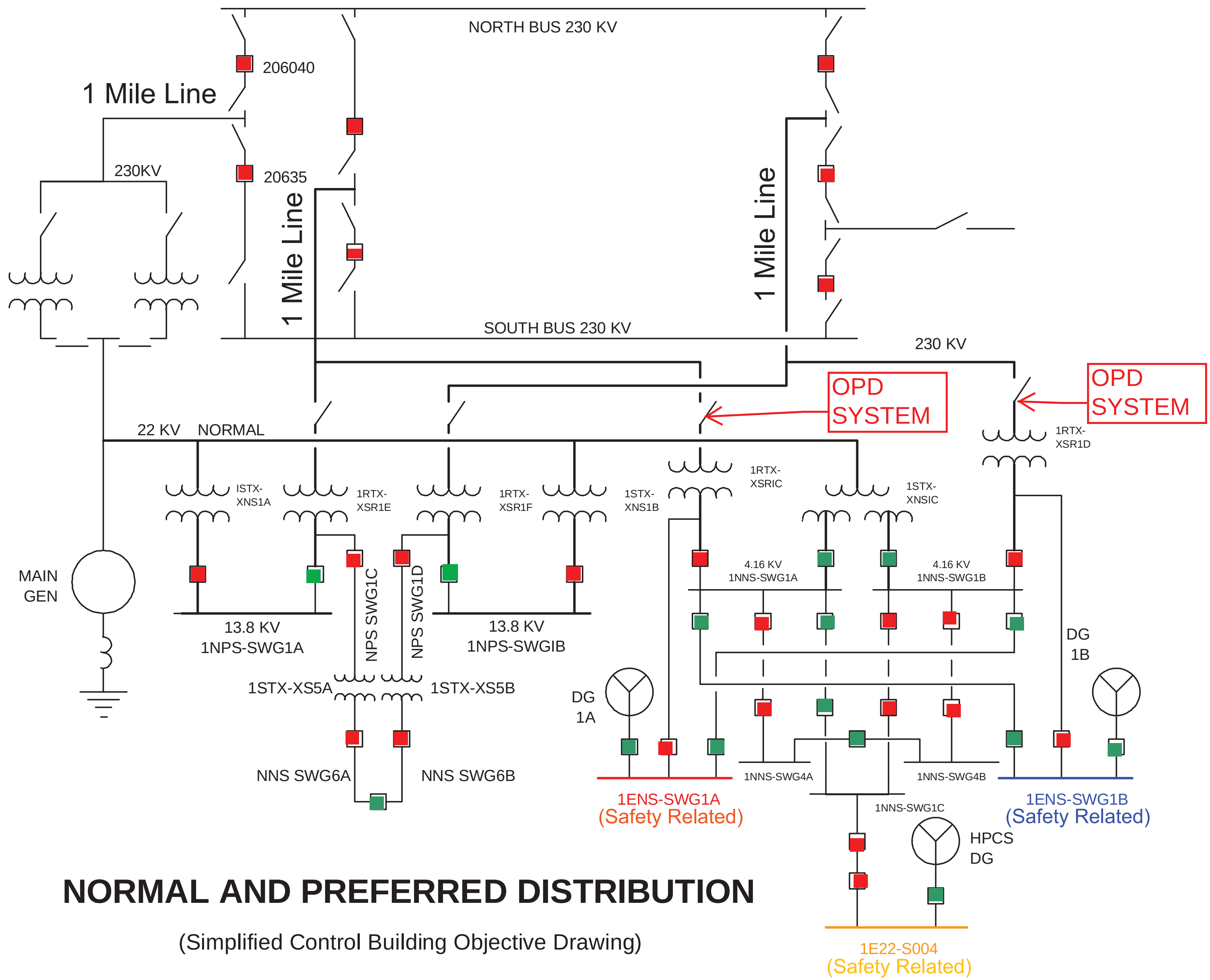
The system layout drawing shows an overview of the standard OPD system and its components installed on a typical transformer. A typical transformer is protected with two independent, redundant OPD systems. Each system is utilizing a set of phase and neutral sensors connected to a relay cabinet. The major components of each relay cabinet are two microprocessor-based relays, one microprocessor-based annunciator, test switches, satellite clock circuitry, and miscellaneous components. One rugged computer is typically used per cabinet pair for data monitoring purposes.

The system has design flexibility to meet the tripping, alarming, communication, and power supply needs as required by the specific user. The standard relay scheme has been arranged to provide one-out-of-two taken twice tripping logic. The system is equipped with alarm logic to identify open phase conditions and OPD system failure modes. Identifiable OPD system failure modes include relay trouble, communication trouble, logic disagreement, and loss of power. All relay-to-relay communications between cabinets are accomplished with fiber optics and can be configured to meet plant cybersecurity needs. Relay to annunciator communications facilitate accurate alarming. Relay to plant communications are possible with managed switches to meet new NERC CIP requirements. Power supply options include a single source for both cabinets, independently-sourced cabinets, or mixed supplies for each cabinets with auctioneering capability.



System Layout Drawing

Riverbend Station



NORMAL AND PREFERRED DISTRIBUTION

(Simplified Control Building Objective Drawing)

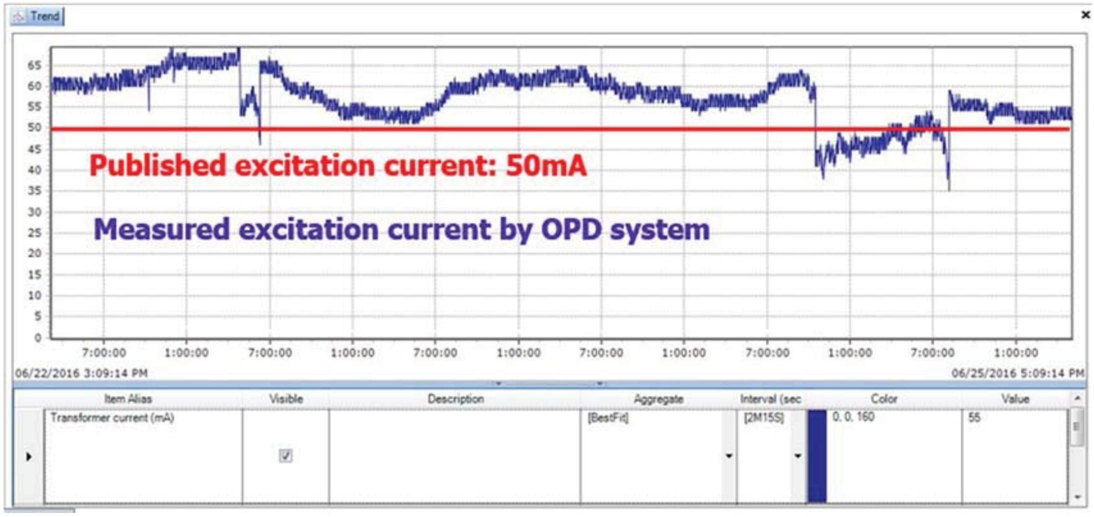


Figure 1: Field data on 345kV transformer exciting current (3φ avg.)
Field data vs. published data

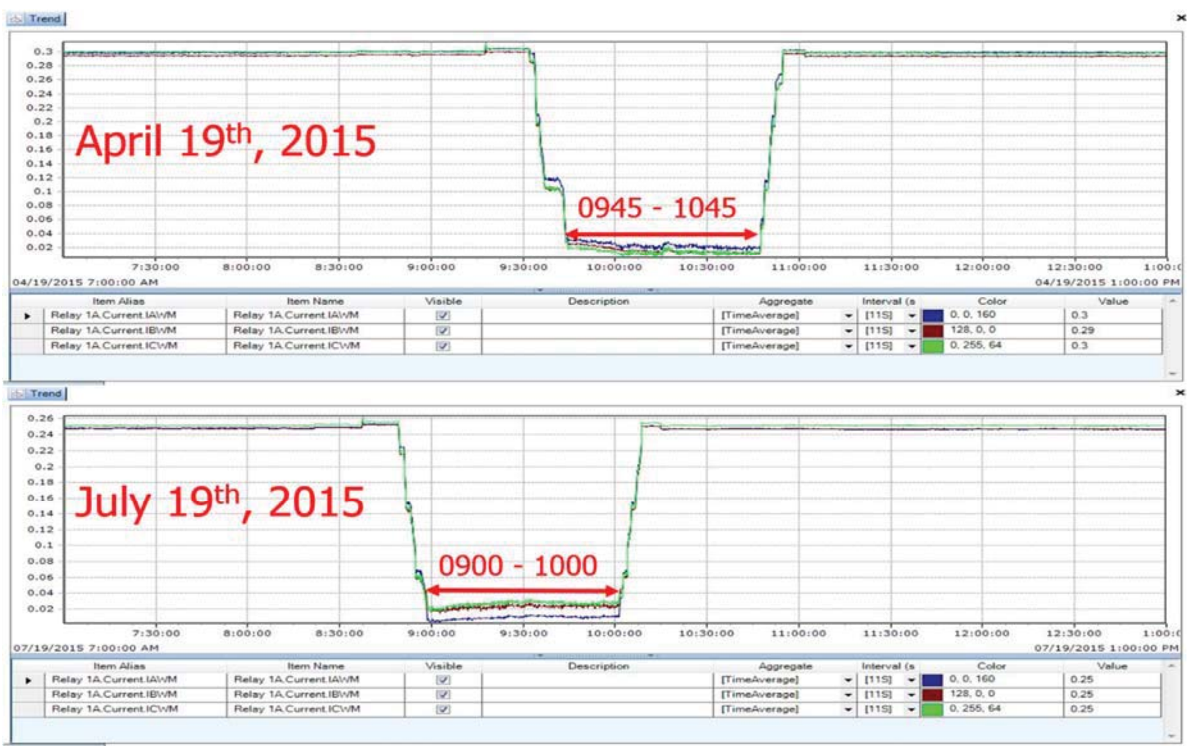


Figure 2: Field data on diesel surveillance pattern
60-minute outage every mid-month between 0800 and 1200
Vertical axis per unit load current on transformer

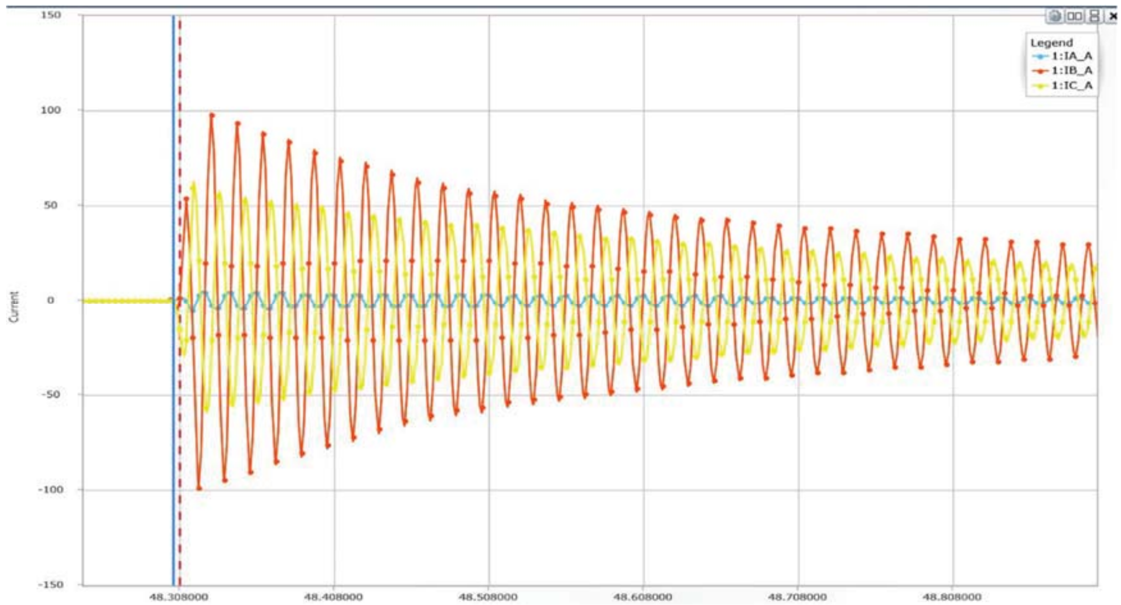


Figure 3: Event report from field on transformer inrush

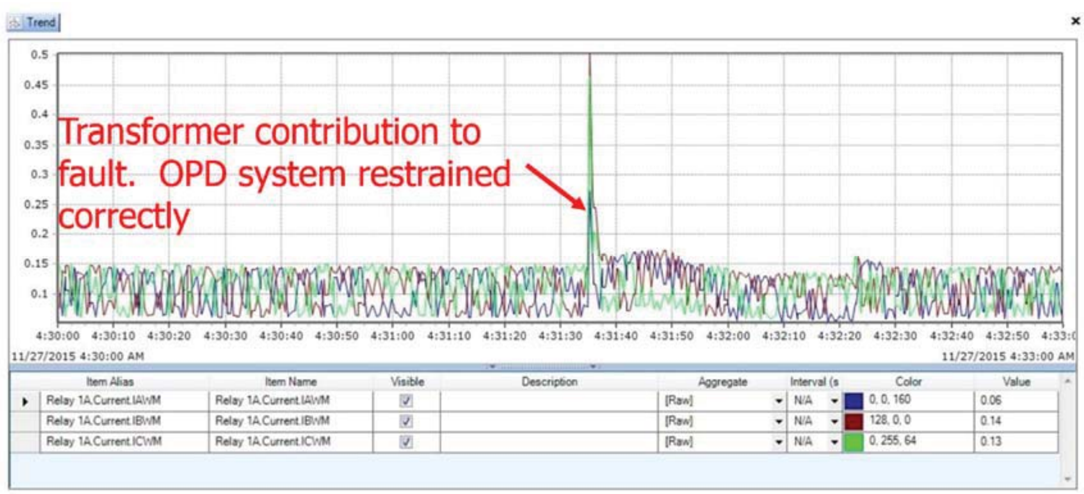


Figure 4: Trend data from field on 230kV ground fault
Vertical axis per unit load current on transformer

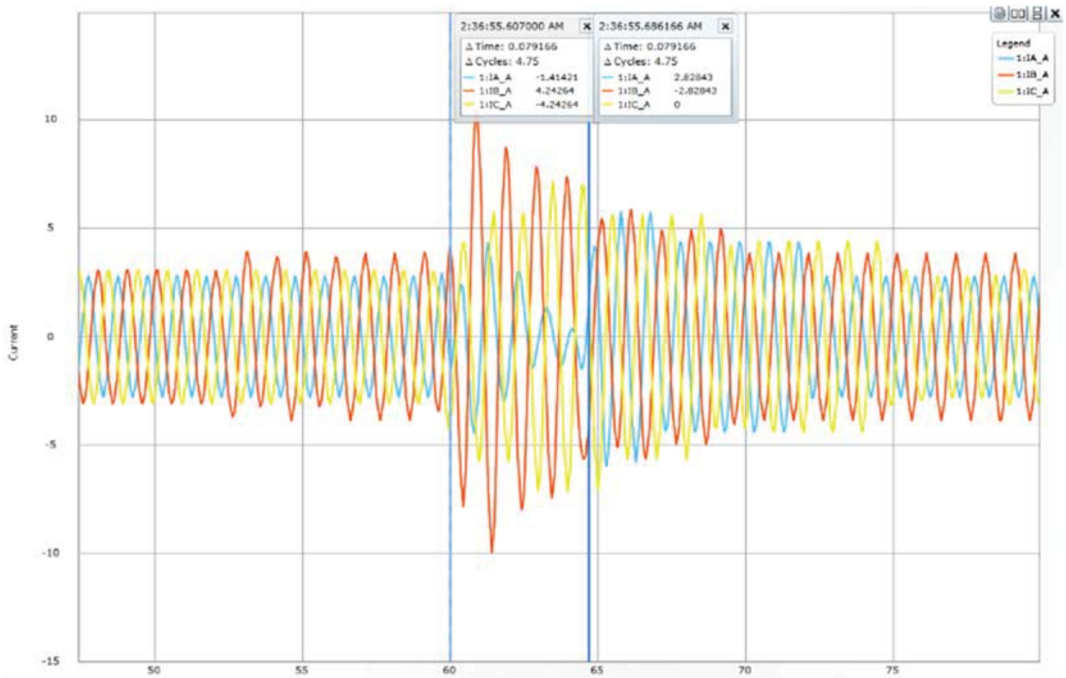


Figure 5: Event report from field on 230kV phase-phase fault

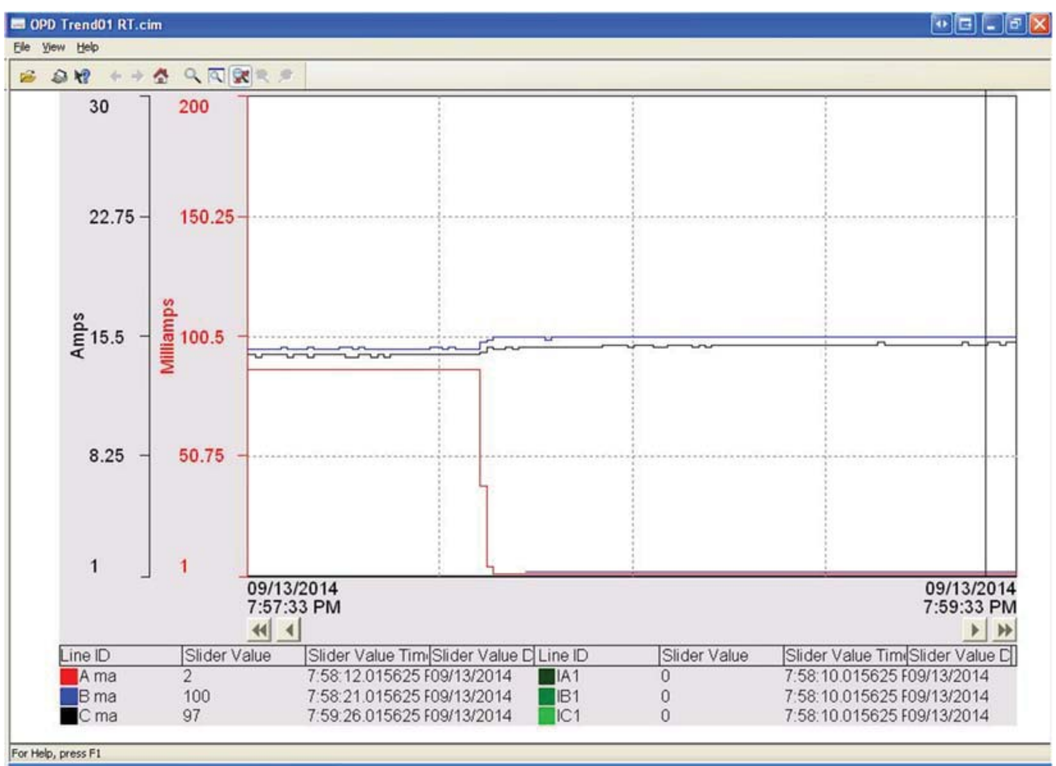


Figure 6: Lab data from "A"-phase open test case.