Feature

PSE&G Insulates Itself From Failure

Online monitoring devices enhance substation reliability.

By George Binas, PSE&G

Deregulation has forced many utilities to operate as "for profit" enterprises, with emphasis on cost reduction. To meet reduction requirements, utilities are making personnel cuts and lengthening the intervals between maintenance inspections. Within this context, utilities are avoiding periodic outages for maintenance to ensure maximum availability of substation equipment. This reduction in maintenance increases the risk of disruptive failures in substation equipment caused by insulation breakdown.

Insulation testing usually has involved periodic inspections, which are labor intensive and require an outage for the process. Typically, insulation deterioration between scheduled testing goes undetected, which introduces a risk element—particularly in an aging infrastructure. Furthermore, utilities must perform offline testing at lower voltages and at no-load conditions. Reliability and accuracy of the measurements taken in this manner are open to question, because testing does not duplicate actual operating conditions.

PSE&G completed a study that concluded new online monitoring and testing techniques would be beneficial for detecting changes in insulation systems. It also recommended the implementation of an Online Monitoring System (OMS) for transformer bushings and current transformers (CTs). AVO Corp. (Valley Forge, Pennsylvania, U.S.) supplied its SOS tan δ (Substation Online System) for field evaluation.

The Concept

A figure of merit for a dielectric is expressed in terms of its dissipation factor, tan δ, which provides a measure of the angular separation between the charging current and the applied voltage. The larger the dissipation factor, the greater the losses in the dielectric. In the extreme, a large dissipation factor is an indication of incipient failure in the dielectric. The dissipation factor can be measured using a Schering Bridge, which uses fixed resistances and capacitances in the classic ratio-arm configuration of an electrical bridge. A variable capacitor is used to effect the balance necessary to obtain the capacitance value for the dielectric being measured.

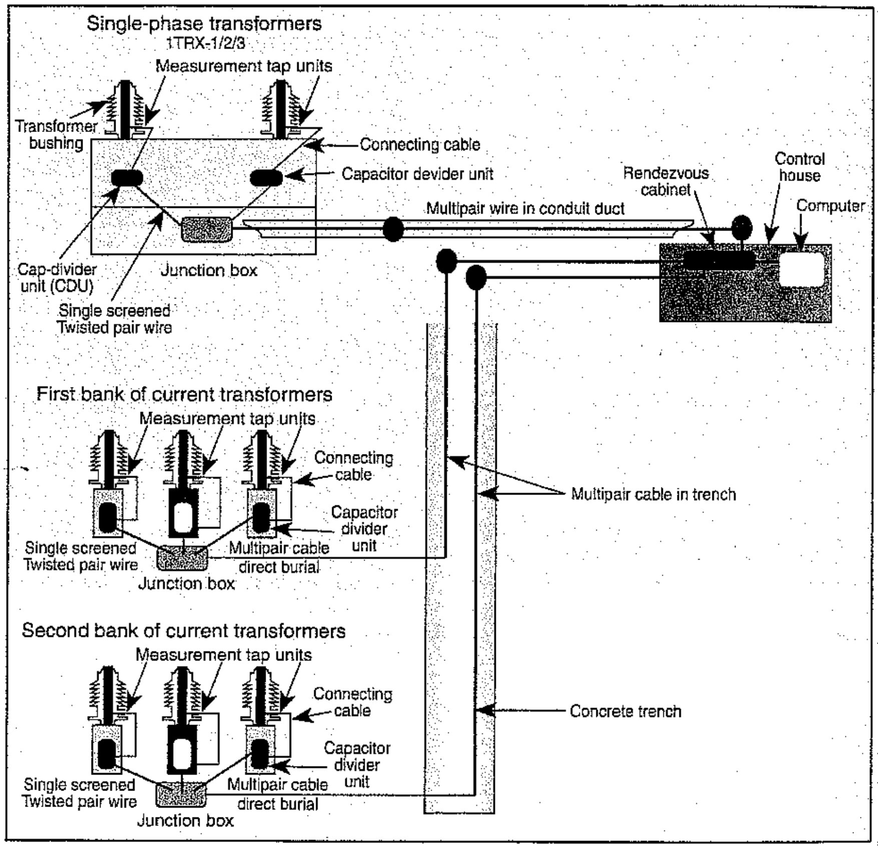

Fig. 1. One line diagram installation of the SOS at PSE&G.

In the AVO SOS system, deterioration in the insulation is estimated by measuring the relative tan δ of the monitoring equipment. It calculates the tan δ of a unit as a relative value compared with a reference voltage from another unit with which it is grouped. Because the system uses relative measurements, the minimum requirement is that at least three units be grouped for each part of an evaluation. The tan δ provides a measure of the capacitive-leakage currents in the dielectric materials used to make a bushing core. One symptom of deterioration is

Tan δ and capacitance are properties of the bushing core design and the dielectric material used in the core as demonstrated in dielectric loss equation:

$P_d = 2 \pi f C V^2 \tan\delta$, watts

Where:

f = applied frequency, Hz

C = capacitance of bushing core (C1), farads

V = applied voltage, rms volts

Tan δ = dissipation factor, p.u.

increased sensitivity to changes in temperature and voltage, manifested in a relative increase in dielectric loss.

Monitoring and measuring tan δ thus gives an indication of the quality and condition of the insulation and its sensitivity to temperature and voltage changes.

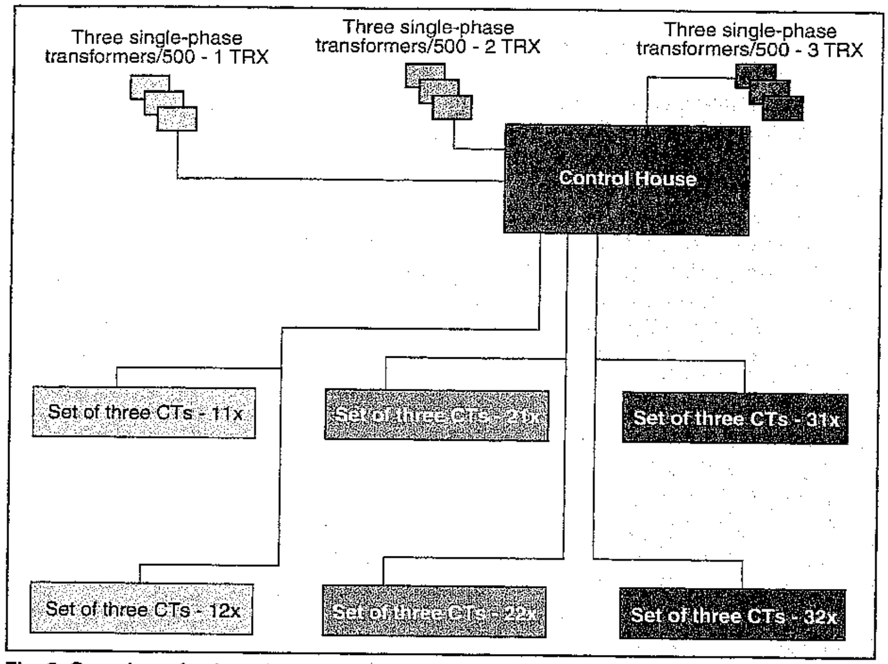

Fig. 2. Overview of substation online monitoring system installation at PSE&G.

The System

PSE&G installed the monitoring system at its switching station to monitor the 500-kV and 230-kV bushings of nine single-phase transformers and 18 CTs in the 500-kV yard. The system collects, evaluates and displays information from 36 monitoring points and provides an early warning of bushing/CT insulation breakdown. Dedicated modem lines provide real-time information locally and remotely to the PSE&G home office in Newark, New Jersey, U.S.

The system consists of:

- A measuring tap unit (MTU) for each monitored device
- A capacitor divider unit (CDU) for each device
- A junction box, where cabling from various CDUs terminates
- A rendezvous cabinet inside the control house, which houses the system electronics and where signals from the various monitored points (carried to the cabinet by underground cabling or through wireless connections) terminate
- A computer where the SOS software resides and the condition of the monitoring devices is displayed.

The system is based on the principle of the Schering Bridge under software control, with minimal hardware, to measure the tan δ. The deterioration of insulation is gauged by its sensitivity to changes in the online operating conditions. The versatility of the system installed at substations allows for the continuous accumulation of data, which are manipulated in matrix operations to present normalized condition values for each monitored unit. The signals are sampled and data processed under software control to calculate the capacitance and dissipation factor changes. A second unit of equipment is used as a standard instead of a standard capacitor; therefore, the values are relative to that unit. This principle is extended to several units within the substation. With specific configuration, relative measurements eliminate common mode effects such as ambient temperature, operating voltages and load conditions, accentuating the differences relative to design and sensitivity to changes in insulation. For this reason, the system requires a minimum of nine monitoring points that must be online. A maximum of 256 points can be monitored in the same substation.

Case Study

To obtain data on a suspected high-voltage CT in one of PSE&G's substations, 18 CTs and bushings on nine single-phase transformers were monitored using the AVO SOS system to collect, evaluate and display information from 36 monitoring points. During the first weeks of March 2000, the system provided indications the insulation integrity of the suspected EHV CT was under stress by exhibiting progressively higher values of tan δ. On March 14, an alarm condition was issued, which was received via fax at PSE&G headquarters and at AVO's fax server that monitors SOS sites. The

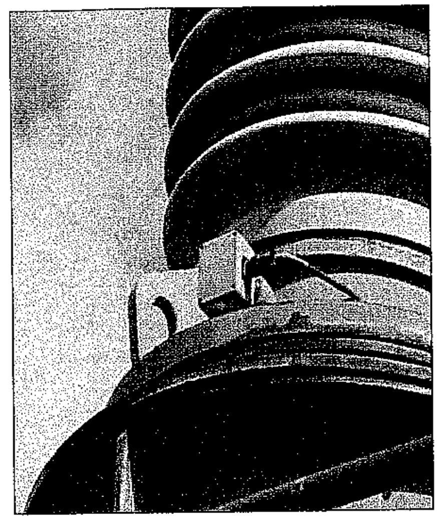

Fig. 3. View of a bushing SOS measurement tap unit.

system produced a graph that showed the insulation condition of the CT changed radically on March 3 and then settled to a normal condition during the next 24 hours. The change caused a warning alarm at the time, which was cleared when the tan δ value decreased. On March 4, the condition value again changed, causing renewed warning alarms until March 14, when the CT was removed from service after an on-site inspection. The oil gage on the CT was pegged at "low," indicating the oil level was low enough to compromise the insulation quality of the CT. By providing the necessary maintenance measures to restore the CT, a power outage was avoided, along with possible injury to personnel and other collateral damage.

In making a cost/benefit analysis for the case illustrated, the total system cost of US$105,000 can be allocated among the 36 points monitored and depreciated over six years to yield a cost per point of US$500 per year. Adding the annual operational costs of US$4375, or US$122 per point, provides an annual depreciated cost of US$622. To replace a failed CT, including the cost and installation of a new CT, removal of the failed CT and testing of the replacement unit, an expenditure of US$31,870 is estimated to have been avoided.

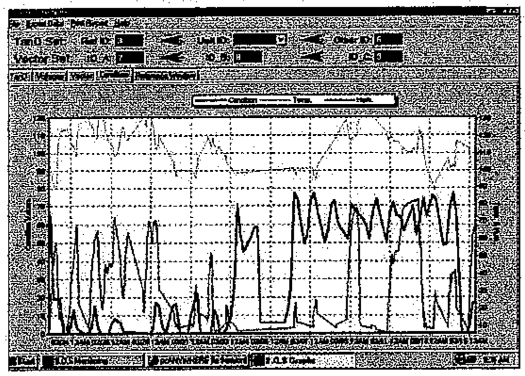

Fig. 4. SOS tan δ graph from the PSE&G substation.

Conclusions

As a preface, note that an OMS is currently based on a pure data-collection philosophy, requiring costly human intervention to process raw data for reaching a decision to take appropriate responsive action. The utility will realize the true benefit of OMS trending when the system evolves into an intelligent system with automated crisis-response capabilities. An OMS strategy adopted at the present time is exposed to the risks and opportunities associated with the early phases of new technology development and its application. Any cost/benefit model attempting to establish the true value of an OMS would need to track these unfolding developments to accurately realize its benefits. Despite the difficulty of accurately building such a long-term model, it is argued that present justification for expenditures be based on the pure merit of gains in maintenance costs and operational efficiency with the system in its present form. Moreover, because safety is crucial, this issue can serve as justification for pursuing the technology described.

The analysis, involving cost per monitoring point compared with the cost of replacement, demonstrates the attractiveness of the monitoring process. It is also reasonable to justify the cost associated with all other non-event monitored points as insurance bought against the early warning of a failure because of some future event.

When comparing the avoidance cost with the total system cost, it appears the system becomes cost effective if it successfully provides warnings resulting in the saving of at least four CTs over its six-year depreciation period. In addition, because the system also monitors transformer bushings, it is not unreasonable to predict a scenario that includes both the cost of bushing failure, as well as the added cost of transformer damage. These considerations further support the adoption of an OMS strategy, at least for the most critical installations. ◗

George Binas has worked in the electric utility industry since 1976 in areas of nuclear construction, engineering, R&D and distribution. He has authored papers on power quality, demand-side management and in-service monitoring of distribution equipment. He presently works in PSE&G's distribution department/customer services. Binas holds the master's degree in engineering from City College of New York.

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