OCB Diagnostics

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I. Introduction

During the B.D. era, before deregulation, run to failure, time based and operation count based maintenance methods were widely employed. These methods were effective in maintaining the power delivery system but were labor intensive and not cost effective. Time based and operation count based maintenance methods could not identify units that developed problems between scheduled inspections. Units were often inspected on a time basis and no problems were identified. After deregulation, A.D., fiscal requirements led to decreases in trained maintenance personnel, deferral of capital expenditures, equipment life extension programs, and efforts to maximize uptime and minimize maintenance costs. Reliability centered and condition based maintenance are key A.D. concepts that have been implemented in the power industry. The ultimate goal of condition based maintenance would be to perform maintenance "just in time", before the equipment fails in service. Condition based maintenance requires periodic or continuous (on-line) equipment monitoring. Equipment is scheduled for inspection and/or maintenance only when diagnostic test results indicate a potential problem.

II. OCB Maintenance

Oil filled circuit breakers; OCB's have traditionally been serviced on a time based, operational count or fault current basis. We believe that OCB condition can be ascertained by non-invasive diagnostic tests that can reliably indicate when an internal inspection and/or maintenance or repair is required. Cinergy, Southern California Edison and Weidmann-ACTI have cooperated in a project to identify a battery of chemical and physical tests to assess OCB condition.

III. Diagnostics

Development of our diagnostic program involved four sequential steps: 1) Identification of fault mechanisms 2) Selection of appropriate physical and chemical tests to detect problem units 3) Correlation of test data with physical inspection of problem units and 4) Development of algorithms to classify OCB condition.

A. Fault Types

OCB contacts can become coated with oxides or sulfides, which result in increased contact resistance and increased contact operating temperatures. Contacts also erode because of mechanical wear or arcing. Arc suppression grids, which are made of cellulose, deteriorate to some degree whenever an arc is suppressed. Each of these OCB problems can be detected with one or more diagnostic tests. Figures 1 shows contacts that have been severely eroded. Figure 2 illustrates a new arc suppression grid and one that shows degradation. A wide range of chemical and physical test methods is available to detect these types of faults**.**

Figure 1

Figure 2

"Good" Grid

Close up of a Degraded Grid.

B. Laboratory Tests

Dissolved Gas Analysis, DGA, has been extensively applied to locate incipient thermal or electrical faults in transformers. Normal OCB operation will produce the “key gases” associated with arcing under oil. These key gases include acetylene and hydrogen, which are produced at the very high temperatures associated with arcing. The “hot metal gases”, methane, ethane and ethylene are produced whenever the oil is overheated from any cause. The temperature required to produce acetylene is considerably higher than that required to produce the hot metal gases. Insulating fluids absorb and distribute fault energy. Thus the temperature of the oil is very high in the vicinity of an arc and decreases with distance away from the arc. This variation of temperature results in the production of acetylene close to the arc and hot metal gases further removed from the arc location. Very little heating occurs in a healthy OCB so the amount of hot metal gases generated should be small. This analysis of key gas production mechanisms indicates that the ratio of heating to arcing gases should be indicative of problems such as increased contact resistance or contact erosion.

Arc suppression grids deteriorate every time that they quench an arc. When the grids are new the arc suppression time is low. The particles generated from the grid degradation are numerous but small in size. As the grid opening enlarges the arc suppression time increases and larger sized degradation particles are produced. A fault is limited only by the maximum current amplitude of the source impedance and the interruption time of the breaker. Maximum fault power (I^2T) determines time to failure. Particle size and count continues to grow until the distance from the point source of heat and the maximum grid hole diameter cause a cooling and blast zone buffer. At this point the production of larger particles decrease and smaller particles again increase. A plot of large particle size production with time seems to follow a bell shaped curve. The difference in the leading edge to the trailing edge of the curve is noted by the measurable increase in contact metals present in the oil. Arc suppression grids are constructed of cellulose and these particles can be distinguished from carbon and shiny metal particles by chemical microscopy. At temperatures above 300^{o} C cellulose is destroyed and the resulting carbon particles are observed in the oil.

Arc tip and arc shaft erosion can be measured by determination of the characteristic metals in oil and with chemical microscopy, which can distinguish between shiny metal and carbon particles. Oil quality assessment tests are also useful in identifying OCB problems. Dielectric breakdown voltage measurements, ASTM D-1816, are effected by moisture, metals, carbon particles and cellulose particles in the oil. Particles, especially carbon, also effect oil color. Since OCB's are free breathing devices the moisture level is higher than that found in sealed components.

Table 1 is a summary of the tests that we have incorporated in our OCB diagnostic program and the type of problem that can be determined with these technologies.

Table 1. Diagnostic Tests

OCB Problem	Test(s)	Result(s)
Increased Contact Resistance	**DGA**	**Increased Hot Metal Gases, Increased Heating to Arcing Gas Ratios**
Contact Tip Erosion	**DGA, Metals, Chemical Microscopy, Dielectric-1816**	**Hot Metal Gases, Metals Observed in Oil, Metal Particles Observed by Chemical Microscopy, Lowered Dielectric Breakdown Voltage**
Arc Suppression Grid Degradation	**DGA, Particle Count, Chemical Microscopy, Dielectric-1816, Color**	**Increased Fault Gas Levels, Large particles in the Oil, Cellulose Fibers ,Decreased Dielectric Breakdown Voltage**

IV. Diagnostic Protocols

Once the appropriate analytical procedures were selected to ascertain the effect of OCB problems it became necessary to determine normal values for each of the measured parameters. We used a statistical approach to evaluate test data from problem free units in order to establish the norms. We then determined the ninetieth percentile values for each parameter, for several thousand OCB samples. For example, the 90th percentile individual fault gas concentration and the total dissolved combustible gas concentration for all samples evaluated are given in Table 2. Data for selected heating to arcing fault gas ratios was calculated in a similar manner. Similar calculations combined with field observations were used to establish norms for particle size distributions and metals in oil. Relevant IEEE guides are used to evaluate results of oil condition assessment tests. These values are all generic in nature and no attempt has made at this time to develop unit specific flag points.

Table 2. 90th Percentile Gas Concentrations in OCB Oil Samples

Fault Gas	90th Percentile Concentration
Hydrogen	62
Carbon Monoxide	136
Methane	28
Ethane	14
Ethylene	71
Acetylene	173
Total Dissolved Combustible Gas	530

Diagnostic software has been developed to evaluate OCB samples according to our established norm values. OCB sample results are placed into three broad categories of Normal, Caution and Warning. Southern California Edison designates OCB condition numerically using a 3, 2, and 1 scale. Normal indicates that the sample should be retested according to the initial utility criteria.

Caution indicates that the sample should be tested more frequently, again at a rate determined by utility protocols. Warning indicates that an internal inspection is appropriate. Figures 3, 4 and 5 are examples of test reports for samples that fit in each of these evaluation categories.

Figure 3. OCB Condition: Normal (3)

Serial number	20695 TK1	**Counter #**	
Model		**Gallons**	267
Pole	C	**Fluid Type**	Mineral
Manufacturer	FPE	**KV Rating**	69
Date		**Interrupt**	

Condition Code:
Normal (3)

Hydrogen	2	**Between 2 and 5:**	3374895	**Moisture**	28
Methane	1	**Between 5 and 15:**	749850	**Color Number**	L2.0
Ethane	0	**Between 15 and 25:**	4084	**Dielectric 1816**	20 1-24
Ethylene	1	**Between 25 and 50:**	571	**Silver**	L0.50
Acetylene	0	**Between 50 and 100:**	90	**Chromium**	L0.50
Carbon Monoxide	84	**Greater than 100:**	0	**Copper**	L0.50
Carbon Dioxide	518	**ISO Code:**	23/20/13	**Nickel**	L0.50
Oxygen	24309	**Fibers:**	20	**Phosphorous**	L0.50
Nitrogen	53664	**Metals:**	10	**Lead**	L0.50
Total Dissolved Gas	78579	**Carbon:**	50	**Tin**	L0.50
Total Combustible Gas	88	**Other**	20	**Zinc**	L0.50
Equivalent TCG Percent	0.0973	**Opacity**	2.0	**Tungsten**	L0.50

Narrative: No problems found. No action taken. Unit stayed in service, reset maintenance schedule.

Figure 4. OCB Condition: Caution (2)

Serial number	28760	**Counter #**	120
Model	CG-38	**Gallons**	220
Pole		**Fluid Type**	Mineral
Manufacturer	MGE	**KV Rating**	38
Date	1987	**Interrupt**	40

Condition Code:
Caution (2)

Hydrogen	1	**Between 2 and 5:**	2199309	**Moisture**	30
Methane	1	**Between 5 and 15:**	3891922	**Color Number**	L3.0
Ethane	1	**Between 15 and 25:**	98949	**Dielectric 1816**	10 1-24
Ethylene	2	**Between 25 and 50:**	2252	**Silver**	2.38
Acetylene	2	**Between 50 and 100:**	60	**Chromium**	L0.50
Carbon Monoxide	17	**Greater than 100:**	0	**Copper**	L0.50
Carbon Dioxide	382	**ISO Code:**	23/22/17	**Nickel**	L0.50
Oxygen	25182	**Fibers:**	10	**Phosphorous**	L0.50
Nitrogen	50557	**Metals:**	5	**Lead**	L0.50
Total Dissolved Gas	76145	**Carbon:**	70	**Tin**	L0.50
Total Combustible Gas	24	**Other**	15	**Zinc**	L0.50
Equivalent TCG Percent	0.0229	**Opacity**	4.0	**Tungsten**	L0.50

Narrative: Analysis indicated mild contact erosion, and poor oil quality.
Remedial Action: Unit was put on ½ maintenance schedule and remained in service.

Figure 5. OCB Condition: Warning (1)

Serial number	318027-A	**Counter #**	608
Model	FZO-69	**Gallons**	855
Pole	A	**Fluid Type**	Mineral
Manufacturer	Allis-	**KV Rating**	57
Date	1953	**Interrupt**	21

Condition Code:
Warning (1)

Hydrogen	7280	**Between 2 and 5:**	901411	**Moisture**	23
Methane	6624	**Between 5 and 15:**	3453273	**Color Number**	L6.5
Ethane	729	**Between 15 and 25:**	2645616	**Dielectric 1816**	10 1-24
Ethylene	5424	**Between 25 and 50:**	221381	**Silver**	L0.50
Acetylene	9356	**Between 50 and 100:**	2462	**Chromium**	L0.50
Carbon Monoxide	91	**Greater than 100:**	0	**Copper**	1.63
Carbon Dioxide	437	**ISO Code:**	29/28/24	**Nickel**	L0.50
Oxygen	44520	**Fibers:**	10	**Phosphorous**	L0.50
Nitrogen	24023	**Metals:**	10	**Lead**	L0.50
Total Dissolved Gas	94686	**Carbon:**	80	**Tin**	L0.50
Total Combustible Gas	25706	**Other**	0	**Zinc**	L0.50
Equivalent TCG Percent	20.618 2	**Opacity**	5.0	**Tungsten**	L0.50

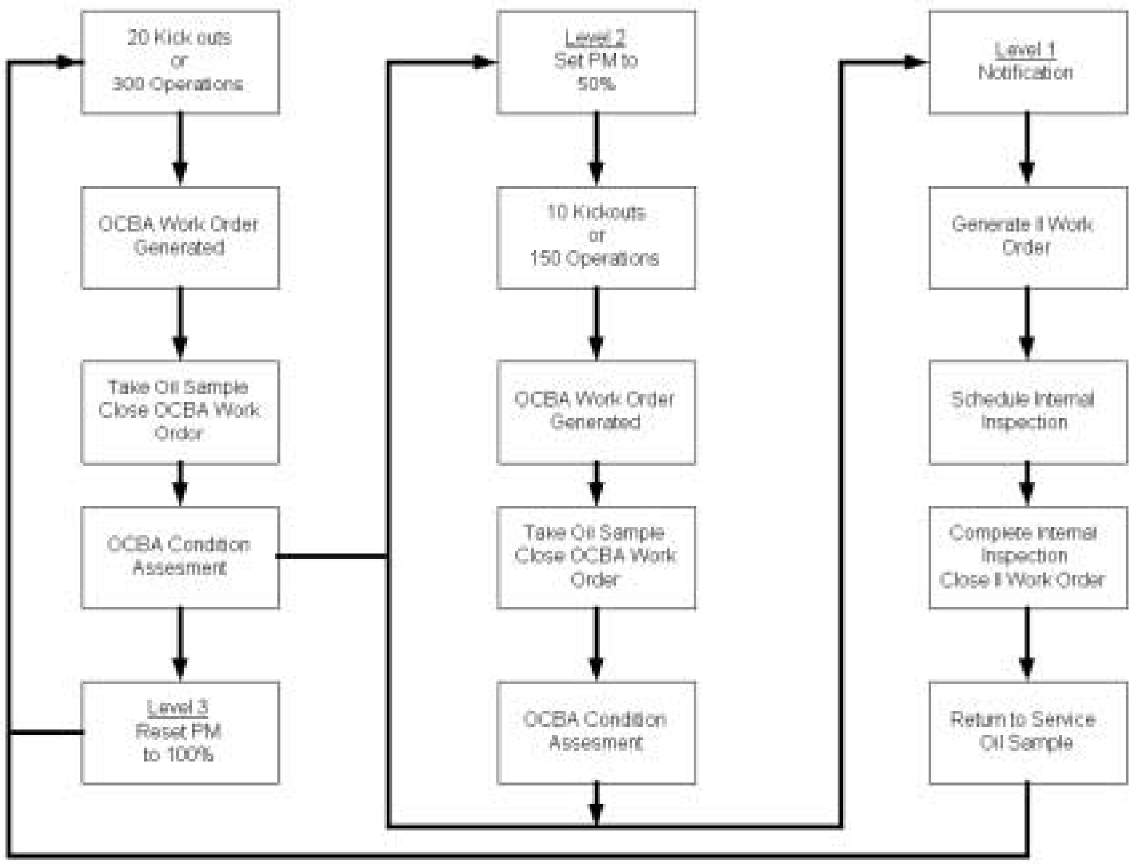
Narrative: Oil sample obtained approximately 4 hours after a 30000 AMP, 3 cycle fault.
Contacts evaluated at 25 percent degraded. Copper present due to shaft wear on movable contact.
Grid not significantly degraded.

Remedial Action:
Rotated movable contact ¼ turn.
Filtered and processed oil.
General maintenance. Returned to service.

V. Sampling Protocols

The overall objective of our OCB diagnostic program is to minimize the number of required internal inspections and thus to realize considerable maintenance cost savings. Utilities must decide when and at what frequency to sample their OCB's. A sampling strategy has been developed by Mr. Alex Salinas at Southern California Edison, SCE, to determine when to draw the initial sample, when to draw subsequent samples and when to conduct an internal inspection. The entire sampling process is incorporated in their system software. The software, which maintains OCB operations data, generates an initial work order when any of three conditions are met: twenty interruptions, three hundred operations or five years from the last test. This first work order will be for an initial oil sample. The results of the initial test generate a code: 1=Schedule internal inspection, 2=Reset oil sample trigger at half the initial values (10 interruptions or 150 operations) and 3=Reset sample trigger at 20 interruptions or 300 operations. The software maintains all of the test data, resets the triggers and prints the work orders. This closed loop operation requires no operator intervention. A flow chart for the SCE protocol is given in Table 3.

Table 3. SCE Flow Chart



Process Flow for Oil Circuit Breaker Assesment

Maintenance cost savings for the SCE program can be estimated considering the number of reduced internal inspections. SCE currently inspects about three hundred breakers a year, both oil filled and others. The oil filled breakers range in voltage class from 7.2 kV to 220 kV. Their largest number of breakers operates at 69 kV. Inspection costs range from 2K$ - 20K$ on OCB's in the voltage range from 7.2 kV to 220 kV. Based on statistical evidence less than ten percent of the units tested will require an internal inspection. The savings promise to be considerable.

Cinergy Corporation currently uses both condition based (CB) and fault adjusted operation count (FAO) as the initial triggers for breaker maintenance. The non-invasive condition based triggers used are thermography, ultrasonics, oil quality and dissolved gas analysis. The main invasive tests are ductor and power factor. The invasive tests are used minimally due to limited outage request acceptance. Fault adjusted operation count is a method that employs knowledge of the maximum fault amplitude based on source and circuit impedance and fault duration. This is used to determine the estimated number of breaker operations before maintenance is needed. Unless the breaker employs the use of some form of I^2T monitors it is still very difficult to determine true fault duty cycle. Additionally, due to deregulation and customer commitment, outages and internal inspections will be kept to a minimum. Although each test gives different positive information to determine maintenance interval, Cinergy has found the addition of oil particle analysis to determine grid and contact health invaluable to determine overall maintenance interval.

VI. Conclusions and Future Work.

Normal or threshold values for OCB test parameters are at this time generic in nature. Because of design variations unit specific normal values may be more appropriate. Unit specific test values will have to be empirically determined. We are maintaining a very detailed database so that we can develop unit specific normal values in the future.

We are cooperating with utility clients to further evaluate testing frequency protocols. For example SCE tests the OCB oil every five years if the interruption (20) or operation (300) criteria are not met. Can this time interval be extended without increasing system outages due to breaker failures?