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APPLICATION OF ON-LINE PARTIAL DISCHARGE TESTS TO ROTATING MACHINES

POSITION PAPER ON BEHALF OF CIGRE SC A1

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1. BACKGROUND

At the meeting of CIGRE SC 11 in September 1999 in Orlando, FL, a proposal from EG11.02 to write a document on partial discharge testing of hydroelectric generators was tabled. The consensus from the ensuing discussion was that the issue of partial discharge testing was also applicable to EG11.01 and EG11.06 and that any document arising would be a shared responsibility between the above mentioned EGs.

However, although the concept of SC 11 being active in providing guidance in the field of partial discharge measurements was considered desirable, the vehicle for delivering this knowledge was not defined. The reason for this situation being that many of the SC members were either aware of, or in some cases participating in, national or transnational activities aimed at writing guide or standards governing such tests. In some cases, e.g., IEEE, these works were quite advanced with documents nearing publication. Hence, a draft copy of IEEE P1434, “Guide to the measurement of partial discharges in rotating machinery”, was circulated to selected members of EG11.01 and EG11.02 to determine whether further effort from SC 11 was warranted and, if so, what type.

The response of those reviewing the IEEE document, now officially issued as IEEE 1434-2000 [1], was that this guide was sufficiently comprehensive and international in perspective that, presently, no further effort in that direction was necessary. During the next SC 11 meeting in Paris in August 2000, it was also agreed that it was not appropriate to create a questionnaire on experience with partial discharge analysis at this time. However, an information gap in the existing documents governing partial discharge testing was identified. Consequently, it was decided to create a white paper providing guidance to those considering the application of this technology on where it is appropriate to apply partial discharge measurements and to provide a proper focus on what results could be expected. In order to provide as wide a perspective on this subject as possible, the paper is co-authored by representatives from generator manufacturers and users as well as from motor experts.

2. INTRODUCTION

The phenomenon of partial discharge (PD), or more generally electrical breakdown of gases, has been extensively studied over the past 120 years. Over the past 50 years, research has focused on the effects of localized gas breakdown, or PD, on the performance of solid insulating materials. From these studies arose the concept of using PD parameters as tools to aid assessment of insulation condition in power apparatus. While many utilities have for significant periods of time dating back to the 1950s used various off-line PD measurement methods, some of which will be discussed below, rapid growth in the penetration of PD-based condition monitoring technology did not occur until the mid to late 1980s. The increase in activity was fuelled in part by technology developments that permitted non-specialists to perform PD measurements, even while the equipment was operating, and also by the growing acceptance within the electricity supply industry of the benefits of PD testing.

Partial discharge testing, specifically of rotating machines, has gained widespread acceptance as a valuable maintenance decision support tool for many utilities and manufacturers. The strength of this acceptance can be gauged from the ever increasing body of literature devoted to the subject and the number and size of conferences with rotating machine PD testing as the sole topic of discussion. Consequently, there are presently a relatively large number of suppliers of PD measurement technology and services. The question for many utilities, faced with this plethora of products, is which one provides the optimal solution to their condition monitoring needs? The purpose of this document is not to discuss basic information related to PD phenomena in rotating machines. This topic is extensively covered in IEEE 1434-2000 as well as other related publications as are the myriad means used to detect the PD signals. Rather, the objective is to produce a document that gives guidance on the appropriate use of PD measurement technology. The scope of this document is limited to on-line measurements.

3. PARTIAL DISCHARGE IN STATOR WINDINGS

Partial discharge occurs, to a greater or lesser extent, in the stator windings of most high voltage motors and generators. However, unlike organic insulation systems such as epoxy castings, used in gas insulated substation equipment, and cross-linked polyethylene (XLPE), used in distribution and transmission cables, stator winding insulation is filled with mica. The presence of mica, which is one of the most partial discharge resistant materials known, permits reliable operation of the machine even with significant levels of partial discharge at the operating voltage. Consequently, partial discharge in the stator windings of high voltage rotating machines may be viewed as,

- a deterioration mechanism, or
- a symptom of problems caused by, for example, operating stresses or errors in design, manufacture or installation.

From a practical point of view, the latter of the two possibilities is of most interest to electric utilities or other users of high voltage rotating machines. This is because stator windings rarely fail due to the action of partial discharge alone. Even in cases where significant partial discharge activity has been detected, it is unlikely that immediate action will be taken. This is especially the case when pronounced internal PD occurs simply because degradation of the groundwall insulation is usually slow and the only remedy is to replace bars or coils or perform a complete rewind. However, even for other discharge sources the warning times before significant problems occur are in most cases rather long.

In general, the four sources of partial discharge in rotating machine stator windings of most interest are,

- internal partial discharge in the groundwall insulation,
- surface discharges within the slot region between the semiconductive armour of the bar or coil and the core iron,
- partial discharge at the interface between the copper conductors and the strand, turn or groundwall insulation, and,
- surface discharges in the stator endwindings.

Depending upon the location of the partial discharge source and the type of material involved, the degree of deterioration and thus the risk of insulation failure will vary. The organic components of the stator insulation, slot support and stress control systems are preferentially attacked under the action of partial discharges. Typically, this type of deterioration occurs in voids at the interface between the copper conductors and the insulation, within voids in the bulk of the insulation, or on the surface of various insulation system components. Usually, because of the higher electrical and thermal stresses at the copper conductors, failure is more likely to result from voids at the copper/insulation interface. Only in severely aged insulation systems is the mica consumed, normally by thermal as opposed to electrical degradation.

Although partial discharge can be a significant aging mechanism in stator winding insulation, due to the presence of mica, the time-to-failure is usually very long. In fact, the time-to-failure due to the action of internal partial discharge in voids in the groundwall insulation is such that there is a higher probability of machine failure due to some other problem. However, as well for other typical PD sources, like surface PD in the endwinding e.g. due to severe contamination, deteriorated semiconductive or stress grading coatings or defective auxiliary components etc., usually no immediate corrective actions are needed. Consequently, most users of partial discharge measurements on electrical machines view the data as a valuable aid to repair or maintenance planning decisions. This is because, as noted above, the deterioration of the stator electrical insulation system due to thermal, electrical, environmental or mechanical stresses can be detected by partial discharge tests. Further, the types of degradation can result in unique partial discharge characteristics thus enhancing the diagnostic power of the measurements.

The potential diagnostic capabilities of partial discharge testing can only be fully realized with knowledge of,

- machine design information,
- operation and maintenance history, and
- the type, manufacturer and vintage of the insulation system.

This information is essential to enable proper conclusions to be made regarding the condition of the insulation system because age alone is a notoriously poor index of stator winding insulation integrity. Furthermore, when performing PD tests, it is important to know that one individual PD measurement on a particular machine gives incomplete information about the actual aging condition of the insulation system. Consequently, the most efficient and, presently, the most reliable way of condition assessment is to trend the PD behavior of the machine over time with regular measurements. The examination of PD trends over time, for the same machine under similar conditions using the same measurement equipment allows a reliable assessment of the condition to be determined.

In general, a void-free stator insulation system is practically not achievable. The reasons for this are due to inevitable process control difficulties associated with taping, impregnating, pressing and curing the insulation system. Normally, quality control procedures and testing minimize the presence of gross defects in the groundwall insulation, however, usually some voids remain. In some cases, due to the operating stresses of the machine these voids may result in further delamination that may have more serious consequences for the integrity of the insulation system. If these voids occur at the interface between copper and strand or interturn insulation, e.g., due to the effects of load cycling in indirect-cooled machines, failure can take place within a relatively short period of time. However, breakdown of insulation due to voids distributed in the bulk of the insulation is relatively rare. In both cases there is little, or no, maintenance that can be performed to reverse the degradation. Usually, the only course of action is to determine the optimum time to rewind the machine. However, in case of other critical PD sources like various discharge phenomena in the endwinding region or PD due to defective auxiliary components, preventive maintenance can be efficiently planned at regular outages of the machine without need for a complete rewind. This allows the availability and reliability of the machine to be increased and thus the total life-cycle costs to be reduced.

The decision whether to implement an on-line PD test program regardless of the choice of methods is often not made on a completely technical basis. For example, decisions may be made on the basis of investment in existing equipment, if any, the type, operation and maintenance history of the machines, the financial consequences of an unplanned or extension to an existing outage. Although cost benefit analyses have been performed, to justify the implementation of programs based on off-line, on-line and even no PD testing, there is probably no true objective means of quantifying the benefits of this type of testing.

4. ON-LINE PARTIAL DISCHARGE TESTING

On-line PD tests refer to measurements performed while the generator or motor is operating normally. Such tests can be performed using coupling devices that are temporarily or permanently installed. A range of such techniques has been developed by a number of organizations, some of which are commercially available. Details of these methods are provided in IEEE 1434-2000. The principle advantage of on-line measurements is that they are recorded with the rotating machine experiencing all of the operating stresses; thermal, electrical, environmental and mechanical. Consequently, if the measurement is performed properly, this method affords the highest probability of assessing the ability of the machine to continue to provide reliable operation. On-line PD testing affords the following advantages,

- the voltage distribution across the winding is correct,
- the measurements are made at operating temperature,
- normal mechanical forces are present.

The first condition reduces the risk of obtaining overly pessimistic PD results on the machine as it renders the measurement preferentially sensitive to the more highly electrical stressed areas of the winding. The second advantage is also extremely important because of the well known temperature dependence of PD in rotating machines as well as other insulating systems. In addition to the influence of temperature on void characteristics, temperature fluctuation is also known to have profound effects on PD behaviour through such mechanisms as,

- thermally induced differential axial expansion between the copper conductors and the insulation and,
- radial expansion of the insulation in the case of thermoplastic insulation systems.

Consequently, it is important to ensure that the machine operating conditions remain substantially the same when tests are performed. However, in special cases it is very helpful for the analysis of the measured PD data to perform PD tests at various load points and temperatures, thereby being able to separate the different influences of temperature and vibrations due to electromagnetic forces acting on the winding. The principle operating parameters of relevance are,

- the terminal voltage,
- real and reactive power,
- hydrogen pressure, if applicable,
- stator temperature, and
- stator current.

Guidance with respect to the tolerances expected of these parameters is provided in IEEE 1434-2000 [1]. The ability to perform PD tests in the presence of the operating stresses is the major advantage of on-line techniques over their off-line counterparts. Off-line tests, when properly performed and analyzed provide valuable insight into insulation condition. However, some uncertainty remains because generally the temperature is significantly different and there are no bar forces. For this latter reason, off-line PD testing cannot determine whether the winding is loose, unless the abrasion of the semi conductive armour resulting from the relative movement between coil/bar surface and core iron is very severe.

There are however, some disadvantages to on-line PD measurement techniques. These are,

- electrical interference,
- volume of data, and
- interpretation.

The first of these disadvantages, the problem of electrical noise, has been discussed extensively elsewhere. Volume of data can become a problem for manufacturers and users monitoring large numbers of machines, even in situations in which the testing interval are several months apart. This problem is further compounded when using continuous on-line techniques. The obvious answer is to use some form of data compression or alarm processing, which is derived from specific PD data trending procedures, such that only excursions from the norm are considered worthy of further attention. Techniques such as artificial neural networks and expert systems are, in principle, suited to this task. Unfortunately, with the present understanding of the causes, mechanisms and effects of PD, it is difficult to define fully the decision points necessary for such automation. Clearly, further work is required in this area before reliable systems can be expected. Similar comments apply to data interpretation. While, there are some basic interpretation rules, which have also appeared in the literature [2], and a concerted CIGRE effort, under TF 15.11.33.02, is updating these rules, complete understanding of the significance of certain types of observed PD behaviour is still far away. Despite claims of success for statistical post-processing of PD data [3], automated interpretation that can provide the same level of confidence as the skilled and experienced observer is not yet a reality.

5. INDUSTRY PRACTICES

The following discussion aims to review the methods and practices of PD testing of rotating machines which are commonly used in industry. This discussion does not encompass the precise details of the techniques used, these can be found in reference [4].

Within North America, development of rotating machine PD measurement techniques and interpretation has been an active area for many decades. Research and development work has been performed by machine manufacturers, e.g., Westinghouse and General Electric, utilities, e.g. Ontario Hydro, Manitoba Hydro, American Electric Power, US Army Corps of Engineers, Tennessee Valley Authority, etc., and instrumentation manufacturers, e.g., Adwel International, Doble Engineering, Iris Power Engineering, etc. Similarly, developments in Europe, Japan and Australia have been driven by manufacturers, utilities and academic institutions, e.g., ABB, Alstom, Siemens, CEGB, EdF, Mitsubishi, CRIEPI, University of New South Wales, etc. Thus there is a large body of laboratory and field experience available. .

a. Radio frequency current transformers

These techniques are based on a radio frequency current transformer (RFCT) connected around the lead between the generator neutral point and the neutral grounding transformer. A 1 MHz bandpass filter was applied to the signal and then fed to a device known as the radio frequency monitor (RFM). This technique was developed by Westinghouse in the early 1950s, originally to detect broken strands in the stator winding [5]. Breaks in the conductors result in arcing, which can be detected by the RFCT. This type of device can also be used, in principle, to detect PD by monitoring the output with an oscilloscope or spectrum analyzer. The bandwidth and location of the RFCT implies that the sensor will detect virtually all sources of RF energy, thus the technique is not only sensitive to PD in the winding but all of the noise sources associated with the generating station environment. Thus, very often, unless very severe discharging is occurring, it is very difficult, for non-specialists, to observe PD. Consequently, significant experience and expertise is required to properly interpret the results of the test. For this reason, the test, although demonstrated to be effective, has not been used widely in North America, outside of the aforementioned organizations. Within Europe, positive experience with RF monitoring has been reported by Siemens [6] and ABB [7], although supplementary capacitive coupler sensors at the phase terminals were used to overcome the problems mentioned above. The RFCT sensors can also be applied at the phase terminals of the machine; however, problems such as saturation of the ferrite core, dielectric qualification, etc. require consideration for successful application.

b. Methods employing capacitive cable-type couplers

An on-line test, in which capacitive couplers, fabricated from appropriately sized lengths of 28 kV, cross-linked polyethylene distribution cable, are temporarily installed at the phase terminals of the generator was developed in the mid-1950s [9]. The coupler has a lower frequency cutoff of about 8 MHz, thus this type of coupler will tend not to detect PD throughout the winding because of the attenuation of high frequency components of the PD signal.

One coupler per phase is installed, usually at the potential transformer cubicle, while the machine is operating. Consequently, this test should be considered as having an element of live-line work and should not be undertaken by personnel unfamiliar or not trained in high voltage work. In any case, extreme caution on the part of the test operator is required for the safe performance of this test. In addition to personnel hazards, improper technique while connecting the coupler to the high voltage bus may cause operation of the generator protection system, resulting in an unplanned outage. For the above reasons, this test has not become widespread and is virtually unique to one North American utility.

A further barrier to greater use of the test is one common to most on-line tests, electrical interference. Great skill and years of experience on the part of the test operator are required to properly discriminate PD from noise and determine the possible source of the PD activity. Since the test was first developed and began to be used systematically, several potential insulation problems on large steam turbine generators have been detected and remedied [10]. Further, the use of the technique has helped to reduce costs by indicating those windings, usually the vast majority, which do not require significant maintenance or expensive testing.

c. On-line PD tests using permanently installed capacitive couplers

One obvious means of eliminating the hazards associated with temporarily installing capacitors on operating generators is to permanently install couplers during a planned maintenance outage. In general there are two different measurement philosophies that differ mainly with regard to their signal to noise ratio for PD detection and their sensitivity to detect PD sources throughout the winding, either close to or far away from the sensor. This is due to significantly different frequency ranges applied for PD detection by different PD measurement systems.

One of these methods, initially applicable to hydraulic generators only, employs coupling capacitors, permanently installed in pairs on the circuit ring bus or in the isolated phase bus. There is a pair of couplers on each phase. Electrical interference is reduced by a time-of-flight technique using these two permanent couplers. By relying on the very high frequency content of a PD pulse, and that there is a propagation time required for the pulse to travel along the generator circuit ring bus, common-mode noise from the power system is eliminated. Systems based on this, or similar concepts, have been commercially available for about twenty years, with various modifications and improvements that took advantage of technological progress in this period. Presently, there are thousands of installations of this technology and its variants, in North and South America, Europe, Africa, and Australasia. The technology has, over the 20 year period of its systematic use, proven useful as an aid to maintenance engineers and has enabled many users to make the transition to a condition-based maintenance policy.
When using this high frequency sensing technique, direct transfer of this technology to steam and gas turbine generators was not possible. The reasons for this difficulty are,

- the lack of an adequate length of circuit ring bus to implement the noise rejection algorithm,
- the higher noise environment inherent in large turbine generators, and
- concerns regarding the dielectric qualification of the original cable-type couplers used in hydraulic applications at the higher terminal voltages used in turbine generators.

Consequently, an alternative coupling scheme was required which would provide the same high level of noise rejection as for the technique used in hydraulic applications. A directional noise rejection scheme was implemented by installing two couplers per phase [11]. One of the couplers was located as close to the generator terminals as possible and the second coupler was positioned at least two metres away from this point. The minimum spacing was determined by the capabilities of the available electronics.

Unfortunately for several well-documented reasons [12], this technique was not employed on large steam turbine generators in noisy environments. However, the method was found to be effective in smaller stations, with lower noise backgrounds and skilled personnel who could properly interpret the data obtained. One North American utility has very significant positive experience using this technique [11].

Lately, this method has been increasingly used on small generators, up to about 150 MVA, and on large, critical motors [12]. In these applications where the noise environment is relatively low, good experience has been obtained.

Several organizations, have also demonstrated good experience with similar types of couplers applied to condition monitoring of high voltage generators [6,7,8,12]. In these applications usually higher value capacitive couplers (e.g. 10nF) have been used with measurement devices working in the lower frequency range according to IEC 60270 [17]. In contrast to the aforementioned technology, these couplers will tend to detect PD throughout the winding since the lower frequency components of PD signals are hardly subjected to attenuation when travelling along the winding. However, since these sensing devices detect more noise than in the higher frequency range, special procedures for noise identification have to be applied. For this purpose, e.g. modern algorithms of digital data processing can be efficiently used. This technology has also been successfully applied in many installations to hydro- and turbine generators up to the highest unit ratings [8,18].

d. Stripline antennae

A sensor, known as the stator slot coupler (SSC), is an ultrawide band antenna, installed on top of the stator winding bars, under the wedges, at the ends of core slots. This antenna detects any electrical signal in the frequency range of 10 MHz to 1000 MHz and is highly sensitive to PD signals originating from sources close to the SSC. The wide bandwidth of such couplers is used to implement a noise rejection scheme based on pulse shape recognition, i.e., signals with short rise time and pulse width are deemed to be PD. Further, these couplers are directional enabling separation of PD occurring in the slot section of bars from the surface discharges in the endwindings. An instrument was developed to acquire the signals from the SSCs, determine their width, and count them as PD or noise [12]. Globally, several hundred large steam turbine generators have been equipped with SSCs. Experience to date with this technology [14] has demonstrated that it is effective in discriminating PD from noise signals in the environments encountered in large generating stations.

Some organizations have sought to utilize the embedded resistance temperature detectors (RTDs) in the stator winding as PD sensors [15, 16]. The principle advantage claimed for this method is that of convenience because there is no need to install additional PD couplers. This method has been applied in North America [16] and Japan [15]. However, there are some serious reservations regarding the effectiveness of the technique, including,

- some manufacturers do not use shielded output leads on the RTDs. Hence, the leads may be prone to electrical interference and will not be efficient transmitters of high frequency signals.
- unless great care is exercised, the output leads from the RTDs may become sources of PD if they are run in close proximity to the high voltage conductors.
- RTDs are not designed to be antennae; hence, their high frequency properties are not optimized for the purposes of efficient PD detection.
- the locations of RTDs within the stator winding are not optimized to the special needs of PD detection to ensure a reliable monitoring of most critical sites of potential PD activity.

Consequently, the efficacy of PD testing based on this coupling is questionable, especially if performed by individuals without particular expertise in this field.

6. DEVELOPING A PARTIAL DISCHARGE TEST PROGRAM

Many organizations contemplating application of PD measurements as part of a predictive maintenance program encounter a number of questions that require resolution before the first measurement can be made. Obviously, cost is one of the first considerations, however, numerous other issues, which can also relate to cost, need to be identified and resolved. Among these issues are,

- selection of appropriate technology,
- who performs the testing and the subsequent data interpretation?
- what test strategy or policy should be adopted?

The cost element, insofar as the cost of specific equipment or sensors, will not be dealt with in this document. Given the numerous suppliers of PD measurement devices and services worldwide, the market or the negotiating skills of the individual, will largely dictate the price. However, the purchaser should consider the value or criticality of the machine with respect to the cost of the PD monitoring technology.

Questions to be considered when specifying or purchasing PD measurement equipment include, the type of sensor and the output format from the system. Issues associated with sensor selection revolve around whether the equipment is to be installed on a new machine or retrofitted to an existing generator, reliability of the coupling device and credibility of the output of the sensor. Generally, on new machines the cost of the PD couplers is a very small fraction of the total cost of the generator. Further, installation of these devices on a new machine is very much simpler to engineer than when retrofitting to an existing unit. Consequently, sensors can be specified that are installed either in the winding, e.g., SSCs, or very close to the machine terminals, e.g., capacitive bus couplers. The advantage with couplers located in close proximity to the stator winding is that they are closer to the source of PD in the generator and tend to be less prone to noise, or at least, there is a higher probability of successfully rejecting the noise.

In most cases, utilities are specifying PD monitoring systems for existing machines, thus a greater emphasis is placed on ease of installation. Often, the time frame during a maintenance outage, within which the coupler installation takes place, is quite short. Consequently, retrofittability of the couplers is a prime consideration. In general, all couplers fit into one of three categories with respect to the ease with which they can be installed.

1. Sensors that are installed in the machine, which require an outage with the rotor removed. Stator slot couplers fall within this category.
2. Sensors which are installed in the machine, which do not require that the rotor be removed. Capacitive couplers connected to the IPB or circuit ring bus belong to this group.
3. Couplers that do not require a high voltage connection that are installed either at the high or low voltage connections to the generator. Radio frequency current transformers.

Couplers that fall within the first category above require a major outage, such as those taken to perform various inspections of the rotor. Typically, such outages occur every 6 to 10 years. Thus, sensors of this type usually imply that the utility or machine user has a long term policy of installing such couplers during outages of this nature. Installation of sensors in the second category also requires a machine outage. However, because the rotor can remain in situ or, if installing IPB couplers, no access to the generator is required, the sensors can be installed during very short outages. Couplers in the last category, while also requiring an outage, require the least time because no high voltage connections are made.

Another factor involved in the selection of suitable sensing devices is that the coupler be compatible with electrical, mechanical, thermal and environmental stresses of the host machine. For example, high voltage coupling capacitors designed to be installed in the IPB should have the same dielectric qualification as the bus, under the same operating conditions. Presently, there is very little, if any, public domain evidence of PD sensors causing machine damage or resulting in unplanned outages.

Often, the choice of instrument is determined by the couplers, or noise rejection / identification scheme, selected. In principle, because some of the sensors and coupling schemes are similar, e.g., the widespread use of 80 pF capacitors deployed in either differential or directional modes, the user is not necessarily committed to purchasing couplers and instruments from the same source. The number of instruments required depends on the number of machines being monitored as well as geographical factors. Generally, because of the relatively slow degradation rates involved a policy of making PD measurements once every six months is adequate. Hence, only one instrument may be required to service this need. Of course, where the stations are physically far apart or depending upon the interface between different functional groups within the utility, more than one instrument may be required.

Some instrument manufacturers offer continuous on-line PD monitoring systems. Such equipment is useful where the generating station is in a remote location where the travel costs are prohibitive. Alternatively, there may be some additional value to using such a system on a generator that is considered to have a temperature or load dependent problem. However, such systems, which in some cases are more costly than conventional instruments for periodic use, imply some special features that need to be considered for general application. In addition to the cost argument, there are practical problems associated with the volume of data that such instruments have the potential to generate. Any utility contemplating the purchase of a continuous PD monitor should consider the budgetary implications of maintaining and analyzing a database of this size. However, when applying specific techniques of data compression and data trending by using modern software algorithms, the dilemma of maintaining huge data volumes can be effectively handled. In addition, the problem of analyzing huge data volumes can nowadays be solved e.g. by remote access to the measurement system by an experienced service provider who relieves the utility from this data analysis work.

Regardless of the choice of instrument or whether periodic or continuous on-line, a significant issue for most utilities is who performs the testing and the subsequent data interpretation. Some organizations have the capability to handle these functions in-house, whereas others contract these services out. Another option is, depending on the equipment, to have the test performed in-house and transmit the data to a third party for interpretation as mentioned above. Contracting out both testing and interpretation has advantages in that the utility is largely free of the overhead burden of owning the instrument and employing the appropriate expertise. However, this approach has the disadvantage that the utility partially loses ownership of maintenance process for the machine. That is, when there is no individual assigned responsibility for this process within the utility there is a risk of the PD results, and their implications, being ignored. Further, the interpretation of data by a third party tends to be very conservative because of the liability issue. In cases where the interpretation is performed by a machine manufacturer there is the potential for a conflict of interest. Overall, the operational and technical needs of the utility are best served if testing and interpretation are performed in-house. Initially, in some situations, the utility may not be comfortable with analyzing the data. In such cases, they may consider engaging a third party to provide interpretation and training services, so as to effect an orderly technology transfer to their own personnel.

Where the latter policy of acquiring and analyzing the data in-house is selected, there must be a commitment from the utility to assign the appropriate staff, usually a test technician and another individual to interpret the data. These tasks are not necessarily full-time jobs, however, unless the responsibilities are defined and the individuals given clear mandates for these functions, the policy will be ineffective.

No matter which technology is selected or who performs the testing and analysis, the output from the PD monitoring program needs to be integrated with operations and maintenance policies. Unless this link is made, there is little or no point investing in this technology. Often, the connection between test results and maintenance actions is lost because the individuals concerned are in positions not directly related to operations, e.g., they belong to a research or testing group. Success is more probable if the station staff is able to perform the testing themselves. Further, the individual responsible for data interpretation should be either on-site or part of a central engineering group with input into maintenance policy.

In some cases, condition monitoring programs, and not just those based on PD, fail because expectations are too high. In the case of PD monitoring, the systems are often sold on the basis that can prevent machine failure. While this is true, the key point to remember is that failure prevention or minimization is driven by maintenance and operation decisions, in which correctly analyzed PD information assist. Further, in many cases a properly run PD test program can provide significant avoided cost savings be reducing unnecessary maintenance.

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