

# Monitoring of electrical equipment failure indicators and zero-planned outages: past, present, and future maintenance practices

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## Abstract

Electrical system preventive and predictive maintenance methodologies have experienced growth due to new available technologies. This paper will review the historical and current approaches to electrical equipment maintenance, and also provide available technologies that support the future modes of equipment maintenance. Low voltage and medium voltage systems will be reviewed. The need for improved reliability and uptime continues, and effective monitoring systems support a new concept of zero-planned outages. Monitoring parameters linked to potential failure modes allows for two key needs to be addressed: first, to notify end users of a pending failure condition; and second, to recommend maintenance and/or inspections based on a trending analysis of failure mode contributing parameters rather than planned outages. This paper shall review both IEEE® and end-user surveyed failure indicators and technologies to continuously monitor and alarm on such failure indicators.

## Preventive maintenance trends

Past maintenance practices were based on original equipment manufacturers or industry standard guidelines. While some of these guidelines were based on the number of equipment operations, the majority resulted in a time-based maintenance program. It was common for circuit breakers and transformers to be tested annually, every three years, and eventually every five years.

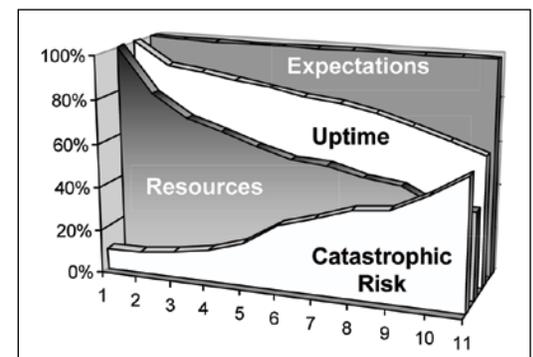
One example of time-based maintenance scheduling is shown in **Table 1** [1].

Most end users adapted the time-based maintenance approach, and in many cases, the maintenance recommendations related to operating conditions were not applied for various reasons. For example, some circuit breaker guidelines would recommend detailed inspections following a fault interruption, but when a fault occurs, most of the resources are diverted to

identifying and correcting the downstream fault, and restoring power as soon as possible, therefore the circuit breaker was usually neglected because the limited resources were required elsewhere and power had to be restored immediately. In addition, the inherent ability of circuit breakers to interrupt repeated faults provided a sense of confidence in the electrical equipment. Other operating-mode recommendations involved the number of operations of electrical equipment. The number of operations is available on a mechanical counter and because electrical power distribution equipment did not operate often, it was simpler to follow a time-based maintenance program.

Present maintenance has been driven by a reduction in maintenance budgets, while the need for electrical uptime has become even more critical. **Figure 1** illustrates the expectations versus the typical maintenance funding resources. As shown, uptime drops as resources are reduced, while the expectations remain the same.

The swings in our economic cycles have added to the lack of maintenance. In times of economic downturns and reduced revenues, all budgets are cut including maintenance budgets. During these slow production periods, equipment can be made available but the reduced maintenance budgets prevent allocation of the resources to complete the maintenance. During good economic cycles, the need for production is greatest and uptime is demanded. While maintenance budgets have been restored, the equipment can not be removed from service, therefore maintenance can not be performed. In summary, when the equipment is available for maintenance, there is no funding to perform the maintenance, and when the funding is available, the equipment is not accessible to perform the required maintenance.



**Figure 1. Present Maintenance Resources and Effects**

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**Table 1. Historical Time-Based Preventative Maintenance (Minimum)**

Equipment Type	Mechanical Operation Check	Visual Inspection Energized	Infrared Inspection and/or Oil Testing	Outage Preventive Maintenance and Testing
Cables terminations and connections	—	1 year	1 year	3 years
Liquid-filled transformers	—	1 year	1 year	3 years
Dry-type transformers	—	1 year	1 year	3 years
Metal-clad switchgear	—	Monthly	1 year	3 years
MV circuit breakers	1 year	1 year	1 year	3 years
Buses and bus ducts	—	1 year	1 year	3 years
Protective relays	—	1 year	—	1 year
Automatic transfer equipment	1 year	6 months	1 year	3 years
Low voltage equipment	—	1 year	1 year	3 years
Switchgear	—	6 months	1 year	3 years
LV circuit breakers	1 year	1 year	1 year	3 years
Panelboards	—	1 year	1 year	3 years
Direct-current systems: batteries	—	3 months	1 year	1 year
Direct-current systems: chargers	—	3 months	1 year	6 months
Electrical safety equipment	—	Per OSHA	Per OSHA	Per OSHA
Ground-fault protection systems	—	—	—	1 year
Motor control centers	1 year	1 year	1 year	3 years
Rotating machinery: AC motors	1 year	1 year	1 year	1 year
Rotating motors and generators	1 year	1 year	1 year	1 year
Metering	—	1 year	1 year	3 years
Outdoor bus structures	—	1 year	1 year	3 years

These present maintenance practices have drifted away from time-based programs and relied on equipment operating conditions, but continue to include a time-based component. One practice has been to review past maintenance records and observe equipment operating conditions and determine the level of maintenance required based on this historical data. Maintenance work scopes would also be adapted to “Full-Maintenance,” which involved the traditional maintenance practices and a lesser level of maintenance, referred to as “Operational Maintenance.”

The equipment would be rated and ranked based on the past maintenance records and ongoing visual inspections. The criteria to evaluate past maintenance records, and the visual inspections, provides for a consistency standard for all equipment that is evaluated. The criterion is based on knowledge of failure modes of electrical power distribution equipment. One of several key maintenance criteria to be evaluated is the low-resistance (Ductor) measurement across circuit breaker contacts. Higher resistance creates greater heat during normal operating conditions and this additional heat can deteriorate the lubricants required for proper circuit breaker mechanical operation. Another example is insulation resistance of electrical distribution equipment, as well as gas-in-oil testing results for transformers. These, and other parameters, are also reviewed to determine if either the detailed “Full Maintenance” or the lesser “Operational Maintenance” is needed for the equipment. Equipment with greater wear and deterioration would be given “Full Maintenance” while equipment in better condition would be given “Operational Maintenance.” This maintenance would still be performed on a time-based cycle. Therefore, if equipment was maintained every three years during a scheduled outage, this time-based maintenance cycle continued, but resources were

shifted so that equipment was provided maintenance in accordance with the rankings resulting from the historical maintenance records and current operating performance. This approach did result in a financial cost savings because usually 30% to 50% of the electrical equipment could be afforded a lesser level of maintenance [2]. This savings was clearly identified because “Operational Maintenance” required fewer hours to complete than “Full Maintenance.” Fewer hours resulted in lower direct maintenance labor costs. In addition, these man-hours were available to apply to other equipment during the scheduled outage. An example of “Full Maintenance” versus “Operational Maintenance” for low voltage air circuit breakers is summarized in **Table 2**.

**Table 2. Full Maintenance vs. Operating Maintenance Example**

LV Breakers Full Maintenance	LV Breakers Operational Maintenance
Inspect and operate	Inspect and operate
Check racking	Check racking
Lubricate	Lubricate
Megger (ins resistance)	Megger (ins resistance)
High-current testing—all phases	Low-current testing—one phase
Clean	—
Contact resistance testing	—
Inspect arc chutes, contacts	—
Check auxiliary devices	—
Check mechanism	—
<b>Man-hours: 3.2</b>	<b>Man-hours: 0.75</b>

The financial savings of this type of “Performance-Based Maintenance” program [3, 4] has been shown to exceed 30% during a typical scheduled outage [2]. In a case study involving 390 low voltage circuit breakers, 52.8% of the circuit breakers were candidates for a reduced scope of maintenance (operational maintenance).

The second case study involved a department of a medium size petro-chemical plant [2]. In this plant, four different types of electrical equipment were evaluated, which included MV breakers, MV starters, LV breakers, and oil-filled transformers.

Key observations of this second case study included:

- No MV starters were identified as candidates for a reduced level of outage-based maintenance (operational maintenance). This may also apply to a larger quantity because MV starters do experience a high number of operations and therefore may always require full maintenance during planned outages
- Low voltage circuit breakers showed considerable potential for savings with 57% as candidates for a reduced level of maintenance. In addition, medium voltage circuit breakers had 61% as candidates for a reduced level of maintenance (operational maintenance)
- For oil-filled transformers, 50% were candidates for a reduced level of maintenance

Future maintenance provides even greater emphasis on equipment operating conditions. In general, end users would prefer to “never” complete scheduled maintenance until required to do so. This is a different mind-set from time-based or condition-based maintenance and requires continuous monitoring of critical failure modes in a cost-effective manner. End-user surveys have provided two key insights into the desired state of future maintenance of electrical equipment. End-user comments can be summarized by two simple sentences:

1. Tell me when I need to do maintenance and what maintenance to do.
2. Tell me that I have a problem now and what I should do about it.

## Equipment failure modes

A review of IEEE data [5] related to both failure contributing causes [6] as well as equipment failures that resulted in the greatest percentage of production losses [7] provide guidelines related to parameters that should be monitored to predict a pending potential failure and provide recommendations for immediate or near-term maintenance.

## Failure contributing causes

IEEE Standard 493-1997 (Gold Book) includes detailed data of a 1972 survey. Because this referenced failure related IEEE data [5] dates back to the 1970s, more recent end-user survey data was also obtained to verify potential failure parameters.

A detailed review and analysis of failure contributing causes and predictive indicators has been conducted and yielded the results shown in **Table 3**. This analysis included the data from Appendix E, Table XVIII and normalized the results from switchgear with both insulated and bare bus configurations [6].

There were other contributing causes that are not candidates for monitoring, such as mechanical structure failure, shorting by tools or metal objects, exposure to chemical or solvents, and testing error, therefore these failure modes can not be adequately predicted.

Contributing causes are shown in **Table 3**.

**Table 3. Failure Contributing Causes Analysis**

IEEE Standard 493-1997

Failure Contributing Causes

Appendix E, Table XVIII, (Insulation and Bare Bus Gear)

Parameter	IEEE failure causes
Humidity	23.1%
Dust sensors	14.9%
Temperature	9.0%
Relay outputs	7.2%
Motion	4.9%
Water	3.6%
Smoke	3.4%
Total	66.1%

The above data was then grouped into subsets that could be monitored. These subsets resulted in three categories: humidity/water-discharges, dust-smoke, and heat-fire. This data was correlated against end-user surveys that were conducted at random IEEE regional meetings. These surveys also inquired into the expected failure contributing causes. This data is illustrated in **Table 4**.

**Table 4. IEEE / End-User Failure Causes**

Failure Contributing Causes

IEEE Failure Causes	End-User Feedback (April, 2008)
Humidity (LV), discharges (MV): 26.7%	Humidity (LV), Discharges (MV): 24.9%
Dust, smoke: 18.3%	Dust, smoke: 16.6%
Heat, fire: 9.0%	Heat, fire: 12.5%
Total: 54.0%	Total: 54.0%

As shown in **Table 4**, approximately 54% of the failure contributing causes was identified by similar parameters by both the IEEE failure causes, dating back to the 1972 survey and end-user feedback summarized as of April, 2008.

Based on the above results, the continuous monitoring, trending, and alarming of the following initial parameters can both warn of pending failures and recommend immediate or near-term maintenance:

- Humidity and the presence of water
- Partial discharges (MV equipment)
- Dust trending and smoke detection
- Temperature trending

## Greatest production losses

IEEE Standard 493-1997 also provided survey results for the types of equipment failures that resulted in the greatest percentage of production losses and the associated downtime [7]. This data is illustrated in Appendix B, Table 58. A summary is shown in **Table 5**.

**Table 5. Equipment Failure Effects on Production**

IEEE 493-1997 Appendix B—Table 58

Equipment	Percent of Failures Resulting in >30% Production Loss
Switchgear bus—bare	50%
Electric utility	27%
Switchgear bus—insulated	20%
Cable terminations	18%
Bus duct	15%
Transformers	15%
Generators	15%
Open wire	13%
Cable	13%
Cable joints	9%
Circuit breakers	8%
Motors	3%
Motor starters	2%

**Table 5** indicates the percentage of failures related to the “type” of electrical distribution equipment that results in a production loss of greater than 30%. For the types of equipment listed, we have provided both the traditional outage-based maintenance options (**Table 6**) and the future continuous monitoring and trending maintenance options (**Table 7**).

**Note:** 27% of the outages related to the electric utility supply can affect 30% of production. Because the electric utility supply is assumed beyond the control of the plant or the facility, this category is not included in either the traditional or future maintenance options.

**Table 6. Outage-Based Maintenance Options**

Equipment	Outage-Based Maintenance Options
Switchgear bus—bare	Outage-based internal inspection
Electric utility	—
Switchgear bus—insulated	Outage-based internal inspection
Cable terminations	Thermography of connections
Bus duct	Thermography—joints / bus plugs
Transformers	Gas-in-oil, doble, turns ratio test
Generators	Megger, vibration
Open wire	Thermography of connections and megger
Cable	Megger
Cable joints	Thermography of connections
Circuit breakers	High-pot, inspection, cleaning and lube
Motors	Megger, partial discharge, vibration
Motor starters	Megger, inspection, cleaning

As previously discussed, the future maintenance goals desire an indication of a potential failure mode and recommendations for immediate or near-term maintenance, therefore we have identified continuous monitoring and trending maintenance options for each of the same equipment types identified.

**Table 7. Continuous Monitoring and Trending Options**

Equipment	Continuous Monitoring and Trending Maintenance Options
Switchgear bus—bare	Partial discharge, temperature, humidity, floor water
Electric utility	—
Switchgear bus—insulated	Partial discharge, temperature, humidity, floor water
Cable terminations	Temperatures, humidity, water
Bus duct	Bus duct temperatures, humidity, water
Transformers	Tx temperature, moisture, dust (air Tx)
Generators	Partial discharge, vibration, temperature
Open wire	Periodic thermography
Cable	Temperatures, humidity, water
Cable joints	Temperatures, humidity, water
Circuit breakers	Temperatures, humidity, floor water, dust
Motors	Temperatures, vibration
Motor starters	Temperatures, humidity, floor water, dust

The analysis of the failure contributing causes and equipment failures that contributed to the greatest production losses, both have identified parameters that can be monitored and trended to provide the future desired maintenance options.

## Available monitoring technologies

The prior analysis has determined that approximately 50% of potential failure contributing causes of electrical distribution equipment can be monitored, trended, and alarmed to provide the desired future maintenance mode of operation.

These causes are:

- Humidity and the presence of water
- Partial discharges (MV equipment)
- Dust trending and smoke detection
- Temperature trending of cubicles, bus-duct, critical cable joints, and/or bus connections
- Bus/cable connection point-temperature sensors
- Load current, heater, and fan circuit currents
- Intrusion or motion
- Vibration of rotating apparatus

The majority of the parameters above can be monitored using available sensors after being integrated into a data collection, trending, and alarming configuration. In addition, the desired future mode of maintenance also indicated a unique request—that data transmission and alarm indications should be independent of the plant IT system. This independence appeared primarily due to the delays in the implementation of new IT-based systems when requested by plant maintenance or engineering personnel, while some comments indicated that failure warnings needed to be independent due to potential future IT firewall changes or updates. For example, there was a concern that while current data may be transmitted for monitoring and alarming today, a future IT firewall change may prevent data transmission. The aforementioned preferences were consistent across most industry segments except for mission-critical or data-center applications. In these segments, there was the requirement to implement the above failure warning indicators within the in-house monitoring and alarming systems. A data-collection, trending, and alarming platform should be able to function both independently or integrated into the facility monitoring system.

While the majority of the above sensing parameters have been available, two newer technologies had emerged that allow for the full implementation of the listing above. First, partial discharges are electrical discharges that occur across voids in medium voltage insulation systems or across surface deterioration. The presence of the medium voltage applies stresses to the insulation system, which will eventually deteriorate and result in a full discharge or system fault. Partial discharge technologies were applied to medium voltage generators and medium voltage motors [8] and were expanded to also protect medium voltage switchgear assemblies [7, 9].

When switchgear bus failures begin to develop, they typically last for a few days or longer depending on the severity of the initial failure [7]. Depending on the age of the switchgear, spare bus pieces may not be readily available and custom manufacturing requires additional time. In the interim, cable bypasses are usually applied, which is labor intensive and requires a second complete outage to restore the damaged bus and insulation with permanent replacement equipment.

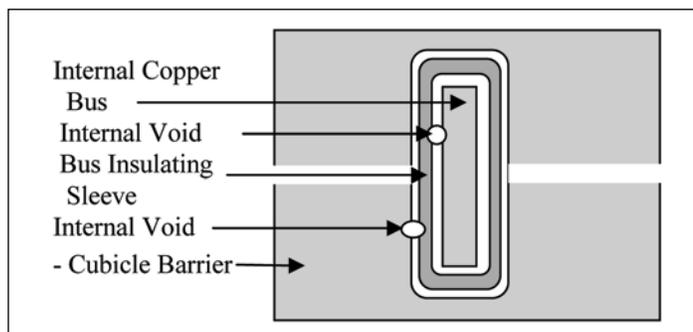
It has been observed that in many cases the short final bridging of medium voltage to ground can have devastating effects. This is due to the ionization of the air within the switchgear bus compartment after the arc is initiated. This ionized air becomes a conductor without any additional help from contamination or conductive paths to ground. The ionized air will continue to bridge other areas of voltage to ground until an upstream protective device isolates the fault.

Another factor is the inherent air gaps that were part of the design of early MV switchgear systems. In the past, these air gaps resulted in high potential stresses, which caused partial discharges across the air gaps and resulted in insulation deterioration until eventual failure if not detected by a visual inspection or by the smell of ozone.

For example, older MV switchgear internal bus consisted of squared-copper bar within an insulation sleeve. This sleeve penetrated the switchgear cells through a surrounding insulating support barrier. This design contains small air gaps, or voids, between the copper bar and the insulation sleeve, and between the insulation sleeve and the support barrier as illustrated in **Figure 2** and by the actual observed corona at these air gaps in **Figure 3**. Modern new switchgear bus designs eliminate both of these air gaps.

These partial discharges emit high-frequency radiation, and the application of specifically designed sensors with filtering and data analysis equipment allows for the continuous monitoring of these partial discharges that will eventually lead to equipment failure. Trending of these partial discharges allows for recommendations for inspections and/or repairs to be scheduled.

A second newer technology is the continuous monitoring of critical switchgear joints and/or cable terminations. In the past, a thermographic survey would be required to observe any overheated connections. These surveys required the direct viewing of energized connections, therefore requiring removal of panels and the exposing of energized equipment. With the arc-flash protection requirements, these thermographic surveys have been very difficult to safely implement. One solution is the installation of infrared viewing windows into the gear, therefore allowing for the manual thermographic surveys to be completed without the removal of power panels. These surveys must still be scheduled and therefore do not provide continuous monitoring to determine a potential immediate failure mode or the automated recommendation for maintenance. One solution is the application of remote continuous point temperature sensors that are directed to a bus or cable connection and then the temperature is recorded, trended, and alarmed as required. Another option is the correlation of these point-connection temperatures to the resultant overall increase in the cubicle or bus-duct area temperatures, whereby an increasing cubicle or bus-duct trend would result in the recommendation for maintenance and/or a site thermographic manual survey.



**Figure 2. Older MV Switchgear Bus and Internal Void**



**Figure 3. MV Switchgear Bus with Corona Evidence at Air Gap Between Bus Insulating Sleeve and Outer Cubical Barrier**

When combined with sensing options such as humidity, floor water, dust, smoke, load/heater/fan currents, cubicle, or bus-duct temperatures and actual equipment currents, partial discharge detection and point-connection temperature sensors provide a robust predictive monitoring package for both low voltage and medium voltage equipment. By adding available vibration sensors, this future maintenance technology is also adapted to rotating equipment.

Another consideration is the development of patented algorithms based on historical and designed-based operating conditions, which will alarm when a parameter is considered out of the normal operating range, when correlated to the context of the other measured parameters [10].

## Remote monitoring plant and system applications

The sensors indicated in the prior section should have a very low failure rate and also have data outputs that are easily interpreted. Ideally, sensors should be passive and require no external power sources such as batteries. Unfortunately there are still some sensors that do require external excitation power in order to function. The placement of some sensors requires that they be installed in medium voltage compartments and, therefore, if external power is required, it should originate from a low voltage control compartment. Battery-powered sensors at the sensor location is strongly discouraged because it would require a shutdown of the equipment being monitored in order to replace a dead battery.

Sensor placement is also critical when monitoring equipment. Sensors must obey all manufacturers' recommendations for air gap distances. Wiring of sensors back to a common control point should follow existing secondary wire routes and cable trays. Creating new holes in switchgear panels for ease of installation is discouraged. Sensor cables should be properly shielded to prevent any EMF interference on the data being transmitted. Sensor installation shall not be the cause of any equipment failure. Installation of the sensors should be completed by bolted means and not with adhesive backed materials that may lose their grip over time and cause the sensors to fail. If the equipment being monitored is critical, then redundancy in sensors should be considered and is highly recommended. Lastly, sensor installation should not affect the operation of switchgear.

Data collection of the sensors is gathered to a piece of hardware called a "data accumulator." This data accumulator needs to accept a wide range of hardwired or wireless inputs and have the ability to transmit the data over a common network for data recording and interpretation.

The input hardwire connections can include twisted pair networks over RS-485/RS-232 connections for Modbus® sensors or twisted pair wires for analog 4–20 mA / 0–10 Vdc sensors. The data accumulator should also have the ability to connect to wireless local sensors for remote locations where running a hardwire is cost prohibitive.

The data accumulator should have the ability and flexibility to translate and transmit the data into many common protocols like Modbus RTU / TCP, BACNet, etc., and to communicate directly to a building management system and a remote data warehouse.

For installations that do not have a central building or facility management system, the data accumulator should have the ability to transmit the data to a common offsite data warehouse. There are several means available to transmit the data including using a cellular data network, land line phone modem connection, and satellite connections for remote locations. Using these methods will help to avoid interaction with any local IT requirements because data is not flowing through a company's firewall but instead is using a separate network to transmit the data.

Transmission rates and uploading of data can be very flexible depending on the equipment being monitored. In most cases, transmitting data every 15 minutes is found to have the best uninterrupted flow of data. Other transmission rates are available from hours to days. The data that is collected can also be logged and sampled again depending on the equipment being monitored.

Transmission rates and uploading of data are determined by how often the data is sent to the data warehouse. Logging and sampling is how often data is collected from the sensor and at what rate. The data accumulator should have the ability to sample in fine intervals down to 1 second and then take the average of hundreds of samples and provide a log of that data at a moment in time. Taking an average of multiple samples and then logging that one average is better than just recording data at one point in time. Finer granularity is accomplished with this method while at the same time reducing the number of data points being transmitted. If data transmission is broken, then the data accumulator should have the ability to locally store the data until communication is restored. Data transmission in this case is reliant on third-party networks and many of these networks have their own redundancy systems in place. Cellular, land line, and satellite networks do go down so the data accumulator will store the data until the network is restored at which point a hand shake occurs between the data accumulator and the data warehouse to begin sending data. If a client has his own building management system (BMS), then data transmission is dependent on the BMS.

Data at the data warehouse is collected and filed in multiple and unique individual registers. Algorithms are located in the data warehouse where the data is correlated and analyzed. The data warehouse has a Web-based portal that allows the end user to view any of the data being collected. The data is shown in graphical format with alarm thresholds presented. The end user should have the ability to mix and match any data into one common graphical representation to see how items like current flow, temperature rise, dust flow, and many others interact with each other.

The idea is to understand how all the sensors provide an overall "Relative Health Index" of the equipment being monitored. Algorithms could be developed to provide virtual sensors. Virtual sensors do not physically exist in the equipment but are the output calculation of two or more actual sensors. For example, an easy way to understand this is the value of dew point, which is derived from sensors monitoring temperature and humidity. Dew point could then be tracked to monitor if condensation is forming in the switchgear. Condensation occurs when switchgear heaters are either off or have failed. Combining current monitoring of switchgear heaters and dew point gives an early indication of a simple and inexpensive component that could be replaced instead of having to deal with a problem that may persist and grow over time leading to costly failures.

Understanding the concept of virtual sensors in combination with actual sensors opens up a large combination of parameters that could be monitored to provide a robust monitoring package that not only tells the end user when to do maintenance but also when there is a problem.

## Smart-Grid applications

While the majority of Smart-Grid applications have been related to power metering, peak-shaving, load leveling, and the control and switching of distributed generation sources, one of the primary focuses of smarter-grids is uptime and reliability. A comment received by one survey participant illustrated how uptime and reliability can be addressed with Smart-Grid applications related to predicting pending failure modes: "Being notified of a potential pending failure, before it occurs, provides us with a smarter grid."

The concepts discussed within this paper provide for the notification of a potential pending failure and allow for actions to be implemented prior to a catastrophic failure. In one case, it was shown that monitoring aforementioned parameters would have warned of a pending major equipment failure due to severe weather conditions and the subject equipment could have been de-energized and isolated from the electrical grid. Because the monitored environmental parameters were not available to the remote operator, the equipment was re-energized in an attempt to clear an anticipated minor fault and resulted in the complete melt-down of the subject medium voltage circuit breaker and the associated enclosure.

## Conclusion

The future of maintenance is here today. The economic swings are preventing past maintenance practices from being implemented. As previously stated, when the equipment is available for maintenance, there is no funding to perform the maintenance, and when the funding is available, the equipment is not accessible to perform the required maintenance. Available IEEE historical data of failure contributing causes and equipment types that result in the greatest production downtime, combined with recent end-user surveyed data, have helped to identify the required parameters to be continuously monitored, trended, and alarmed. The application of new technologies such as medium voltage partial discharge detection and point-connection temperature monitoring, with other failure mode predictor parameters, including patented algorithms integrated into an IT-independent or a facility monitoring and alarming system, can provide for the desires of the future state of electrical equipment maintenance. This future maintenance state is summarized by two requirements: Tell me when I need to do maintenance and what maintenance to do; and Tell me that I have a problem now and what I should do about it. The Smart-Grid requirements for improved system uptime and reliability also point to the need for systems that can self-predict a pending failure and also provide for ongoing maintenance recommendations. The technological solutions exist today to support this future maintenance mode.

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Gabriel J. Paoletti, P.E., received a B.S.E.E degree from Drexel University, Philadelphia, PA in 1976 and an MBA from Rutgers University, Camden, NJ in 2009. Mr. Paoletti more than 33 years of engineering service experience with Westinghouse, ABB and Eaton Electrical Engineering Services. His electrical distribution equipment experience includes field-testing, predictive and preventive maintenance, partial discharge technologies, RCM programs, applications engineering, failure analysis, and power systems studies. He has design experience with vacuum circuit breaker modernization, low voltage circuit breaker cell-retrofits, and motor and transformer repair experience. He is also a patent participant for a switchgear partial discharge sensor and he received Patent # 11928335: "System for Monitoring Electrical Equipment and Providing Predictive Diagnostics Therefore," October 30, 2007. Mr. Paoletti also received a Patent #7,646,308B2 System for Monitoring Electrical Equipment and Providing Predictive Diagnostics Therefore on January 12, 2010. Mr. Paoletti is a Senior Member of IEEE and a Registered Professional Engineer in the States of Pennsylvania and Delaware. Mr. Paoletti has had technical papers published in the IEEE-IAS concerning microprocessor-based protective relays (1990), vacuum modernization of MV circuit breakers (1997), partial discharge technology related to MV motors and MV switchgear (2001 and 2004), condition-based maintenance of MV switchgear (2002), failure indicators of electrical equipment (2005), and safety and environmental evaluation of insulating materials in MV (2009). Mr. Paoletti is currently Division Applications Engineering Manager for the Eaton Engineering Services and Systems Division. He also was a contributing author to the IEEE-Buff Book regarding topics on maintenance, testing, and calibration (2002) and received the IEEE Engineer of the Year Award for 2009 (Northern New Jersey Chapter) for new product and service innovation that improved the efficient distribution of electrical power.

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George Herman received a B.S.E.E. degree from New Jersey Institute of Technology, Newark, NJ in 1994. Mr. Herman has more than 16 years of field service experience with Westinghouse and Eaton Electrical Engineering Services. His field services experience involved testing and startup of all types of distribution equipment. He has been involved with designing, working, and managing large projects that included numerous design build installations. Experiences include Generator Control System designs, SCADA installations, generator excitation systems, MV switchgear retrofits, and controls. Mr. Herman received a Patent #7,646,308B2 System for Monitoring Electrical Equipment and Providing Predictive Diagnostics Therefore on January 12, 2010. Mr. Herman is a current member of the IEEE. Mr. Herman is currently Renewable Energy Supervisor and leads the remote monitoring applications for the Eaton Engineering Services & Systems Division. Mr. Herman has also developed a monitoring system for photovoltaic systems including traditional power data and environmental data from the system, and for also monitoring the health of the key components of the system.

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