DETECTING FAILING JOINTS IN A POWER PLANT USING ELECTROMAGNETIC INTERFERENCE (EMI) EQUIPMENT

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POWER PLANT ELECTRICAL EQUIPMENT DETERIORATION

Scope of this paper

There are numerous instrumentation systems used in attempts to assess the condition of power plant electrical equipment. The library of papers discussing these instrumentation systems is vast. A few examples are listed at end of paper. [1] - [8] But papers discussing detection of failing electrical connections inside generators or bus systems are limited in number. [9] [10]

This present paper will focus on equipment that will readily detect joints that are in the early stages of distress with the objective of preventing expensive in-service failure.

Bolted Joint Deterioration

There are thousands of high current (non-instrumentation) electrical connections in a power plant. All of these connections are subject to deterioration. Bolted joints are particularly subject to deterioration. They may eventually fail if not well designed and properly assembled. The lack of proper torque on these connections is the number one cause of failure.

Photo 1 shows the locations of several bolted connections internal to a large generator. Every design is different but there are often many bolted connections inside a generator and at the connections from the generator terminals to the bus. Failure of these connections is rare but can be extremely costly when they do occur.

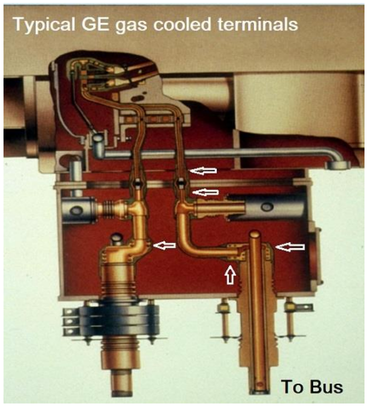


Photo 1. Typical flexible lead bolt connections inside a generator.

Deterioration from imperfect high voltage bushing flexible connection joints is shown in Photos 2 & 3. This condition was the result of high contact resistance due to less than specified torque on the connection bolts and/or improper cleaning of the joint faces. Repair of this condition would involve cleaning and re-plating of the connection surfaces on the plates and on the flexible links. Or replacement of links if significantly deteriorated.

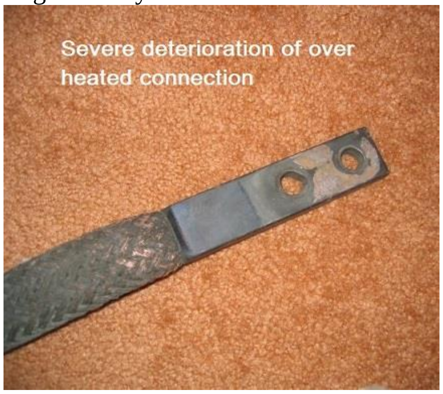


Photo 2. Arcing damage to flexible lead contact surfaces.

Photo 3. Arcing damage to bus connection surfaces.

A more serious joint failure is shown in Photo 4. Restoration of this condition would involve local cleaning, replacement of lost metal and reconditioning of the plated surfaces. Costs in outage time and repair would be modest.

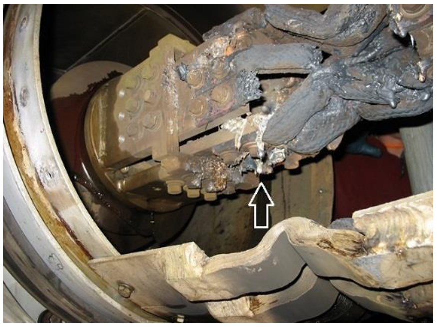


Photo 4. Failing flexible connection joint.

At the extreme high end of the damage spectrum is the failure of a new 900 MW generator shown in Photos 5-7.

Photo 5. Remains of failed connection.

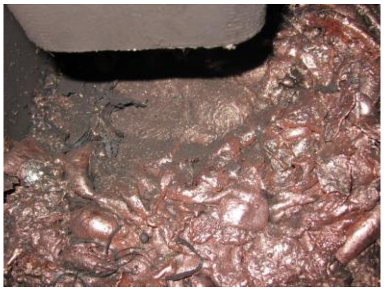


Photo 6. Many pounds of melted copper from this connection failure.

Photo 7. Resulting contamination to stator winding.

Repair of this failure involved installation of a new stator winding, field rewind to facilitate cleaning of winding, and extensive difficult cleaning of the core and frame. The total costs for repairs and 6 months of replacement power were remarkably high.

All of these conditions would have been readily detectable by periodic scan for radiated electromagnetic interference (EMI).

ASSESSING CONDITION OF ELECTRICAL EQUIPMENT

Assessing equipment condition can be difficult. The most powerful tool is visual inspection, but this often requires equipment shutdown and at least some disassembly. Thus high emphasis has always been on testing, with on-line testing preferred. For example, on a generator stator winding there are many such tests, e.g., several versions of over-voltage, various partial discharge (PD) systems, flux assessment, winding modal analysis, wedge tightness, numerous special tests of winding direct cooling systems, and electromagnetic interference (EMI) testing.

EMI testing may be done by either of 2 common methods. One method is referred to as Electromagnetic Spectrum Analysis (EMSA). The EMI signal is obtained from a radio frequency current transformer (RFCT) commonly placed on the grounding cable of the equipment in question. This full spectrum analysis, while valuable, does not have the ability to detect where a defect is located. Also it is difficult for the laymen engineer to interpret the signal with accuracy relative to severity and isolation. As a result EMSA use has been limited.

A second EMI method is the use of a hand-held "sniffer", and this will be the focus of this paper. Measurement of radiated EMI using the hand-held sniffer method has powerful condition assessment capability for electric equipment. However, it has also been a not well understood or widely used technology relative to power plant equipment. A common question revolves around the belief that a generator frame or bus enclosure acts as a Faraday cage that does not allow EMI to escape.

An actual radio frequency Faraday cage must be constructed of conductive materials with only a few well shielded openings. Commercial EMI-free rooms are often two layers thick with the layers insulated from each other and with both layers grounded at a single location. Special conductive gaskets and grounding methods are used at the doors and openings.

An example of a small copper “screen room” Faraday cage is seen in Photo 8. Larger shielded rooms have a magnetic or steel box inside the conductive or copper box; these are insulated from each other and grounded at only one common location.

Photo 8. Commercial Faraday Cage.

Power plant generators, motors, bus enclosures and switchgear are very imperfect Faraday cages. The strong EMI signals emitted by failing joints are able to pass through the enclosure. This radiated EMI field can be detected and measured with sensitive instrumentation. Both an electric, E field, and a magnetic, H field, will be present. PD for example will generate a strong electric field and arcing will generate a strong magnetic field. Maxwell’s equations state both E fields and H fields are always present.

This paper is narrowly focused on the use of the measurement of radiated EMI in detecting deteriorating electrical current connections. There is a reason for the narrow focus of this paper. Consider:
a) Many types of highly important deterioration can be detected by in-service EMI testing.
b) EMI testing is completely non-intrusive.
c) There is no danger to personnel or equipment.
d) Relatively small effort is involved as an entire turbine-generation and its associated electrical equipment can be comfortably assessed in an hour.
e) The saving from avoiding a single forced outage on a single piece of equipment can be huge.

DETECTING FAILING ELECTRICAL JOINTS IN A POWER PLANT USING EMI

Detection of EMI radiation in power systems for assessing condition of power line insulators dates back many decades. More recently its use in finding failing connections has been found to be very effective. The technology is basic and easy to understand, e.g., any poor electrical connection produces arcing. The arc will produce electromagnetic radiation of some strength, depending on magnitude of the arc and distance from the arc source. A small, hand-held device can measure the strength of this radiation.

Since arcing is a common deterioration mechanism where electric current is flowing, this type of monitoring is a potentially powerful tool for assessing power plant condition.

There are several devices on the market that will perform this function. Some are general function types of instrument; at least one is relatively narrowly focused on this target. This paper will discuss only the EMI equipment produced by Iris Power, Radar Engineers and Doble Engineering, although there are other systems available.

These devices will be discussed under the heading of the source of that equipment. It is hoped that this focus will not end up appearing as a commercial enterprise. There is no personal vested interest in these devices by the authors.

Iris Power TVA Probe

Iris Power, founded in 1990, is a global leader for condition-based monitoring, in particular partial discharge (PD) monitoring of stator winding condition. Their PD system is widely used throughout the world, their data record base huge, and their engineering support to their clients unusually high. [11]

Since 1997, Adwel (now a part of Iris Power) has manufactured one of the oldest (if not the oldest) radiated EMI instrument, the “TVA probe”, sold today as the Iris PPM 97. The TVA probe was developed by Smith as a version of the “Corona Probe” developed by Westinghouse in the 1950s [8].

The probe was initially used on hydro-generator stators to locate stator slot locations with high PD. The probe is placed across the stator slot and moved along the slot to locate areas of slot discharge.

The PPM 97 consists of an insulated shaft at the end of which is a sensor coil; the signal is read on a hand-held instrument. Photo 9.

Photo 9. PPM 97 Probe

The PPM 97 measures the magnetic field radiated from the slots due to PD activity in the slot. It is very sensitive to location and can pinpoint PD activity in a slot. Response is centered around 5 MHz.

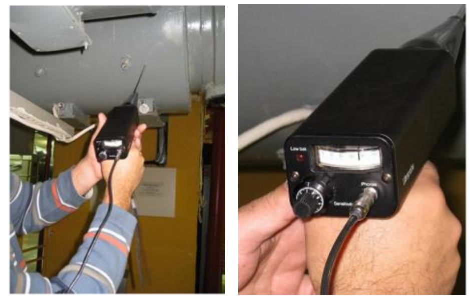
As a complimentary tool to Iris on-line PD instrumentation, the PPM 97 has been used both off-line and on-line in troubleshooting of insulated phase buses (IPBs), high voltage circuit breakers and bushings.

For example, during periodic PD data collection on a 200 MW pump-storage generator, high levels of external PD pulses were detected using the Iris on-line PD instrumentation. The plant personnel were advised to attempt localization of the source using the PPM 97 as a scanning tool on the IPB.

Since the generator was not in operation, the IPB scan was performed with one phase energized at the time, to 4000 V. (Line-to-neutral voltage on this unit is 9090 V) The source of high PD was quickly found to be at the location of line current transformers on C phase, with readings higher than the maximum measurement range of instrument. Photos 10a and 10b.

Photos 10a & 10b. PPM 97 measuring a bus EMI source.

This finding was verified by another tool, an ultrasound probe made by UE Systems, as shown in Photos 11a & 11b.



Photos 11a & 11b. Using the Ultraprobe™ assessing the acoustic noise that accompanies EMI

Visual inspection confirmed evidence of arcing between the current transformer supports and the bus conductor.

PPM 97 has also been successfully used in locating high PD sites emanating from generator breakers and on transformer and generator bushings.

<u>Doble Engineering Company</u>

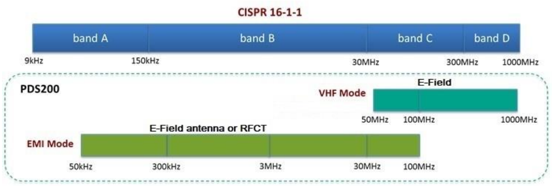
Doble has been an important participant in electrical equipment testing for nearly a century. They have provided high quality power factor insulation test equipment for so long that the test is usually referred to industry-wide as a “Doble test”.

Relative to EMI testing for joint deterioration, their EMI instrument is the EMI Surveyor, a PDS-200. Photos 12a and 12b. (In the Surveyor package they also include the Radar Engineers 246 equipment, to be discussed later.)

Photos 12a and 12b. Doble PDS-200 EMI Surveyor.

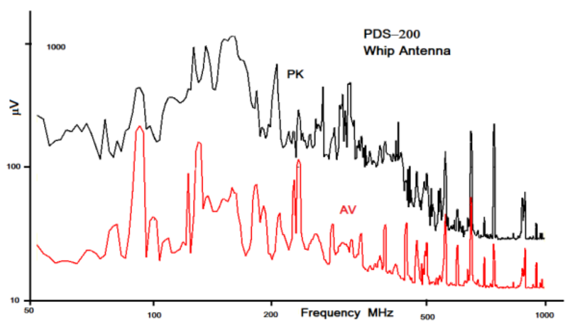
The device can be used to scan for radiated EMI or used with an RFCT for EMI signature analysis. Data is collected following the international standard, CISPR 16. This permits direct comparison with data collected from other instruments that follow this protocol. The frequencies covered are shown in Table I. The band from 50 kHz to 100 MHz is the most useful for electrical equipment found in industry.

Table I



The PDS-200 has a higher range available and can go up to 1000 MHz which is most useful in high voltage and UHV switchyards. A whip antenna is used for the E field radiated EMI scan.

A useful Doble feature is the comparison of data collected with different detectors. The curve below shows the 50 MHz to 1000 MHz ambient signals outside a plant. The peak, PK and average, AV detectors are used. The AV detector is useful in identifying transmitters. These are the spikes on the curve. Those on the far right are cell phone towers.



Spectrum curves with different detectors.

Radar Engineers

The present instrument is identified as 246A, and is shown in Photos 13a and 13b.

Photos 13a and 13b Radar 246A instrument.

This is a small device weighing less than a pound. It is versatile and can be used in the low sensitivity range on the magnetic, H field antenna. The higher sensitive is with the LF/HF/UHF, electric or E field antenna. It has 12 ranges of gain and a 10 LED bar graph; both are log scales resulting in a wide sensitive range.

The instrument comes with detailed written instructions for use in a power plant. Thus the device can be used by a competent engineer without formal on-site training.

The 246 has been in use since about 1980. But wide-spread application has been limited due in part to lack of knowledge of its availability and capability.

Searching for EMI emissions with this hand-held device simply involves walking around the plant equipment in question and observing the output of the device. Photo 14. A typical generator or bus can be scanned in a few minutes. Historical experience suggests that roughly 90% of typical equipment failure modes emit detectable radiation EM energy, thus accounting for the extreme value of the test.

Photo 14. Ambient Radiated Survey with 246.

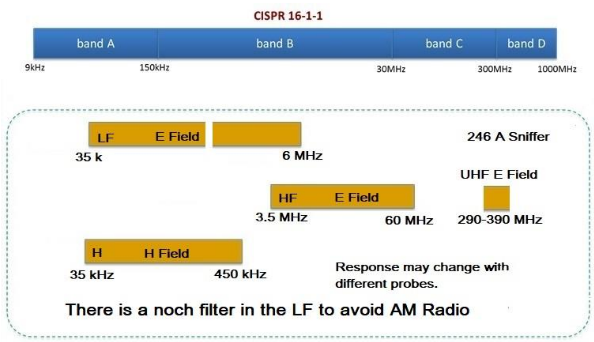
By observing the location and magnitude of detected signals it is possible to make valid judgments relative to the nature of suspected deterioration. Based on this information, necessary inspection and additional tests can be planned to reduce the likelihood of further damage and/or forced outage on the specific piece of plant equipment.

With careful following of the instructions supplied with the device, an operator can perform the necessary scans throughout the power plant. Photos 15 and 16.

Photo 15. Checking the end of a generator for radiated EMI.

Photo 16. Checking a bus for radiated EMI.

Table II



246A Sniffer Ranges

There are several gaps in the 246A response; these are in place to avoid common radio transmitters.

In spite of limited use, the 246A and predecessors have found many dozens of actual defects ranging from minor to serious.

A particularly important case involved a large generator that had extensive repairs to the bushings in the terminal box. (The case discussed in Photos 5, 6 & 7.) After the machine was returned to service, the plant electrical maintenance superintendent was concerned about the bolted joints of the new connections. An expert operator was retained to bring in a Radar Engineers 246 instrument in order to check the newly installed bolted joints. Significant EMI signal was readily detected from arcing of the new joints. There was no difficulty detecting the signal through the imperfect Faraday cage of the generator bushing box.

When the mica insulating tape was removed, joints inside the generator showed signs of high temperatures. This resulted from the arcing detected by radiated EMI. The connections were repaired and proper bolt torque applied this time. Photo 17.

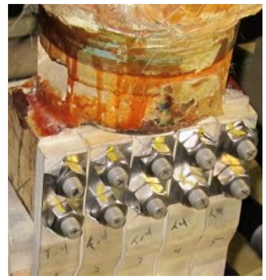


Photo 17. New bolted joint.

An example of a serious bolted joint failure is shown in Photo 18. This neutral bus was replaced with a new design and a scheduled generator EMI scan was performed several months after returning to service. Radiated EMI readings were extremely high near the generator neutral. Since the bus was "new" the recommended inspection was not performed. The jumpers melted after less than a year in service. Repairs and lost production were very expensive.

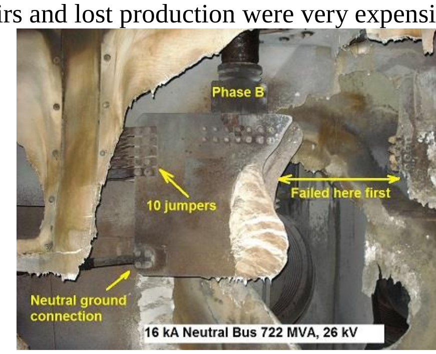


Photo 18. Failed Neutral bus

Deterioration of connections in switchgear has also been detected. Problems with connections to bus potential transformers are a common problem with some designs. In Photo 19 the radiated HF scale indicates no activity at the bottom where the breakers are located. However along the top where the potential transformers are located the readings were high. An inspection to correct the bad connections will prevent a failure.

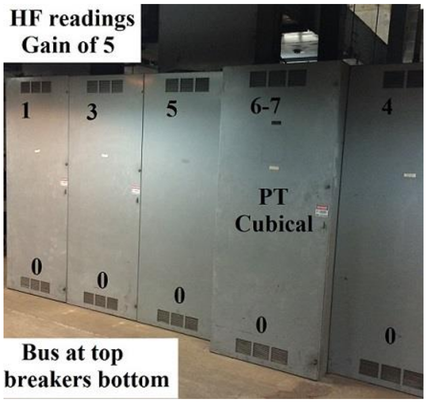


Photo 19. Scan results for 6.9 kV breakers.

A variety of conditions have been detected inside generators, bus and switchgear. For example:

1. Loose bolts on center conductor
2. Loose bolts on enclosure
3. Loose disconnect switch parts
4. Broken high current shunts
5. Defective PT connections
6. Open fuse links
7. Defective breaker contacts
8. Contaminated insulators
9. Cracked and loose insulators
10. Shorted enclosure insulation
11. Foreign objects inside enclosures
12. Loose connections to surge pack

CONCLUSION

Radiated radio frequency EMI energy from defective electrical joints can be detected and the source localized with the use of devices readily available. Corrective actions can then be taken well before a failure can develop.

The dollars returned for these scans for radiated EMI are orders of magnitude more than the cost of the tests.

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