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PD technology for on-line insulation testing in power generators / motors and experience in Iranian power stations

M. Kotlica
International LTD
Toronto Canada

Mr. D.Hekmatshoar
MATN Research Inst
Tehran - Iran

Mr. K. Rahmani
.NEKA Power Generation
Neaka -Iran

Abstract:

The requirement of any power generating utility is to achieve reliable and trouble free power generation in their facilities. Systems for on-line quality and reliability assessment of High Voltage power equipment have became very popular in recent years. By having access to power equipment while in normal operation, plant engineers have been able to avoid catastrophic in service failures, costly forced outages of power generators and associated equipment, as well as prolong significantly the life of the equipment. By early detection of developing problems on power systems, maintenance can be scheduled promptly and only when necessary. Planning of work and resources can be done well in advance, which will tremendously reduce the cost of such intervention. Also by performing test before and after repair it is easy to control the effectiveness of repair. On-line monitoring systems which are non destructive, reliable, quick and easy to use, have in fact become a kind of standard in many power utilities worldwide. A major problem in HV power equipment is electrical insulation. One on-line tests for the integrity of power equipment is thePD (Partial Discharge) test for electrical insulation. The PD test besides testing power generators and motors is also applicable for factory screening of stator bars, testing HV power cables and power transformers.

Introduction

One of the major factors in the aging of stator insulation is electrical stress, which in turn causes "sparks" resulting from flow of electrons and ions when a small volume of gas breaks down. The discharge is partial since there is a solid insulation in series with the air gap where discharge occurs, which prevents complete break down. Partial discharge damages are usually accompanied and aggravated by thermal, mechanical and other stresses acting on the stator winding. While partial discharges may not affect the break down voltage during a high voltage "proof" test, deterioration of voids or gaps in the stator insulation as a result of partial discharges will eventually cause failure on most high voltage machines.

Partial discharge pulses are very fast

phenomena which originate with a duration of at most a few nanoseconds. However, the signal detectable outside the machine depends upon the nature of the propagation path at the site of the PD. The medium in which the PD occurs also plays a significant role in the rise time of PD pulses. Pulse rise times are much faster in electronegative gases, such as SF6 than in other gases such as H2 or air. When associated with AC voltage in HV machinery, PD pulses are superimposed on sinus wave.

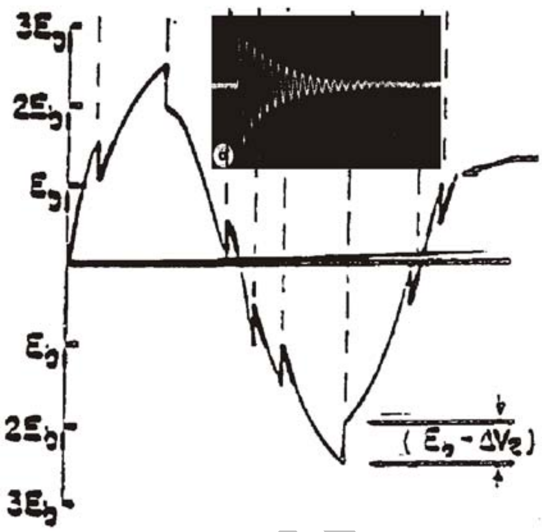

Figure 1. PD pulses imposed on sinus wave and a typical PD pulse

They are mostly located between 0-90 degrees and 180-270 degrees of related sinus wave. By frequency filtering HF pulses are extracted, picked up by the PDA sensors, and transmitted to a PD instrument where they can be sorted and counted. Special precautions have to be made in order to prevent the pulses from other sources from interfering with the partial discharge pulses from monitored machine

PD Pulse Transfer through Generator Winding

The extent to which PD pulses propagate through stator windings is an important factor in the measurement of PD activity. Partial discharge pulses are very fast phenomena which originate with a duration of at most a few nanoseconds. However, the signal detectable outside the machine depends upon the nature of the propagation path at the site of the PD. Fast pulses propagate throughout much better than a low rise time pulses. This type of propagation through stator winding is also associated with a "capacitive transmission" within the winding. The following test was conducted on 355 MVA, 13.8 kV, 60 Hz hydro generator, with characteristics as follows:

Total number of slots: 864.
Total number of bars:1728
Rotation speed:81.8 rpm
Number of poles:88
Stator Core Diameter16 meters
Stator length:2.2 meters
Parallel circuits per phase8

Injection points were winding jumpers as in Figure 2. Typical responses are shown on Figure 3. Fast square wave pulses, having a rise time of less than 3 ns, were injected through the capacitors of roughly 300 pF, attached to the phase jumpers. The response was recorded using an 150 MHz oscilloscope attached to the HV end of the parallel. The test showed that pulses were capable of propagating through the winding, even when they were injected in the very far end (neutral end) of the winding parallel. Attenuation was not found to be so high to completely attenuate the pulses traveling from opposite end of the winding. Of course, the measured pulse magnitudes and rise time of the pulses were significantly lower when pulses were injected further from the HV end. Similar conclusions were drawn from some other tests conducted on different stator windings.

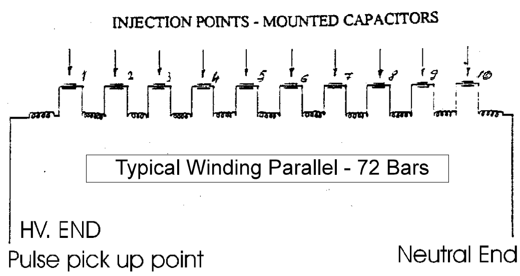

Figure 2. Pulse propagation test setup

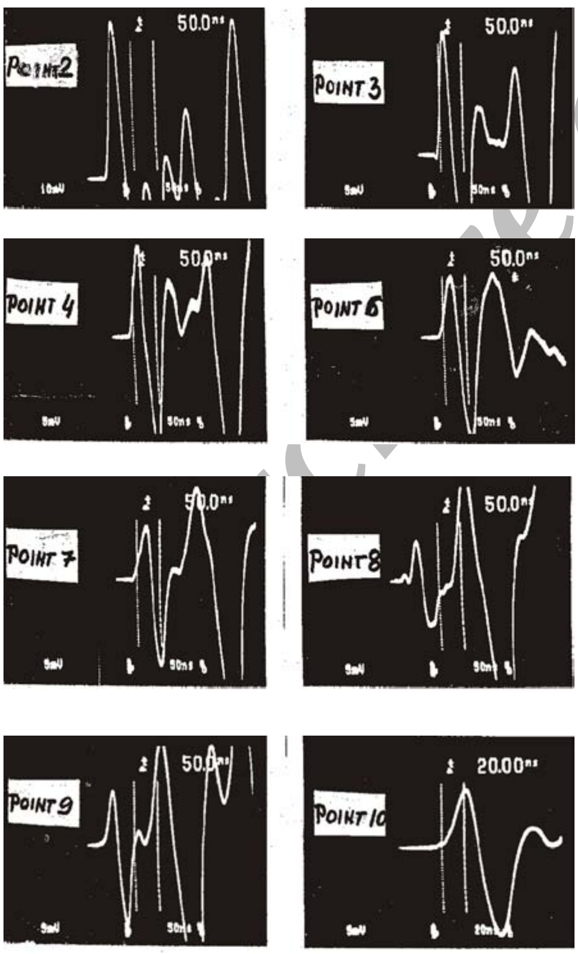

Figure 3. Typical responses on different points of the winding parallel.

PD Test Systems

There are many different systems for PD acquisition . Different PD sensors can be employed either on line end of the winding or on neutral end. Depending on the instrumentation used and noise cancellation techniques, PD sensor installation is different. The most commonly used method for PD acquisition was introduced 20 years ago by Canadian Electricity Association (CEA). The capacitive PD sensors are connected to the phase jumpers inside the generator (differential configuration) or to the outcoming phase terminal bus (directional configuration). The electrical noise usually present in the power house environment interfere with the Partial Discharges from the machine.

Cable type capacitive sensors along with "common mode noise rejection technique" were successfully used over the years in the differential configuration and accepted by many power generation utilities worldwide.

Importance of Temperature Stabilization

PD testing should be done under thermally stable conditions, since the test pattern in transient periods is changing rapidly and PD test results are mostly inconclusive. That is related to thermal expansion of the stator bars and rapidly changing conditions (volume, pressure, temperature) inside the air voids with "spark" activity. When generator reaches thermal stability (normal working "hot" stage) some of the "active" voids will reduce in size significantly and initially present Partial Discharge will cease. That is mostly result of electrical stress not being high enough to continuously have a spark in the voids which reduce in size during the thermal expansion of the stator bars. As a result of these phenomena the test results in "hot" condition, when related to PD inside the solid insulation, are mostly lower than in "cold" or transient conditions. Of course, as being quite complex phenomena, some types of discharges will have different temperature dependent trends.

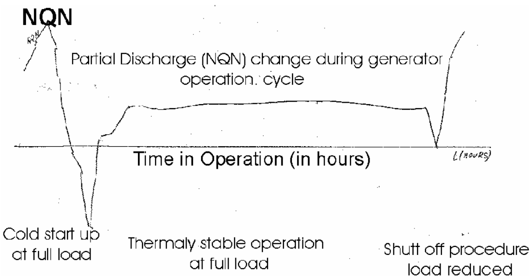

Figure 4. PD Test taken during 10 hours of operation - from cold start through thermally stable stage to shut off

The diagram on Figure 11 was recorded during the 10 hours of operation of a 250 MVA picking unit. At the cold start up, PD test results were irregular and inconclusive. The measured PD activity varied from 20% to 300% of the PD test results after the temperature stabilization. After approximately 3-4 hours of full load operation the PD test was showing signs of stabilization and tests results were repeatable. During the normal full load operation after the thermal stabilization PD test was completely stable, and results were similar. After the load was reduced and unit entered cooling period before the shut down, the PD test results become irregular and inconclusive again. It clearly indicates that PD test should be, as explained, taken under thermally stable condition.

Experience from Iranian power stations

Since the beginning of PD technology use in Iranian power market, generators at NEKA power generation corporation were installed with PD sensors as well as the power motors in the same power generation station.

Also 3 largest generators at Rey power station were also furnished with PD sensors.

All installations are done using directional PD mode, which means that PD sensors are installed on phase bus attached to generator (motor). Directional PD installation is convenient for turbo generators as space inside the generator is restricted for different reasons.

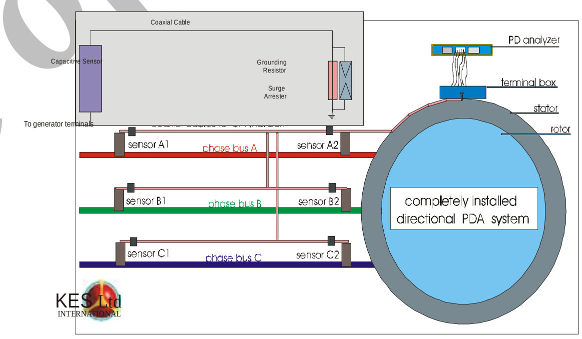

Figure 5. Installation Diagram - Directional Type

The first sensors A2, B2, C2 were installed on the phase bus exit from the generator. The most convenient place was CT cubicle on the top of each generator. The other set of sensors A1, B1, C1 were installed approximately 4-6 meters away on the enclosed phase bus. PD sensor connections were done similar to ones on the photographs 5 and 6.

Figure 6. PD sensors - A2, B2, C2 on generator phase bus

As the first set of PD sensors was installed right on the phase bus exit from the generator winding housing (sensors A2, B2, C2) and the other set of sensors approximately 4-6 meters away - downstream along the enclosed generator phase bus, this is the optimal distance in reaching the good PD results. The enclosed phase bus is free of any attachments to it in between two sensors of the same phase. This ensures the accuracy of the test results and noise free PD test results. The commissioning with the accuracy of 1 nanosecond ensures maximum elimination of eventual external interference.

As for the motor's PDA installation at NEKA power station, special smaller PD sensors were manufactured to fit tight spaces in motor terminal boxes.

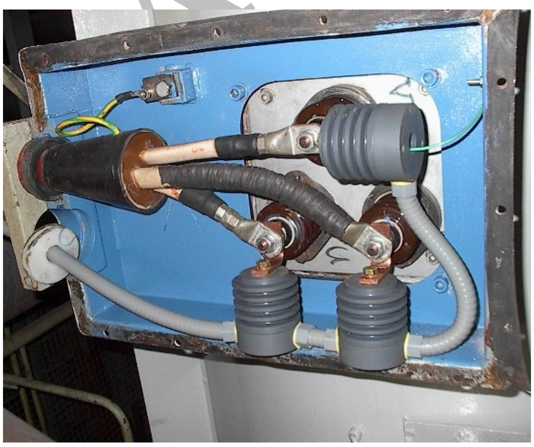

Figure 7- 90 mm PD sensors inside motor box

Figure 8 – 120 mm PD sensors inside motor box

As PD sensors were specially manufactured for known size motor terminal box, they fit perfectly on the motor terminals and allowed perfect distance and length of coaxial cables to PD terminal box. PD terminal box itself was installed on motor housing.

PD test results at NEKA power station

The turbo generators 1, 2,3,4 at NEKA power station of 500MVA each are the largest in Iran. They are hydrogen cooled with operating hydrogen pressure classified as medium high. As it is known Partial Discharges PD are dependent on gas pressure. They are also different in different gases (air and hydrogen). For that reason it is not possible to compare PD test results from air cooled generator to the results of hydrogen cooled generator under pressure.

In general PD activity is much lower with higher gas pressure. For that reason generators with higher gas pressures have lower PD activity compared to the same type generators under atmospheric pressure or

under lower pressure. Typical PD test results from

generator #4 are as per figure 9. Typical PD test results from generator #4 are as per figure #9.

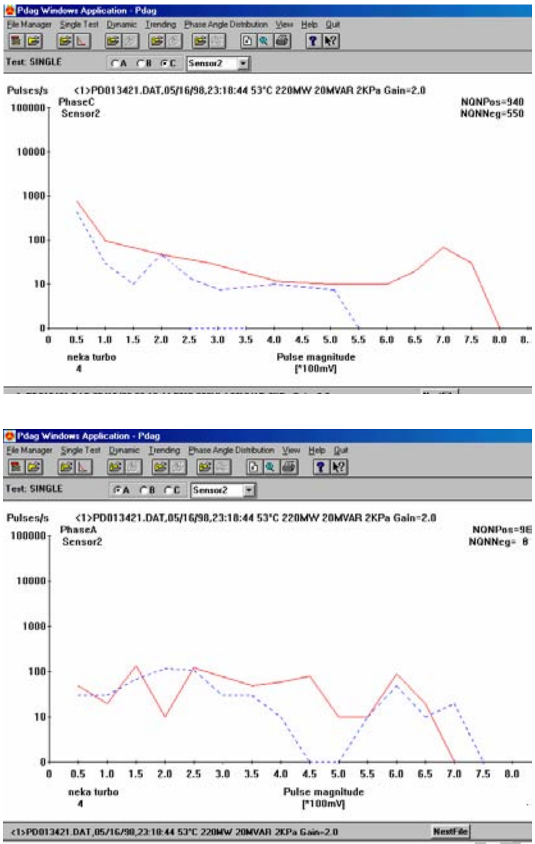

Figure 9. typical PD results from generator #4

According to experience, this type of graphs indicate several problems in generator winding. Semiconductive layer problem is obvious in all phases which roduces surface (insulation to iron slot) discharge. Looseness of the stator bars in the slots is also expected, along to contamination of end-winding. Visual inspection and eventual corrective action should be taken to partially solve the problem. Generally, this levels of partial discharges are considered high and further consideration is needed soon.

Based on the condition of the generator winding, size and importance of these 4 large generating units the best solution will be to install automated continuous PD monitoring system PDA-Watch. PDA-Watch will monitor generator continuously 24 hours per day and automatically prevent any sudden failure of this generator.

10 motors used in Neka power plant were installed with PD sensors and tested on PD. In general PD are low and motors are considered being in good conditions. Typical graphs from these motors are as per figure 10.

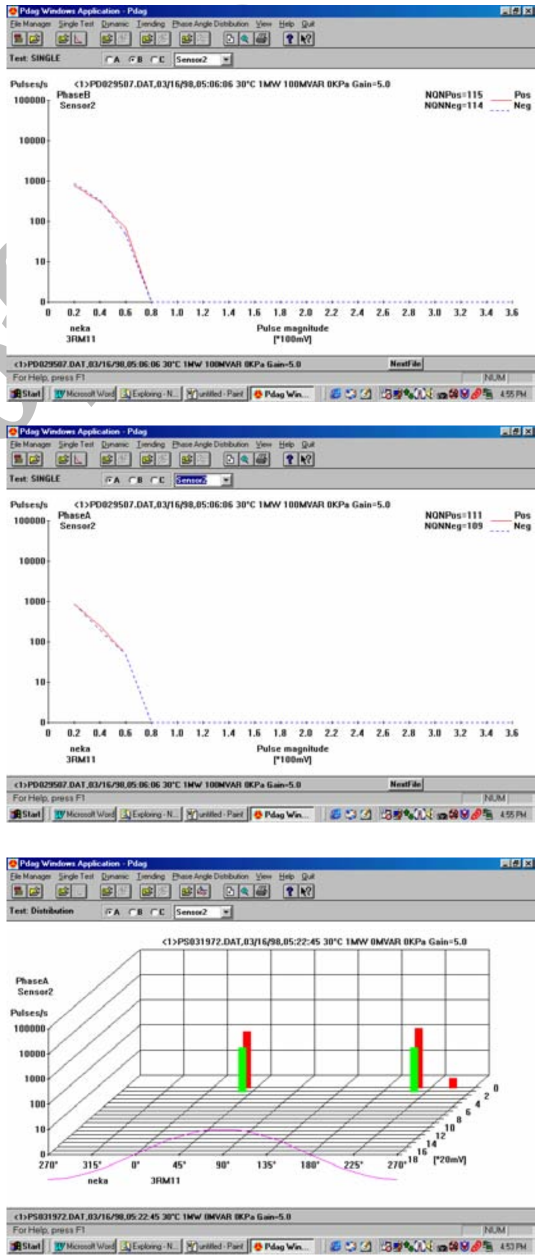

Figure 10. Typical PD graphs from motors at Neka

As most of the discharges are with equal positive and negative levels about equal it shows presence of voids within the solid insulation (ground-wall), which is typical for hard epoxy resin or similar insulation.

At Rey power plant PD sensors were installed in 3 100 MVA turbo generators. These generators are air cooled.

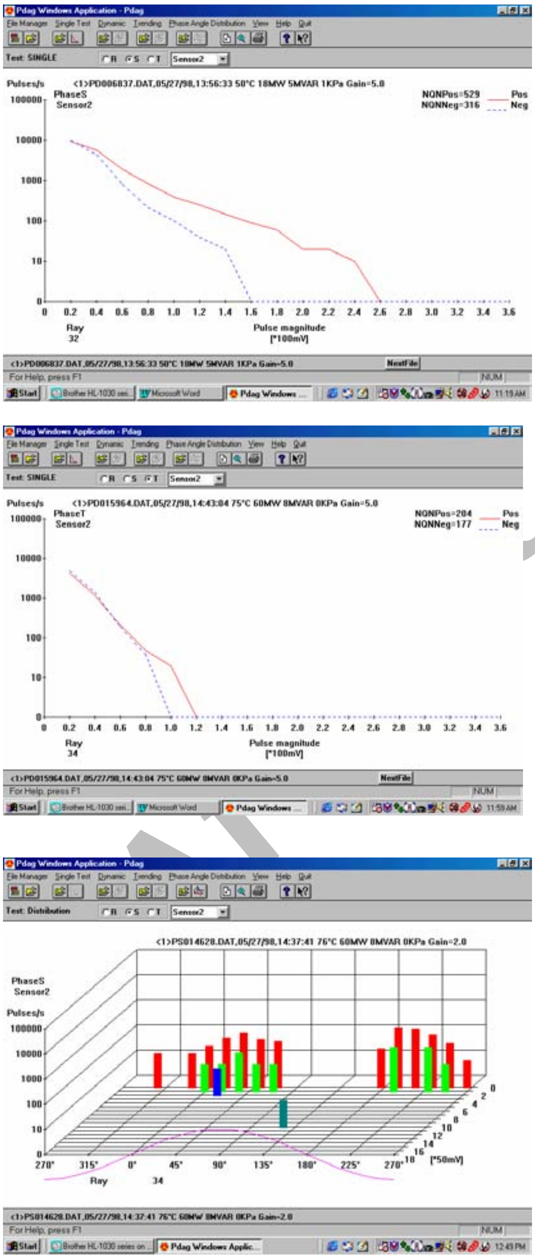

Figure 11. Typical graphs from 100MVA generators at Rey power plant

Initial test showed low PD activity and generators are considered being in good conditions. All three generators have the same type of pattern (positive PD predominant over the negative). That indicated damages in semiconductive layer inside the slots. This type of damage is present in all phases. Considering the age of the generators, operating mode (picking load), insulation is considered good.

Conclusion.

Partial discharge PD test is very convenient and quick way for initial quality assessment of generator windings. Special advantage is that PD test is taken on-line, during regular operation when all electrical and mechanical stresses are present in the winding. That ensures accuracy and reliability of winding condition assessment. As for these reasons, PD test has become the standard in the industry.

Most of power utilities over the world today use this test as the most convenient and reliable method for testing high voltage winding condition

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