A Study of On-line Monitoring System for a KEPCO Pumped Storage Generator/Motor

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An on-line diagnostic test has been studied and performed for the pumped storage generator/ motor. This study aims at reducing the diagnostic cost, minimizing the technical dependency on third party manufactures. Further design of on-line diagnostic system such as shorted-turn of rotor winding, partial discharge (PD) of stator winding and air-gap between stator and rotor for pumped storage generator/motor has been verified. In addition, it needs to be validated on site performance of the developed continuous on-line monitoring system for corresponding tasks for the improvement of the availability & reliability during operation.

Keywords : Hydro generator/motor, Life management, Condition monitoring and assessment, Electrical winding insulation, On-line diagnostics, Partial discharge

1. INTRODUCTION

1.1 Objective of the study

Concerning improvement of the reliability as well as availability of power generation system operation, on-line diagnostic tests have been studied and carried out for the hydro-generator/motor set. Scope of this study is briefly described as follows:

1.2 Scope of the study

To improve and strengthen the reliability and availability of the power system it is introduced a new insulation tests and condition assessment techniques to reduce maintenance costs integrated computer database and asset management systems. That will be based on advanced information technologies and new techniques to identify aged equipment and assess the failure risks based on application of emerging technologies for condition monitoring

In this paper assessments of some corresponding application research works and their validity have been also identified in conjunction with a certain selected feasible and effective partial discharge coupler, and some proper shorted-turn- and air-gap sensors respectively.

Further field tests for development of partial discharge capacitive couplers; shorted-turn and air-gap diagnostic algorithm has been researched for usefulness.

A research work of on-line partial discharge, shorted-turn and air-gap monitoring system in this concerns was performed for incipient fault diagnosis and aging process and failure analysis for remaining life prediction and insulation pre-breakdown symptom analysis respectively.

A proper on-line measurement has been also shown for a pumped storage generator/motor power system, namely with KEPCO Samrangjin pumped storage generator /motor #1.

In order to verify the reliability of an appropriate shorted-turn monitoring system, an investigation into the mechanism of failure phenomena, several field tests have been demonstrated, and the effectiveness of tests were conducted based on new monitoring systems, using PDA and a Digital Oscilloscope for partial discharge detection, location and pattern analysis respectively.

Further on due to limit of available space reporting those concerned works here, so thus only some part of this corresponding extensive R&D works are to be presented and to be discussed in this paper[1,2].

2. ON-LINE MONITORING AND DIAGNOSTIC SYSTEM

The stator of a pumped storage generator/motor is generally consisting of 4 stator cores winding in parallel. For the detection of PD, 2 couplers of each phase, in total 6-cable coupler (80pF, ADWEL Inc.) are installed. Using time-of-flight (difference between time intervals) methods transferring input signal, corresponding measuring system can be performed to measure only PD magnitude and PD pattern after removing noise signal.

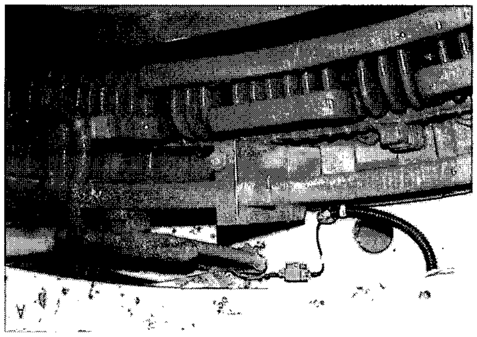
For on-line monitoring and in order to test of stator core winding during operation, PDA and the developed CMS (continuous on-line monitoring system) are used to detect PD magnitude and number of PD, PD pattern shape, etc. for the purpose of insulation diagnosis.

For measuring and detecting a possible shorted-turn in stator, an air-gap flux probe (Generatortech Inc.) has been mounted. In further in order to measure air gap between stator and rotor, 4 pieces of capacitive sensors (VM 5.0, Vibrosystm.Inc.) have been installed at intervals of 90 ° degree apart in clockwise. So thus using the developed system, possible shorted turn of rotor core winding and its eccentric displacement grade between two parts could be on-line monitored and analyzed continuously.

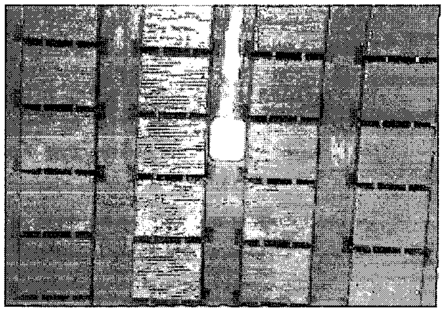
Figure 1 depicts the corresponding installed PD sensor (a) and flux probe (b), and air gap sensor(c).

For measurement of tanδ and PD test with standstill generator/motor set, a coupling capacitor, a Schering Bridge, a partial discharge detector (PDD, Tettex Instruments TE 571) is employed. Measuring system with Schering Bridge is consisted of a power supply (HV supply, Type 5283), a bridge (Bridge, Type 2818), a resonating inductor (Resonating inductor, Type 5285). A brief overview of schematic block diagram for measurement and test system is shown below in Fig. 2.

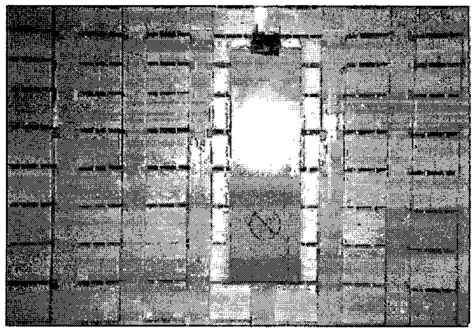
Connecting generator/motor core winding to terminal of Schering Bridge, and by putting into it with the AC alternating current supply, input signal included corresponding information is sent to coupling unit (Coupling Unit, Tettex Instruments AKV 572) for signal amplification by coupling capacitor. Using this PD signal and PD patterns are to be analyzed and evaluated. The frequency bandwidth is provided with 40 ~ 400 kHz.



(a) Installed PD sensor



(b) Flux probe



(c) Air gap sensor

Fig. 1. Sensor installation.

3. ON-LINE CONTINUOUS MONITORING AND SUPERVISION SYSTEM

An constructional overview of an on-line monitoring & supervision system of a pump storage generator/motor set is demonstrated in Fig. 3, in which has included with a data acquisition system, a gateway, a main server system, 2 display PCs connected to local area network system.

As mentioned above the system is organized with components by the sensor for detecting corresponding information, data acquisition system gathering necessary information to be processed, and a gateway managing jobs between different system levels (lower -, upper levels), a main server system, display PCs respectively.

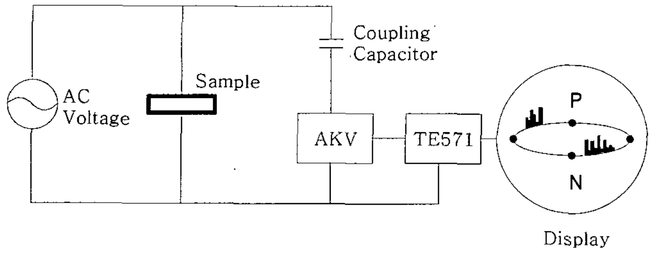


Fig. 2. The measurement of partial discharge.

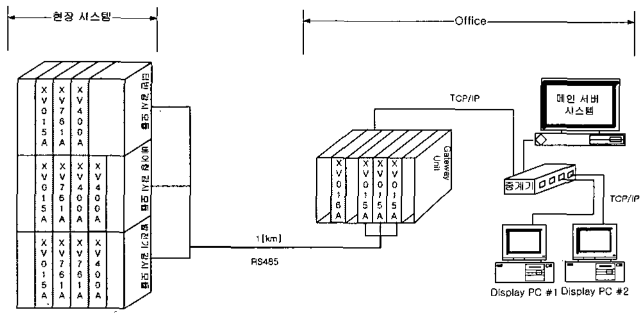


Fig. 3. The diagram of continuous monitoring system for hydro generator/motor set.

4. EXPERIMENTAL RESULTS

4.1 Air gap

The measured result is depicted in Fig. 4, the information of eccentric displacement, location between rotor and stator position can normally be identified by developed system respectively. After inspection of corresponding generator/motor set, it is found that the system has maintained in good normal condition without any irregular change.

Using periodical inspection and continuously on-line monitoring, the trend of possible abnormal change of operational machine condition could be checked whether or not the abnormality.

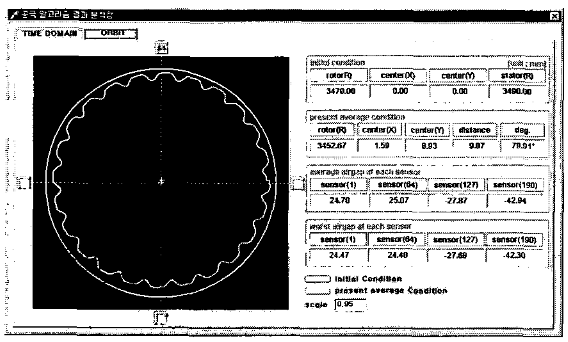


Fig. 4. The measurement results of air-gap.

4.2 PD analysis of stator winding

Using PDA and on-line condition monitoring system based on the cable coupler installed in generator/motor set (18 kV, 336 MVA), the PD characteristics has been measured and analyzed during machine operation.

In further externally delivered AC test voltage/power into stator core winding, and comparing PD test result in case of operational condition with its opposite case value during standstill condition, possible abnormal change of PD magnitude and individually occurring number of PD and its characteristic PD pattern have been studied and validated. In further degradation degree (rate, extent, condition) due to $\Delta\tan\delta$ and appeared PD has been collectively analyzed.

4.3 On-line PD analysis under operation

In Fig. 5, Fig. 6, and Fig. 7, there has been illustrated of some PD pattern characteristics and NQN (normalized quantity number) on A-, B-, and C Phase during various operational conditions respectively. There a PDA has been provided for measurement and analyses of these results.

After evaluation of PD pattern characteristics of each phase respectively, and due to the reason that phase A and C have shown a PD magnitude with positive polarity rather than negative one, its pattern are characterized as a slot discharge. A partly relative internal movement between ground-wall insulation and slot causes to arise abrasion, resulting for insulation damages of semi-conducting coating. So thus partly weakened condition of ground-wall insulation against earth leads to gathering electric charge on the surface, which cause to generate discharge between machine winding and iron core.

So, consequently this kind of electric discharge between the surface of stator core winding and the iron core is conducted (lead, cause) to develop relatively large amount of electric energy. These discharges lead to produce ozone, and insulation material of stator core winding and rubber material are to be intensively oxidized and damage.

On the other hand in case of B-phase, because PD magnitude in positive polarity has higher value than PD in negative polarity, PD pattern could be recognized as discharge at conductor surface.

Surface discharge appears in a void between core winding with ground-wall insulation and strand insulation. That is built up by the space or gap between strand insulations where have not been completely filled with the impregnation varnish or (synthetic) resin partly as well as an intersecting point of spread strand insulations.

The small void can be formed by thermal cycle during normal machine operation, and it has come into existence with copper conductor separated from ground-wall insulation as well. PD generated by small void

Table 1. Measurement of on-line PDA and CMS output.

Phase	NQN/Qm[mV]	PDA	CMS
A	NQN (+)	460	586
	NQN (-)	306	570
	Qm (+)	380	305
	Qm (-)	341	285
B	NQN (+)	548	643
	NQN (-)	555	597
	Qm (+)	435	355
	Qm (-)	488	445
C	NQN (+)	429	483
	NQN (-)	277	425
	Qm (+)	378	220
	Qm (-)	321	240

develops and grows into an electrical treeing. It leads consequently to wear the ground-wall insulation, strand insulation, and turn insulation respectively and conducts to have a short circuit for strand insulation - strand insulation and turn-turn insulation respectively.

As it can be seen in Table 1, using PDA and corresponding developed system during operation condition, the results of measurement of NQN and magnitude (Qm) of PD has indicated that its value of magnitude in Phase B has shown the highest one, lower downward in the order of Phase A and Phase C each. So thus the insulation condition in Phase B has been deteriorated and degraded most of all, and it means that in sequence of Phase of A and C the deterioration proceeding grade (rate) is lowered and minimized.

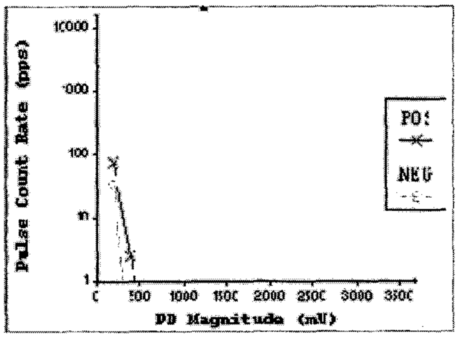
According to analyses per each phase with measured value Qm by PDA, the result shows the worst case of phase B has Qm (+) < 435 mV and Qm (-) <488 mV in each, however the condition of stator core winding found satisfactory good progress.

Based on the developed system and PDA during operation, PD test are performed. Due to different characteristic frequency band of measuring instruments the measure value of NQN presented some differences, however these measured PD signal is agreed with those one using PDA in all 3-phase cases respectively.

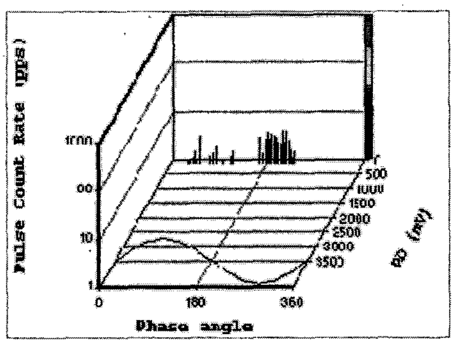
4.4 Δtanδ and PD analysis during standstill

PD and Δtanδ test of a pumped storage generator/ motor set with more than 20 years operating history has been performed and inspected after dismantling of phase terminal connection at standstill operational condition.

The average value of possibility of PD appearance, starting voltage value of PD process, PD production quantity respectively could be assumed by measuring and analyzing the characteristics of Δtanδ and PD.

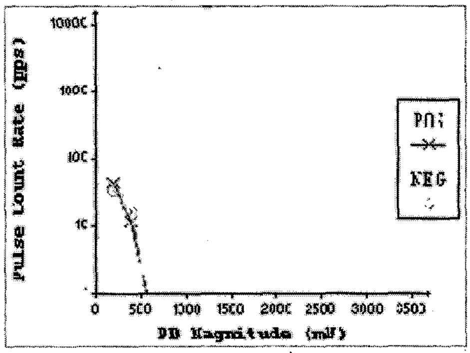


(a) 2 dimensional measurement

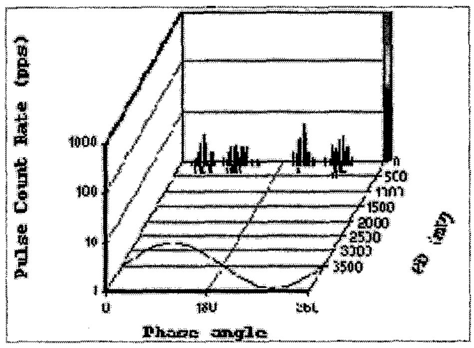


(b) 3 dimensional measurement

Fig. 5. Partial discharge pattern using PDA in phase A.

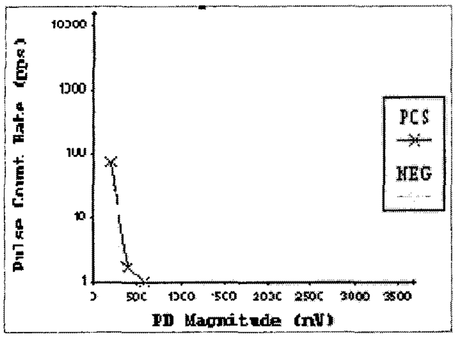


(a) 2 dimensional measurement

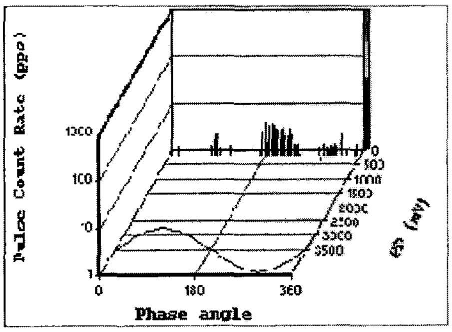


(b) 3 dimensional measurement

Fig. 6. Partial discharge pattern using PDA in phase B.



(a) 2 dimensional measurement



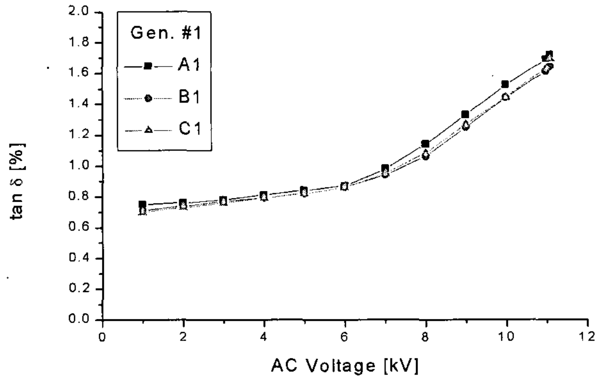
(b) 3 dimensional measurement

Fig. 7. Partial discharge pattern using PDA in phase C.

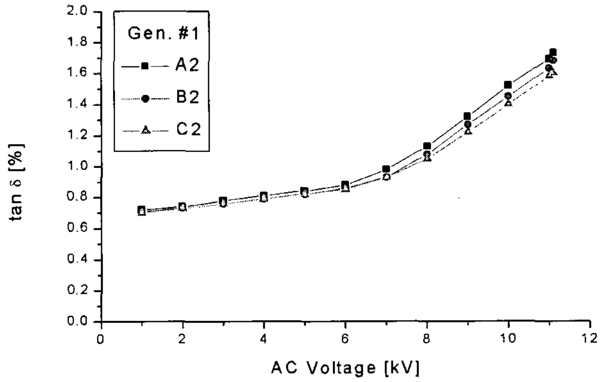
In Fig. 8 it is demonstrated Δtanδ-voltage test characteristics as AC Voltage is raised up to 11.1 kV. Δtanδ has the values of 0.96 %, 0.90 %, and 0.96 % in A1-, B1-, and C1 phase respectively. A2-, B2-, and C2 phase 0.99 %, 0.95 %, and 0.87 % respectively. Due to very small value of Δtanδ and good characteristics of Δtanδ test, it is recognized that the internal status of stator core winding insulation has maintained to keep a good condition. According to tanδ-voltage characteristic, the value of Δtanδ test is increased rapidly at point of 7.0 kV. PD process is starting around this voltage value, and therefore it is expected that the production quantity of PD will be a smaller amount due to slow rate of increasing PD pattern.

During PD measurement test, line noise is detected by about 1.3 nC in each phase. PD starting voltage provides 8.9 kV, 8.9 kV, and 8.8 kV per each phase, and A2, B2, C2 phase 9.5 kV, 8.6 kV, and 8.5 kV respectively. In further the magnitude of PD based on phase voltage presents, for A1, B1, C1 phase, 2.7 nC, 3.1 nC, 2.5 nC and A2, B2, C2 phase, with 2.3 nC, 2.5 nC, and 2.0 nC respectively.

PD magnitude at standstill precedes the largest value in Phase B, and analyzed downward smaller in order A, B, C phase in each. Therefore it is confirmed that the measured PD magnitude and PD pattern during standstill of generator/motor is agreed mutually with those value of PD Pattern and magnitude during normal operation.



(a) A1-, B1-, C1 phase



(b) A2-, B2-, C2 phase

Fig. 8. The tanδ-voltage properties of the pumped storage generator/motor.

5. DISCUSSION OF EXPERIMENTAL RESULTS

5.1 On-line PD analysis of stator windings

During normal machine operation, tests have been performed with partial discharge analyzer (PDA-IV) in three hydro generators. Six cable couplers were installed in the ring bus as well as within hydro generator terminal box. PDA showed that the normalized quantity number (NQN) and the partial discharge magnitude were very low in hydro generator #1.

The comparison of positive to negative PD indicates whether the defect elements of PD are within the insulation or on the insulation surface. Discharge at conductor surface was discovered in B phase of hydro generator #2 at the rated voltage. Internal discharges were generated in A, B and C phases of hydro generator #1 and in A and C phases of hydro generator #2. Slot discharges occurred in A, B and C phases of hydro generator #3. PD patterns were displayed two-dimensional and three-dimensional. These hydro generator stator windings were in good condition.

5.2 R&D of continuous monitoring system for pumped storage generator/motor

Continuous monitoring system (CMS) has been developed for the pumped storage generator/motor. The CMS is applied to diagnosis of the PD activity of stator insulation, the shorted-turn of rotor winding and the variation of the air-gap between stator and rotor. The CMS consists of DAS (data acquisition system), main server system, gateway and display PC. The DAS measures the PD, the shorted-turn and air-gap from three sensors installed on the generator/motor. The gateway controls the data, which sent by DAS. The main server system saves the data, analyzes the data and conducts the diagnostic algorithm. The display PC shows the diagnostic results of partial discharge, shorted-turn and air-gap. Field tests were conducted using PDA. The results of the CMS and PDA measurements can be directly correlated with normalized quantity number (NQN), PD pattern and PD magnitude (Qm).

6. CONCLUSION

In this report we have developed an on-line continuous diagnostic system for the KEPCO hydro power generator/motor set, in which consists of DAS, computing main server, and gateway and display PC respectively, in view of further extension and R&D works into power generation condition monitoring system regarding an integrated (wireless) LAN. The system performs on-line partial discharge measurement, detecting shorted-turn, and monitoring air-gap abnormality respectively for the pumped storage generator/motor.

For the verification of corresponding R&D works, different tests were performed at the Samrangjin hydropower plant #1. The tests were conducted using new monitoring systems, PDA and digital oscilloscope. We have also studied and evaluated an analysis method that can identify insulation conditions of the rotor and stator in each. The reliability of this system was acquired by comparing with third party originated measurement equipments. This system will replace those instruments and equipments and will be used as insulation condition monitoring system for the generator/motor set. Most of the results in this paper are taken from the previous R&D reports of KEPRI[1,2] and It has been also presented and discussed during CIGRE2004 SC A1 Group session meeting in Paris[4].

Further on the recent topic of emerging diagnostic techniques, such as AI based expert systems and their impact on the practice and economics as well as the performance of the general (continuous) diagnostic systems are also to be studied and discussed in next forthcoming CIGRE sessions.

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