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Operation Challenges of Ageing Geothermal Power Plants Gn. Salak 180 MW and Kamojang 140 MW – West Java, Indonesia

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ABSTRACT

Kamojang is the first Geothermal Field to produce the first commercial power plants with a capacity of 30 MW since 1982, and subsequently, an additional of 2 x 55 MW completed in operation in 1987. It has been operating for 37 years. Similarly, the second geothermal field is Gunung Salak power plant drilled in 1983, and the first power plants 55 MW operation in 1994, and following expansion units were installed with total capacity 340 MW since the startup. It has been operating for 25 years.

On March 2012, Kamojang Unit 1 capacity of 30 MW, major equipment's failure was from the generator. After the unit was shut off due to high vibration, the presence of foreign objects in spacer material between the coil end rotor was detected. This spacer material has been deteriorating, because of heat dissipation from rotor winding, after the operation in many years. Seven months would be required for the unit to be stopped in order for the IP's engineers to fix the problem.

On November 2013, Kamojang Unit 3 capacity of 55 MW, there was a major failure on the deformation of generator insulation, spacer end winding generator, causing generator short winding. More than five months would be required in order to recover the plant back in operation.

On March 2017, Gunung Salak Unit 3 capacity of 60 MW, there was a major failure on the rotor generator. Two months were required to fix the problem. Thorough inspection indicates that the problem on rotor generator was caused equipment's ageing, non-properly cooling process due deposition, in consequences generator's short circuit during operation. To prevent the same situation on others generator, properly regular measurements to predict the potential failure can be avoided, by replacing the insulations during annual plan maintenance.

1. INTRODUCTION

PT. Indonesia Power is managing and operating the first Geothermal Field in Indonesia, and it is known as one of vapour dominated geothermal systems located on Java Island. It was since 1978; the first started producing steam in 1978 after drilling accomplished under supervision from the New Zealand government. The first commercial operations of 30 MW started in 1982. Subsequently, an additional 110 MW started commercials operations in 1987.

This first unit has been operating for 37 years, the 2nd and 3rd unit operating for 32 years. One of the challenging in operation of old units is performance deterioration due to the operation of power plants above the technical design lifetime of power plants. As well, the challenging operation of 180 MW Salak and 140 MW Kamojang are damages phenomenon because of ageing equipment.

In this particular report, to describe only deterioration related to the performance of generator insulation, both on the stator side and rotor side. Generator – the rotor is one of the highest critical equipment from the power plant, which has no redundancy, operating continuously, and commercially expenses equipment. Dealing with the ageing generator – rotor, immediate actions have to be taken when abnormality parameter operation noticed, any delay in doing fixing the abnormalities parameter will lead to potential accelerated systemic faulty of others equipment's, in this power plant.

PT. Indonesia Power has managing and operating more than 15.000 MW installed of various power plants to include coal-fired power plants, gas combined cycle power plants, geothermal power plants and others type power plants. Hence PT. Indonesia Power has long experience on maintenance of power plants, that is supported by a solid technical team and quite complete tools for maintenance. To include in this special skill is experiences in partial repairment and or total re-insulation of damages generations rotor power plants. PT. Indonesia Power is also having a strong business networking to provide insulation materials during repairing generator rotors or total replacement of the generator.

The specific experiences and expertise required concerning on repairing insulation generator rotor is normally no complete guideline in the power plant's manual book related to the technical guideline for tolerance limit or clearance of the insulation gap. In order to anticipate potential error during repairing or replacement insulation, our standard procedure, among others is to do physical measurement before and during removing main parts of the rotor. International standards guidelines are used as a reference to ascertain the proper work during process removing, reassembling, and re-installing the generator rotor.

In most of the cases, when dealing with ageing generator rotor power plants is decreasing performance that caused by deteriorating quality of insulation, after many years of operation. Our normal period during repairing or replacement of generator rotor insulation takes about 60 – 65 days. This period days of maintenance is quite substantial in term of loss of operating time, and then prudent decision to only doing generator rotor maintenance during period planned overhaul is commercially crucial.

Table 1 and Table 2: Below is the generator specification that we have experiences successful on replacement of damaging rotor insulation. Those both generator rotor has short inter-turn of the rotor coil as a symptom, before further problem on ground fault rotor.

Table 1: Generator specification of Kamojang, Unit 1.

Manufacture	Mitsubishi Electric Corp.
Type	MB
Voltage	11.800 V
Current	1.835 A
Frequency	50 Hz
Speed	3000 rpm
Power	0,8 lagging
Temperature stator	99 ^{0}C
Temperature rotor	90 ^{0}C
Insulation Class Stator	F
Insulation Class Rotor	B
Output	37.500 kVA / 30.000 KW
Altitude	1.500 m
Cooling water temperature	34 ^{0}C
Excitation Volt	250 V
Excitation Amp.	410 A
Total Enclosed	Self-Ventilated
H. Cont.	1,46
Standard	IEC 34-1

Table 2: Generator specification of Gunung Salak, Unit 3.

Manufacture	Ansaldo Energia s.p.a Year : 1995
Type	TR-2-68750-3000-11800
Voltage	11.800 V
Current	3.364 A
Frequency	50 Hz
Speed	3000 rpm
Power	0,8 lagging
Insulation Class Stator	F
Output	68.750 kVA
Excitation Volt	175 V
Excitation Amp.	861 A
Total Enclosed	Self-Ventilated
H. Cont.	1,46
Standard	IEC 34-1

The specific attention is given during in situ repairing generator rotor. Because the normally geothermal area is exposing of H_2S for NGC (non-condensable gas) release stripping from geothermal steam, during proses re-insulation of Kamojang generator rotor, unit 1 and Unit 3, the generator rotor was taken to the workshop, considering exposing H_2S gases in the environment may cause to damage the rotor coil because of the oxidation process.

2. HISTORICAL DAMAGES OF ROTOR GENERATOR

2.1 Damages of Rotor Generator Kamojang Unit 1

After 30 years of operation, the damage of generator rotor unit 1 Kamojang 30 MW initially driven by 150 kV transmission line voltage drop. In the period of January 1 2012, to March 13 2012, there were recorded 103 times the voltage drop in the 150 kV transmission system. As a response to the transmission voltage drop, Kamojang unit 1 delivered MVAR beyond its normal operation, as shown in figure 1. As per shown in table 3, the number frequency of voltage drop in the period of January to March 2012.

Table 3: The number of frequency drop within January – March 2012 on 150 kV Kamojang unit 1 transmission system.

No	Month Period	Frequency	System voltage	MVAR Unit 1
1.	1 – 15 January 2012	4	133 kV	22,5
2.	15 – 31 January 2012	30	132 kV	29
3.	1 – 15 February 2012	53	131 kV	27
4.	15 – 29 February 2012	11	131 kV	25
5.	1 – 13 March 2012	5	133 kV	20

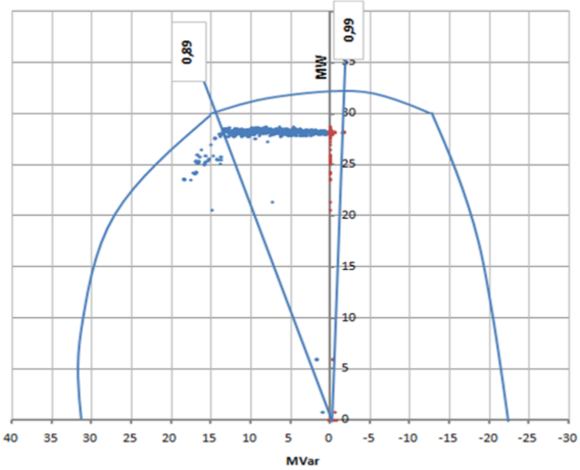

Figure 1: The capability curve of the generator, showing many operation evens beyond the safe operation curve.

It was concluded that the operation Kamojang unit 1 with MVAR out of normal generator capability curve would impact on overheating condition on the generator, leading to potential damage on generator insulation. In summary, the damages generator of Kamojang Unit 1 can be summarised as follows:

1. The number of voltage drop for 150 kV transmission network located on Kamojang Substation very high.
2. In response to voltage drop, number operation for Kamojang unit 1, to serve MVAR beyond the generator capability curve is also very high.
3. As a consequence of number operation on large reactive power demand, the temperature risen on the coil of the stator generator reaches an alarm value of 120 degrees Celsius.

On March 13 2012, at 16.06 Kamojang Unit 1 tripped. At that time, the capacity output was 24.5 MW, 21.2 MVAR. After some checking and evaluation, the unit was able to synchronise at 22.27. During increasing MW output, again the unit trip for the 2nd time, timely on March 13 2012, at 23.07 at a load of 25.6 MW, 10.6 MVAR.

Relay trip is 30F, 63T, 86G1.

Indications during turbine trip are high vibration of bearings as per following recorded data;

- Bearing no. 3 reached 340 µm (exceeding the trip setting of 250 µm).
- Bearing no. 4 reached 264 µm (exceeding the trip setting of 250 µm).

To ascertain the recorded value of high bearing vibration, the turbine then is rotated of 400 rpm. The result: there was an indication of noise/vibration and a turbine was stopped again. Figure 2 is shown the event recorder graph to conclude the signature of the generator rotor ground fault then followed by the appearance of high vibrations on the bearings.

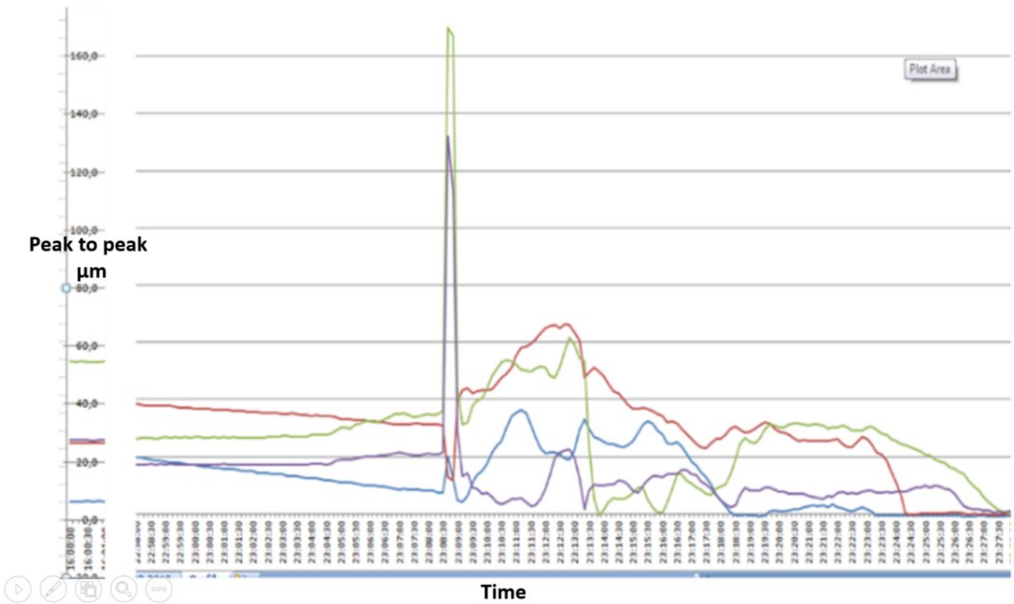

Figure 2: Vibration of generator bearing during turbine trip.

Finally, it is concluded that Kamojang Unit 1 was not in safe operation. A further thorough investigation on the generator shall be carried out immediately.

2.2 Damages of Rotor Generator Gunung Salak Unit 3

A similar phenomenon of generator fault due to ageing insulation occurred in Gunung Salak Unit 3 with a capacity of 55 MW. It was on February 28 2017, Unit 3 of Gunung Salak geothermal tripped because of 150 kV transmission problem, due to external factors. After all the necessary instrumentation were checked, it was decided to start rolling turbine and later on followed by synchronising generator to the grid system. During increase rotor spinning, at a rotation of ± 1000 rpm, the 64R protection relay was energised, tripping the rotor. That was an earth fault rotor relay and cannot be reset to start continuing spinning rotor to target 3000 rpm. Therefore, the 64R relay can be reset, after reducing the rotor speed rotation down to 460 rpm 64R relay can be reset, finally.

After the turbine rotation completely stops, the resistance/meger measurement is carried out. The resistance of the generator based on the results of the meger measurement shown that the insulation conditions are in good condition. Then the unit was ready to start again, at 1000 rpm the relay 64R returns to energise and again, this 64R relay cannot be reset. It was decided to increase the speed of turbine rotation at working speed of 3000 rpm, but the 64R relay still cannot be reset. In an effort to reset 64R relay, still at a turbine speed of 3000 rpm, is to localise the equipment's by removing the charcoal brush for 64R relay, and the relay can be reset.

Considering the above conditions, it was concluded that the energising of 64R relay because there is an earth fault on the rotor generator.

3. DETAILED INVESTIGATION DAMAGES OF ROTOR GENERATOR

It was a common understanding of our maintenance team that the common problems of the ageing generator are deterioration rotor generator insulation after years of operation. Deterioration of generator insulation will lead to short to the ground problem and short inter-turn of the rotor coil. In case of both Kamojang # 1 and Gunung Salak # 3 generator rotors problem was due to a ground fault rotor

3.1 Site Investigation on Damages of Rotor Generator Kamojang Unit 1

Further thorough investigation during Kamojang Unit 1 stop, during the dismantling of the rotor generator, it was founded splinter insulation material in the coupling side generator. This foreign material was thought to be a fractional spacer that originally installed between the coil end rotor (turn to turn coil). This chunk of a broken spacer as per shown in Figure 3, was suspected because of spacer material deterioration after years of operation. It was concluded that the broken spacer was due to thermal effect or probably excessive temperature rose occurred on the coil end rotor.

To ascertain the root cause of abnormality parameters, further surge testing was done. As per shown in Figure 4, the graph in the screen was the result of a surge comparison test on Pole-A and Pole-B winding rotor with 500 V DC injecting voltage. The two graphs did not coincide, which indicate the rotor coil imbalance between pole-A and pole-B.

Figure 3: Vibration of generator bearing during turbine trip.

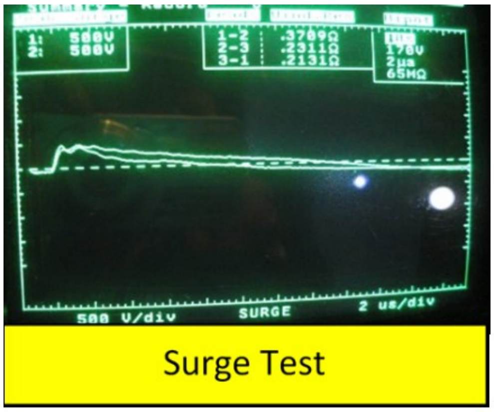

Figure 4: Vibration of generator bearing during turbine trip.

Voltage Balance Testing

The detailed measurement on how imbalance occurred on pole – A and pole – B, Table 4 show the result of the measured voltage drop between pole (Va and Vb) that lead to happen short circuit inter-turn on one pole.

Under normal condition voltage of pole-A and pole-B has the same value, and will show on the screen as a coincide graph between pole -A and pole-B,

Table 4: Voltage drop of Pole – A and pole – B.

No	Vt input (V)	I (A)	Va (V)	Vb (V)
1	10.64	1.5	3.80	6.98
2	20.69	3.1	7.22	18.8
3	30.58	4.0	11.8	19.52
4	40.67	6.0	13.80	27.4
5	50.43	6.4	18.97	32.28
6	60.20	7.5	21.2	39.7
7	70.10	9.3	20.2	51.3
8	80.60	11.1	19.5	62.9
9	90.50	12.8	18.9	74.0
10	100.5	14.0	18.8	84.5

3.2 Site Investigation on Damages of Rotor Generator Gunung Salak Unit 3

Borescope Test Results

Figure 5: Borescope of end winding, end winding in a dirty condition

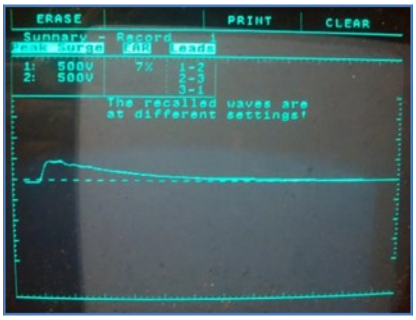

Figure 6: Surge test, the results of the surge test on the generator (EAR 7 %)

During the thorough investigation on Gunung Salak unit 3, the rotor generator was pulled out for visual inspection, as per Figure 5. It was founded foreign materials contaminants in the rotor winding. The contaminants were hard bonded with rotor winding, and cannot be cleaned by a vacuum pump, as well was not able to be cleaned by the typical chemical, electric motor cleaner. Finally, the mechanical cleaning was the only option needed by brushing or gouging contaminants to remove from rotor material.

The result of a surge comparison test as per Figure 6 shown on Pole-A and Pole-B winding rotor with 500 V DC injecting voltage. The two graphs do not coincide so that the rotor coil in pole-A and pole-B occur imbalance. Results: 7% EAR indicates short inter-turn (Standard Normal EAR <5%).

4. METHODOLOGY RECOVERY FROM DAMAGES OF ROTOR GENERATOR

PT. Indonesia Power has a skilled team to do repairing the insulation of rotor generator that manage by Business Unit PT. Indonesia Power. When it was decided to do re-insulation of the rotor generator Kamojang unit 1 and Gunung Salak Unit 3 under our own management, considering that we have experienced on many repairments of the various different generator rotor. The highlights steps taken during the process of repairing the generator rotor such as to investigate damage to the generator rotor (testing and fault history). Then followed by disassembly the generator rotors and record the damaged parts, and finally to do assembly the generator rotor back to the original place.

4.1 Voltage balance test for rotor generator Kamojang Unit 1

Before some measurements were taken, the first step was to open the generator cover to do visual checking. It was founded fragments of flakes. Then followed by measurement of insulation resistance rotor generator meger type with a result of 0 MΩ. Finally, to do pull out the generator rotor for further testing such as winding resistance test, voltage drop balance test and surge test.

Considering that the geothermal environment contains a lot of H_2S sulphuric acid gas which will oxidise the generator rotor coil, the generator rotor repair will be carried out at the workshop in Bandung.

The step by step recovery preparation, as among others to the mobilisation of generator rotors to workshops. In some cases, it is needed to do manufacturing special tools, then followed by preparation of SOPs and work methods, and then finally making isolating rooms to avoid any unnecessary dirty dust inside the room.

In case of Kamojang Unit 1 repair, knowing that the geothermal environment contains a lot of H_2S sulfuric acid gas which will oxidise the generator rotor coil, the generator rotor repair will be carried out at the workshop in Bandung. The step by step work preparation is shown in the following figures.

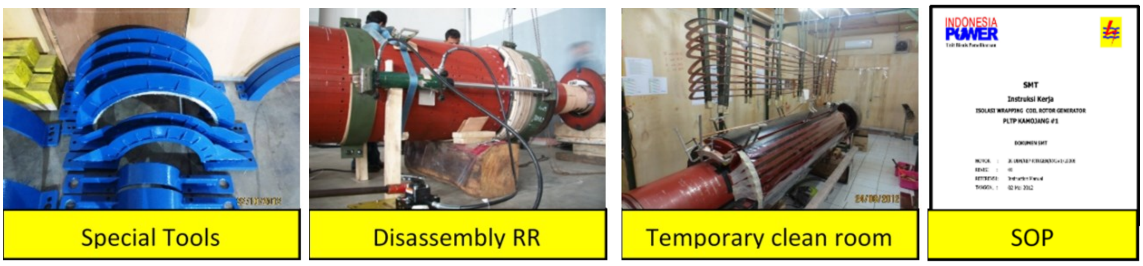

Figure 7: Preparation special tools, proses disassembly retaining ring and make a temporary cleanroom.

4.2 Dismantling of Rotor Generator Kamojang Unit 1

Fact-finding of ground fault rotors:

After dismantling the retaining ring and wedge rotor generator, a coil was founded to be melting. Dirty block spacers are characterised by carbon in the area. Insulation is brittle and weathered. Figure 8 shows these rotor visual conditions after the dismantling.

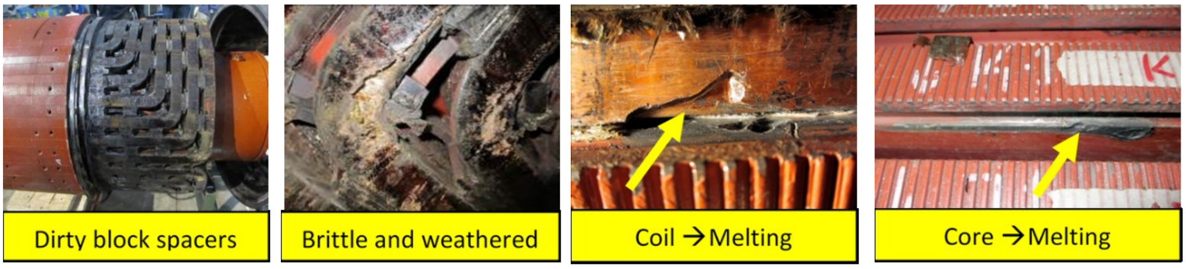

Figure 8: Fact-finding of ground fault rotors and condition of the end winding that dirty & brittle.

4.3 Complete Assembly of Rotor Generator Kamojang Unit 1

After investigation of damage, cleaning parts of the rotor generator, then re-installation was carried out. The procurement of insulation material was done parallelly while cleaning process of generator parts, as shown in Figure 9.

Repair & Installation Process:

- Repair damaged coil parts.
- Hand taping (re-insulation) coil.
- Inserting coil.
- Installation of End winding spacers & wedges.

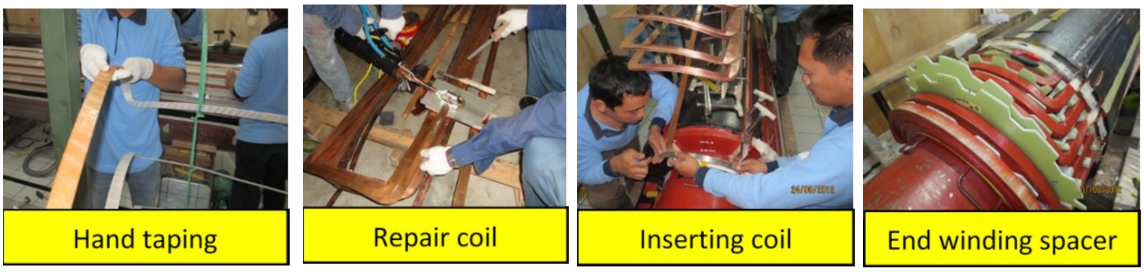

Figure 9: Process repairing of the rotor generator.

Learning Process:

- Insulation for the slot liner, both for type and dimensions adjusted to the rotor voltage rating.
- Insulation retaining ring, with heating to see endurance on temperature.

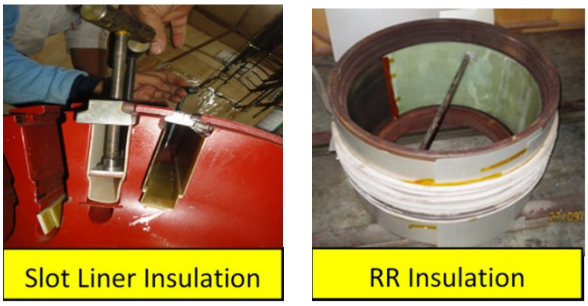

Figure 10: Preparation insulation material (slot liner and retaining ring) before being to do the assembling of slot liner and retaining ring and coil and retaining ring.

4.4 Borescope Test Result for Rotor Generator Gunung Salak Unit 3

The alarm from the 64R relay (Rotor ground fault) only appears when the rotor is rotated above 1000 rpm, and can only be reset at a rotation below 70 rpm, RSO test results state that there are short inter-turn indications.

The next step was to pull out the generator rotor for further testing, such as winding resistance, voltage drop balance, surge test.

The test results show that the generator rotor has a ground fault, so it was needed to be repaired immediately.

4.5 Dismantling of Rotor Generator Gunung Salak Unit 3

During the dismantling of the rotor generator, visual investigation to assess damages of the generator, as per Figure 11.
Recovery Preparation:

- Manufacturing of special tools.
- Preparation of SOPs and work methods.

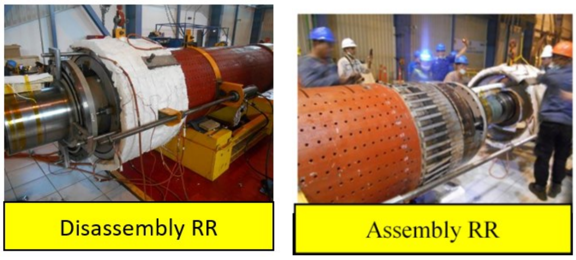

Figure 11: Process disassembly retaining ring to do visual checking.

Fact-Finding of ground fault rotors:
After dismantling the retaining ring, cracks were founded in the insulation. The cause of short inter-turn was founded in contaminants that hard sticky bonded at the end winding generator coil, as per figure 12.

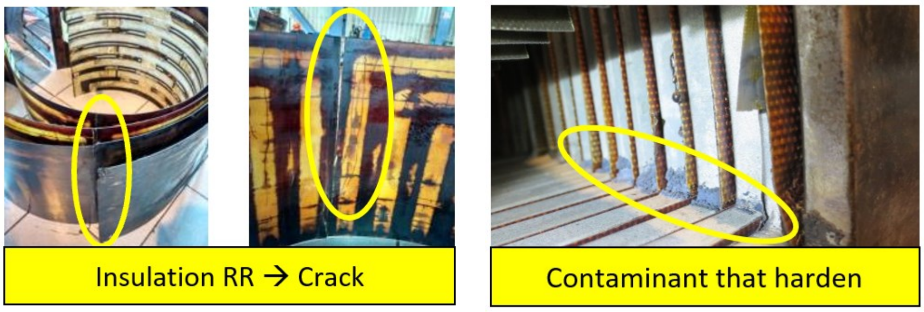

Figure 12: Retaining ring insulation in crack condition, possible due to ground fault and harden contaminant due to inter-turn short.

4.6 Complete Assembly of Rotor Generator Gunung Salak Unit 3

After investigation of damage, cleaning parts of the rotor generator, then re-installation was carried out. The procurement of insulation material was done parallelly while cleaning process of generator parts, as shown in Figure 9.

Repair & Installation Process:

- Repair damaged coil parts.
- Hand taping (re-insulation) coil.
- Inserting coil.
- Installation of End winding spacers & wedges
- Electrical testing
- Assembly the generator rotor.

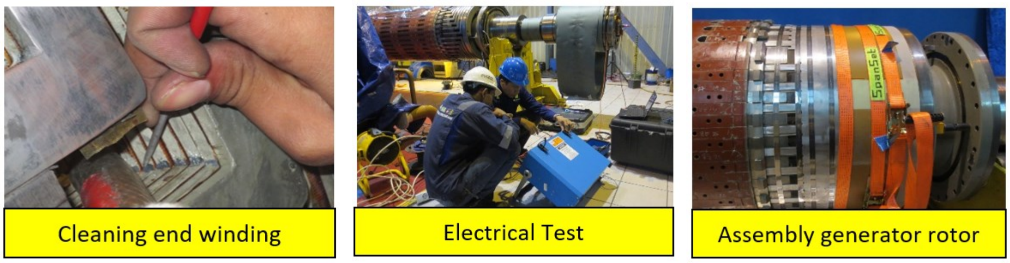

Figure 13: Cleaning hardens the contaminant, electric test and assembly new retaining ring insulation.

5. CONCLUSIONS

Operation challenging on an ageing generator can be managed by PT. Indonesia Power without any supervision from the power plant's manufacturer. The typical damages of generator rotors are caused by damage to insulation deterioration after 30 years of operation. Operational generator in the outside of the generator capability curve will cause excessive heat that leads to more rapid deterioration of the generator insulation.

After visual checking during pull out generator, further testing's are required to ascertain the level of damages before decided to do total rewinding work. Such importance test, among others surge testing and resistance testing.

Finally, the success of total re-insulation or rewinding of Kamojang unit 1, with a capacity of 30 MW installed and Gunung Salak Unit 3 with a capacity of 60 MW installed, are a proven legacy of PT. Indonesia Power capability to do maintenance power plants.

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