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Title: Replacement of Main Electrical Generator in NPP Krško

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The purpose of this article is to present an overview of the replacement process of the main electrical generator in Krško NPP, which took place during the outage 2010 and the outage 2012. Stator replacement of the electrical generator was performed in the outage 2010 while rotor replacement of the electrical generator was performed in the outage 2012. Process of the purchasing, designing, fabricating, shipment and transportation, installation and testing of the electrical generator is presented in this paper.

Large electrical generators are used in many applications in nuclear power plants. The primary function of main electrical generator is to generate power which is then transmitted to the grid. The generator is also a vital component for the plant itself because it provides power to the plant auxiliary loads. Electrical generator life is not infinite. Winding Insulation degradation is most critical parameter when assessing generator condition and the primary cause of generator aging, a factor which increases the probability of winding failures.

Krško NPP utilizes hydrogen inner-cooled generator with water cooled stator winding furnished by Siemens Energy Corporation. Due to Krško NPP license extension application and the service condition of the old electrical generator, replacement of the electrical generator was significant contribution for safe and stable operation of the plant.

Keywords: *electrical generator, aging, winding failures, replacement process, reliability*

1.0 INTRODUCTION

Krško NPP is a two-loop Westinghouse designed pressurized water reactor (PWR) plant. It started with its commercial operation in 1983. It is owned by HEP, Croatian Power Utility and GEN, Slovenian Power Company. Nuclear power plant lifetime extension (PLEX) is becoming a common practise among the nuclear power plant owners. Initially predicted design lifetime of 40 years is being extended for to 20 more years.

The purpose of this article is to present an overview of the replacement process of the main electrical generator in Krško NPP. Also in this paper will be presented basic principles of modernization of main electrical generator in Krško NPP.

2.0 BASIC INFORMATION OF MAIN GENERATOR AND ASSOCIATED SYSTEMS

The main generator of Krško NPP is a four-pole synchronous turbo generator. The main generator design is based on hydrogen inner-cooled stator and rotor with water cooled stator windings. Original generator is rated as follows at rated load.

Table 1 Generator originally rated parameters

Generator Output	813 MVA
Stator Voltage (phase to phase)	21 kV
Power Factor	0,85 PF
Excitation Current	7046 A
Exciter Voltage	425 V
Phase	3
Speed	1500 RPM
Frequency	50 Hz
Hydrogen Pressure	75 psig

The generator is provided with a directly coupled brushless exciter and auxiliary systems which include a hydrogen gas cooling system and a seal oil system.

3.0 CONDITION OVERVIEW OF ORIGINAL MAIN ELECTRICAL GENERATOR

Original main generator has started with its operation in 1981. In order to accomplish increase of the power output of NPP Krško in the past, following main components replacement were performed:

- Steam generators (Outage 2000, 6,3 % up-rate)
- High pressure heaters and Low Pressure Turbine (Outage 2006, 2,5 % up-rate)
- Moisture Separator Reheaters (MSR) and Low Pressure Heaters (Outage 2007, 0,4 % up-rate)

The total available net capacity of the main generator has been increased from 669 MW to 730 MW. After replacement of low pressure turbine which resulted in increasing active power, rated active power, i.e. the P-Q diagram limits have been exceeded.

Stator and rotor insulations are the most exposed to aging effect of all generator parts. The thermalastic insulation system of original stator winding is based on vacuum pressure impregnation technology and meets thermal class 130 (IEC)/ class B (IEEE) standards. Stator and rotor insulations are specified and fabricated for life expectancy between thirty and forty years under normal operation condition. Insulation systems of new generation power generators are specified and designed in class 155 (IEC)/ class F (IEEE) standards.

During the outage 2000, as a part of regular electrical testing of the main generator, off-line partial discharge measurement was performed. In two phases the measurement, readings showed unusually high values which represented a huge deviation compared to previous years. From that period, negative trend of partial discharge level had been recorded which had for a consequence accelerated aging of stator insulation system. Due to increased load on the main generator, degradation of insulation system could not to be predicted in advance. That was the justification for Krško NPP decision to replace stator mid-section in Outage 2010.

During the outage 2010, as a part of regular testing of the rotor, off-line pole balance and RSO measurements were performed. The results indicated that a short was present in one of four rotor poles. Consequently, shorted turns in the rotor winding can cause unbalanced magnetic forces (pole imbalance). Westinghouse fleet history of large four pole generators had found that the risk is low when operating with a 4-5% pole imbalance. NPP Krško decision was to replace rotor at the first opportunity.

4.0 STATOR REPLACEMENT

During the refuelling outage in 2010, generator stator mid-section was replaced with a new modernized and uprated one, which is capable of supporting the available target uprate of 880 MVA /0,872 PF.

The following key features and design improvements were incorporated on the new stator: [1]

- RIGI-FLEX Stator Winding
- New water cooled parallel rings
- New stator water system skid
- High temperature core lamination insulation
- New generator bushing – gas cooled

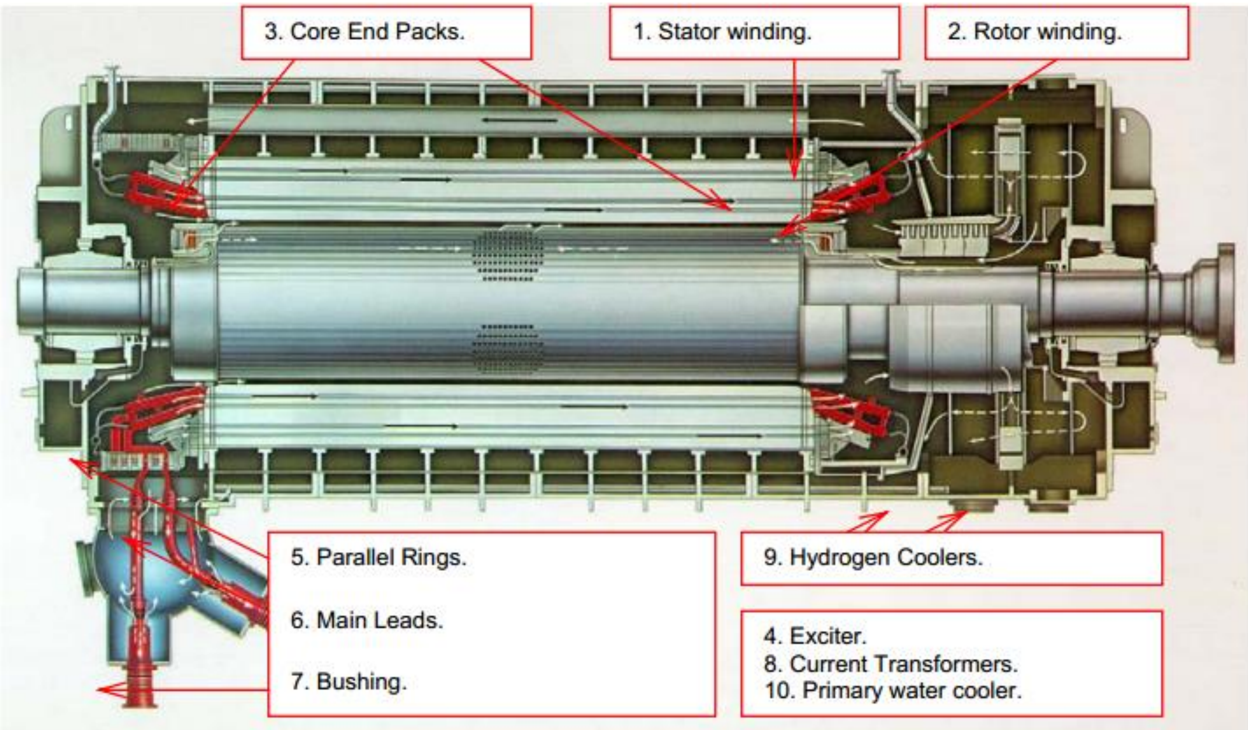

Figure 1: Generator cross-section

The generator frame is a heavily ribbed cylinder which supports the stator core and windings, bearing brackets and rotor assembly and is designed to be explosion safe. The frame and enclosing end brackets are fabricated from formed and welded steel plate.

The stator core is built of thin, high permeability, low-loss, silicon steel segmental punchings. Each punching is insulated on both sides with a high-temperature insulation to obtain a high interlaminar resistance, thereby reducing the transformer type losses caused by eddy currents. The punchings are manufactured in packets (donuts) which are assembled on the outer diameter of the core.

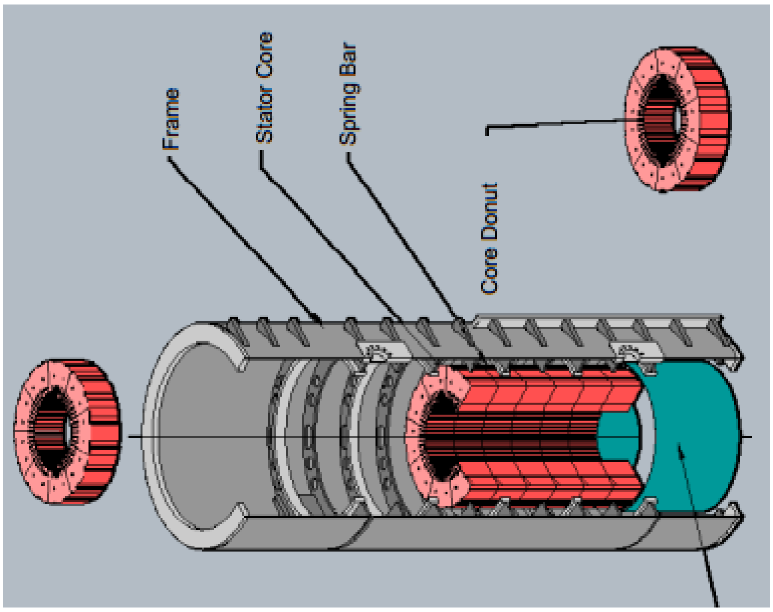

Figure 2: Manufacturing of a donut section

The stator winding which includes the stator coils and parallel rings are water cooled. The main lead connectors and generator lead bushings are gas cooled.

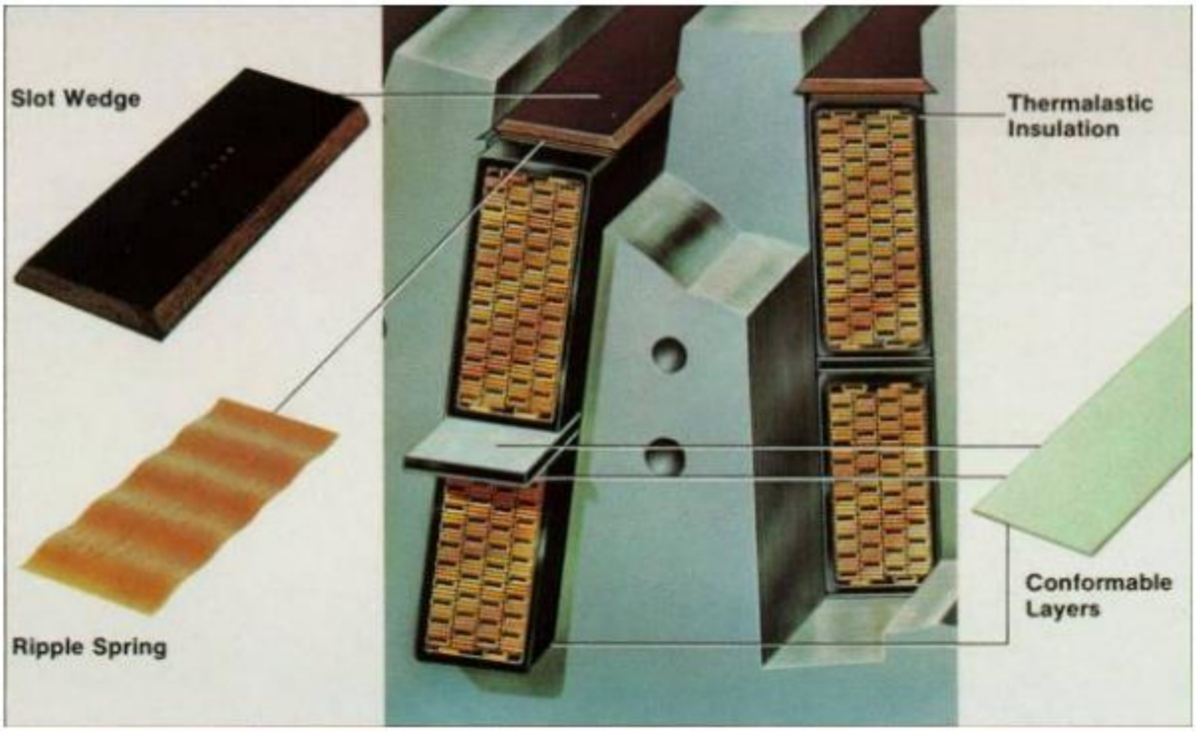

Figure 3: Water Cooled Stator winding

Bearing and glad seal are insulated on both end of the generator to prevent shaft currents from flowing through the bearings. Insulation is provided between the bearing pad and the bearing seat, between the gland seals and the brackets, between the bearing oil seals and the brackets and at the stop dowel and bearing key.

5.0 ROTOR REPLACEMENT

During the outage 2012, the rotor was replaced with a new one based on the proven in-kind winding design which is capable of supporting the target available uprate of 880 MVA /0,872 PF. The new generator rotor was manufactured with the latest upgrades and modernizations. The following key features and design improvements were incorporated on the new rotor:

- Winding design that employs multiple slip layers
- Teflon coated glass epoxy top slot filler
- Booted slot cells to prevent axial migration
- New insulation system – Class F Insulation System
- Tooth top design to reduce risk of crack initiation
- Stress relief grooves at blower hub fit areas

New generator rotor is manufactured from one piece, integral, cylindrical rotor forging. The windings are placed in variable width slots. Complete rotor body and rotor windings are cooled by hydrogen which means suitably positioned holes are provided in the conductors and insulation. [2]

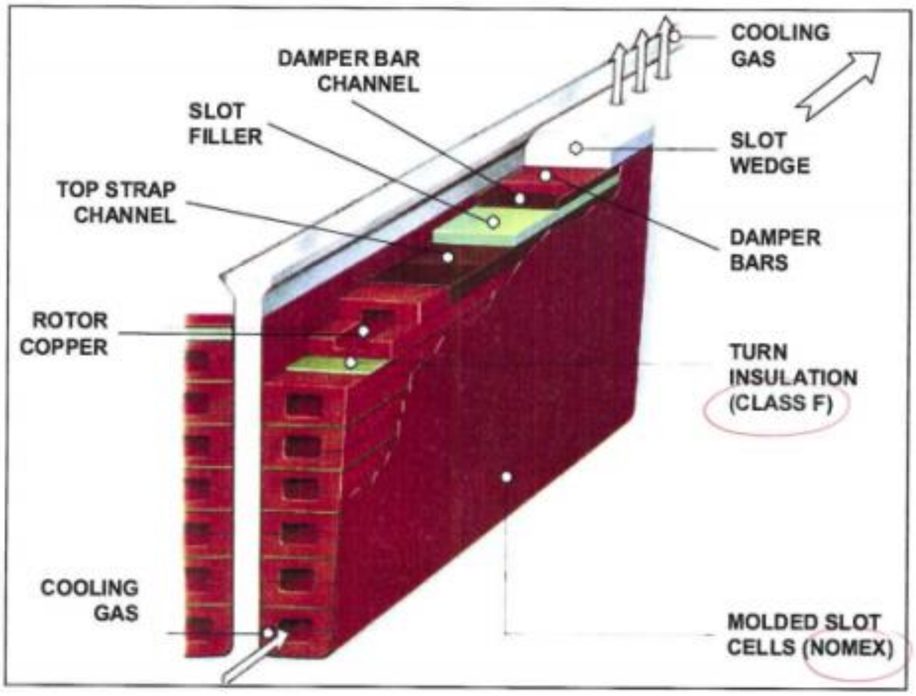

Figure 4: Insulation components of the generator rotor winding

The rotor winding is held firmly against rotational forces by suitable high strength wedges driven in the tops of the slots. The rotor end turns are supported by non-magnetic retaining rings which are shrunk onto the rotor body ends and maintain a form fit throughout the rotor’s normal operating range, as far as rotating speed and temperature. The retaining rings are manufactured from non-magnetic 18Mn18Cr steel forgings.

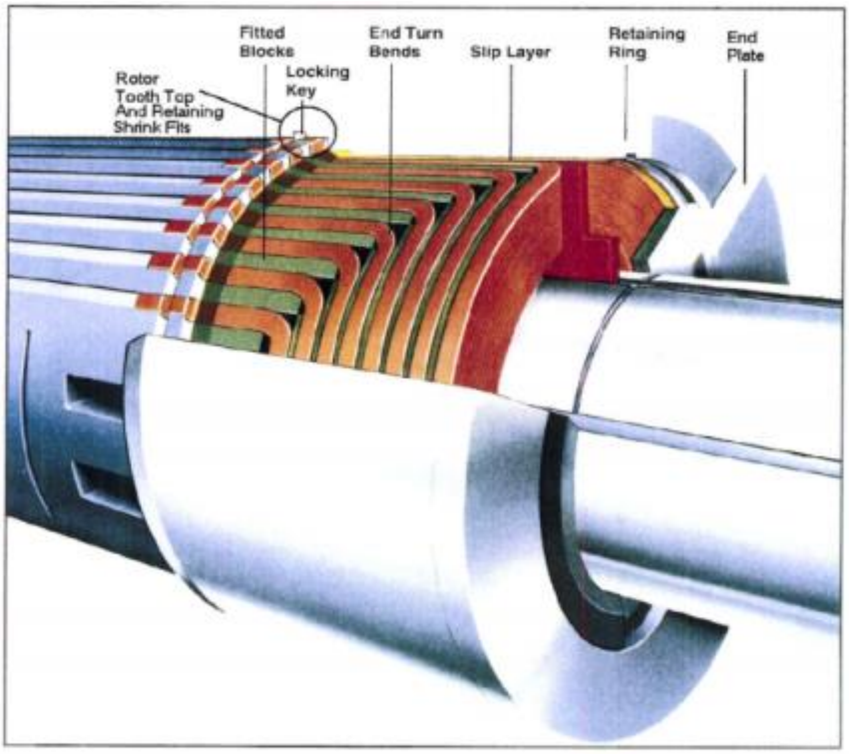

Figure 5: Retaining ring attachment

6.0 CONCLUSION

Replacement of main parts of generator (stator, rotor, exciter), stator or rotor rewinding or complete generator replacement with modernization of support systems and components are common investment projects in industry. Those typical activities solve different issues, i.e lifetime expiration of machine, issues on the individual parts of generator, generator output uprate due to modernization.

After generator modernization which took place in Krško NPP, available generator output is 880 MVA, 767 MW, cosφ=0,872, 431 Mvar. Together with past plant modernization projects and future high-pressure turbine replacement it shall provide 3 % power uprate. Generator output which is generated to electroenergetic system of Slovenia (EES) is 3% less than available generator output which represents 850 MVA, 745 MW, cosφ=0,876, 409 Mvar. The reason for that is aging limitations in excitation system which will be finally replaced during refuelling outage in 2018.

Stator and rotor replacement in Krško NPP enable generator operation in case of extension of power plant operating licence to 2043, corresponding to a lifetime of sixty years. It also enables increase of generator output. For increased generator output it is necessary to modernize or to replace support systems.

6.0 REFERENCES

[1] V. Leonov, EC-07004 Krsko 1, S.O. 85P415, Generator Uprating study for 860 MVA, 0.85 PF output, 2007.

[2] IEEE Std C50.13 IEEE Standard for Cylindrical-Rotor 50 Hz and 60 Hz Synchronous Generators Rated 10 MVA and Above, 2005