Detecting generator stator winding bar vibration with on-line PD measurements

Two case studies

TGS FINLAND OY

Osmo Koponen, 16.6.2022

Stator winding bar vibration

- Vibration of bars in the core slots
- Vibration of winding ends not considered here; it is another story

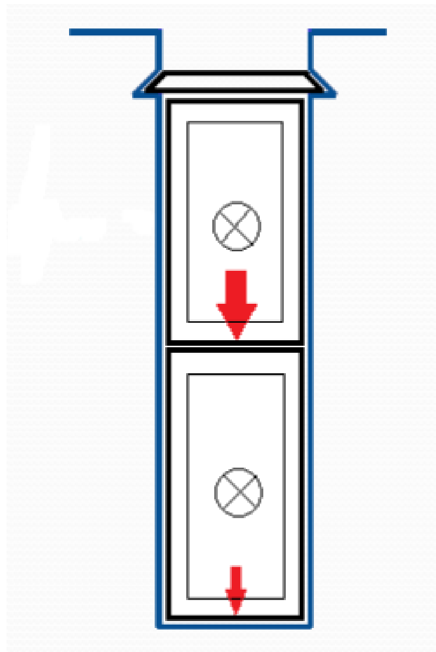
Stator winding bar vibration

- If winding bars are loose, they will start vibrating due to the high forces (kilonewtons – tens of kilonewtons) acting on them due to the magnetic field of the machine.
- The forces are highest in slots with both bars in the same winding phase, where the force affects in slot direction towards the slot bottom.
- The downward force is pulsating at 2 x power frequency (100 Hz or 120 Hz) and it is proportional to the square of the stator current.
- Eventually a vibrating bar will almost certainly fail due to the punctured main insulation. The process may take years but not decades.
- Main insulation puncture is caused by 1) mechanical wear possibly combined with 2) strong classic PD caused by the damaged slot corona protection and/or 3) vibration sparking erosion.

Stator winding bar vibration

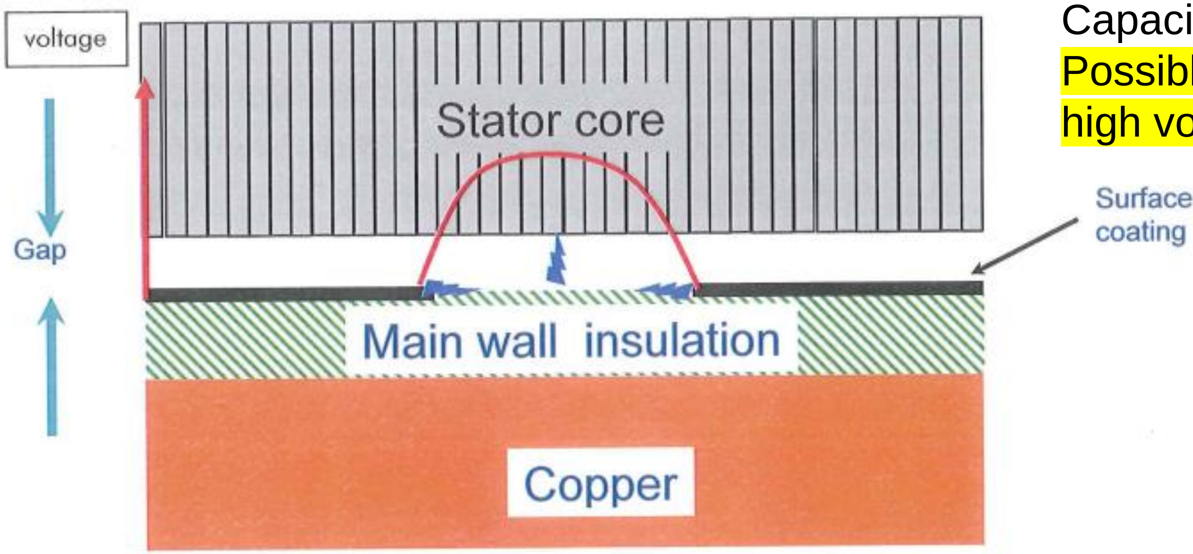
Both bars on the same phase

- Top bar downward force is three times bigger than bottom bar force (flux density is 3 times higher)
- Total force on bottom bar is 4 times bottom bar force

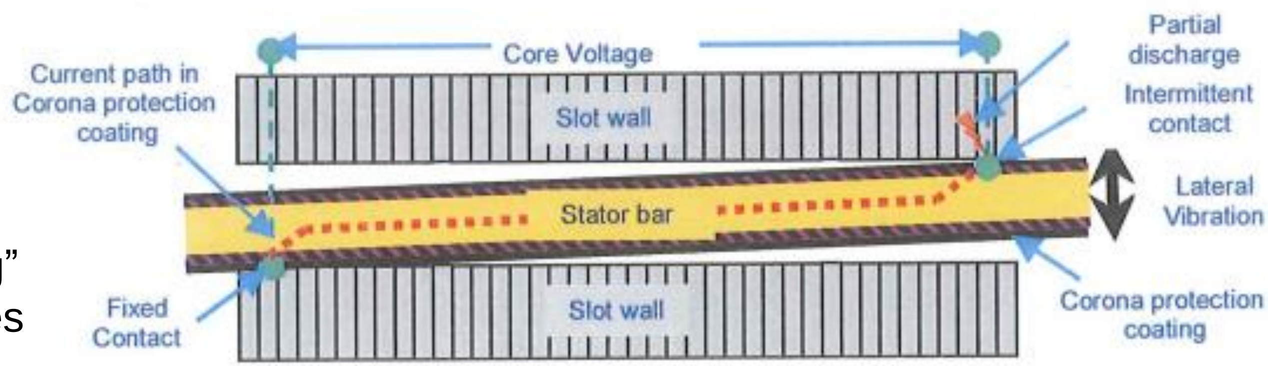


Source:
Iris endwinding vibration course IRMC 2018

Discharge types



“”Classic PD”
Capacitive discharges
Possible only in bars with high voltage to ground



“”Vibration sparking”
Inductive discharges
Possible in all bars

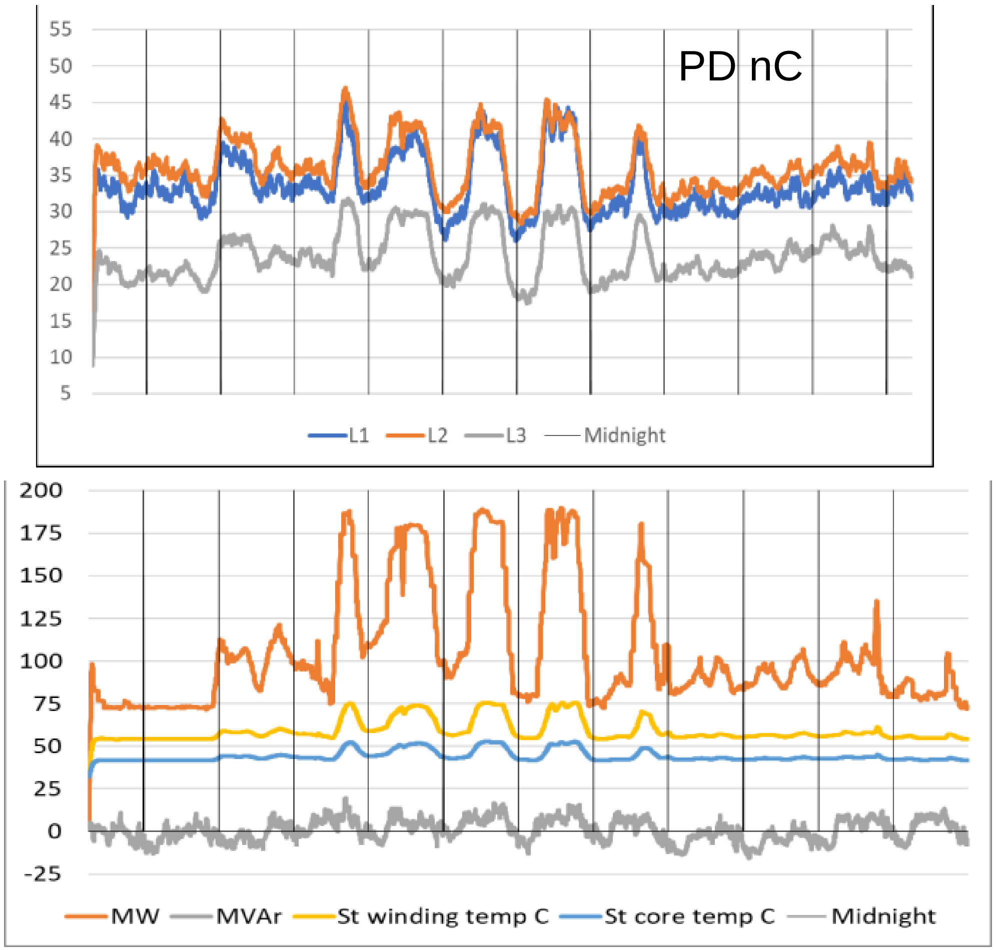
Case 1:
230 MVA air cooled turbo generator

Damaged and failed bar Case 1

For comparison: almost undamaged bar

Case 1: 230 MVA air cooled turbo generator

- Has already failed once due to a vibrating top bar but was repaired
- Demonstrates very power (or current) dependent high on-line PD level

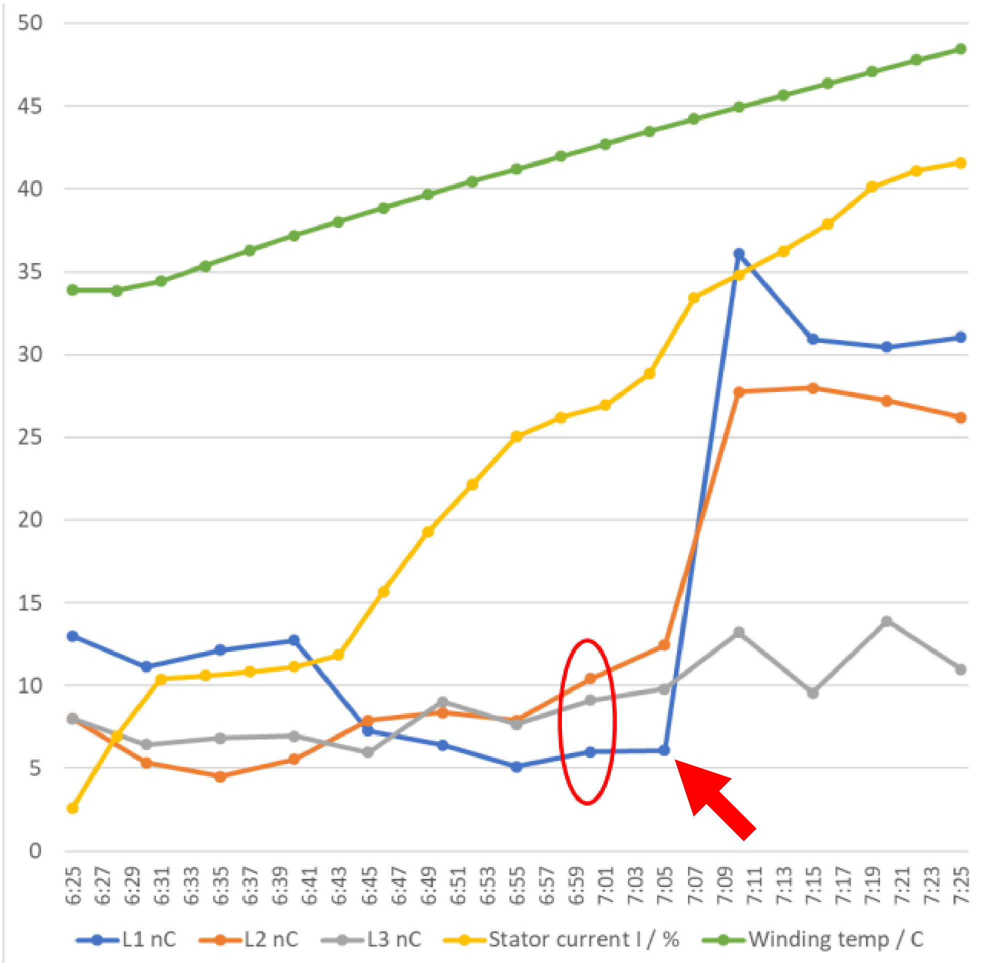


Measured with Omicron MPD600 system

Shows also periods where the discharge level is steadily increasing (several days) without obvious reason and periods with no correlation with output power.

Case 1: 230 MVA air cooled turbo generator

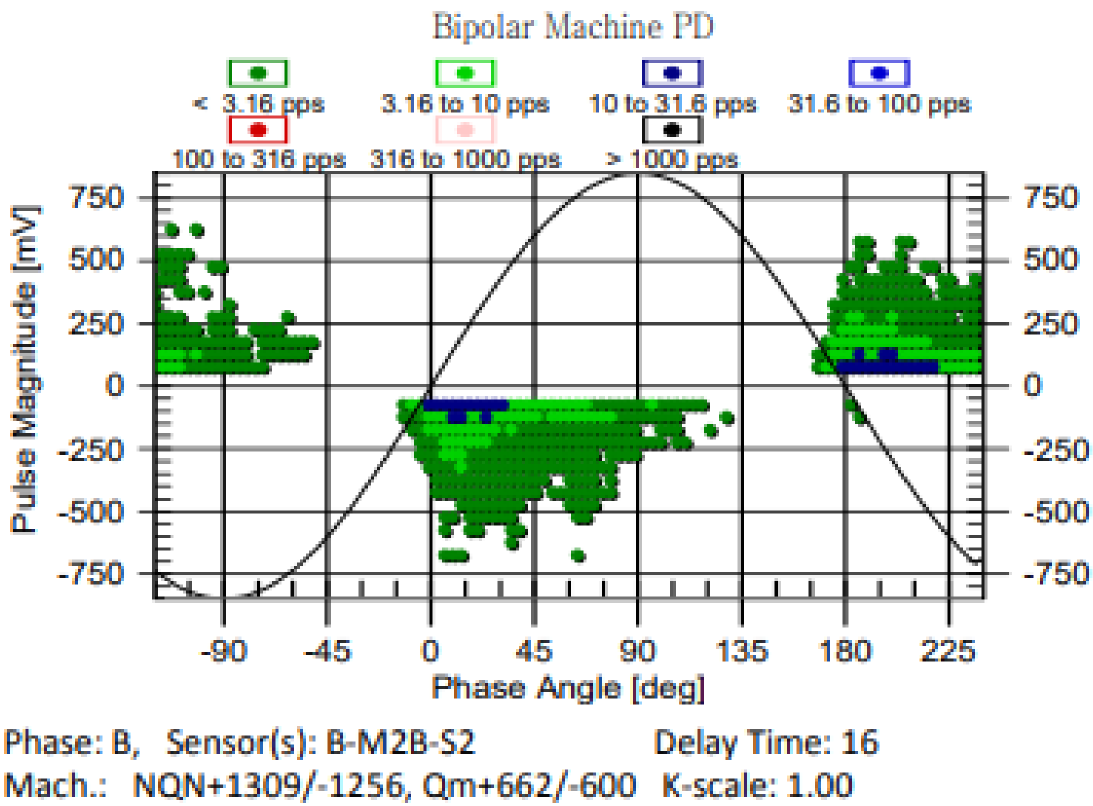
- Demonstrates a clear activation threshold in on-line PD when power increased in start-up



Measured with Omicron MPD600 system

Case 1: 230 MVA air cooled turbo generator

- Demonstrates now high on-line PD level (here 84 MW + 13 MVAr)
- On-line PD was not measured before the first failure



Measured with
Iris TGA-B system

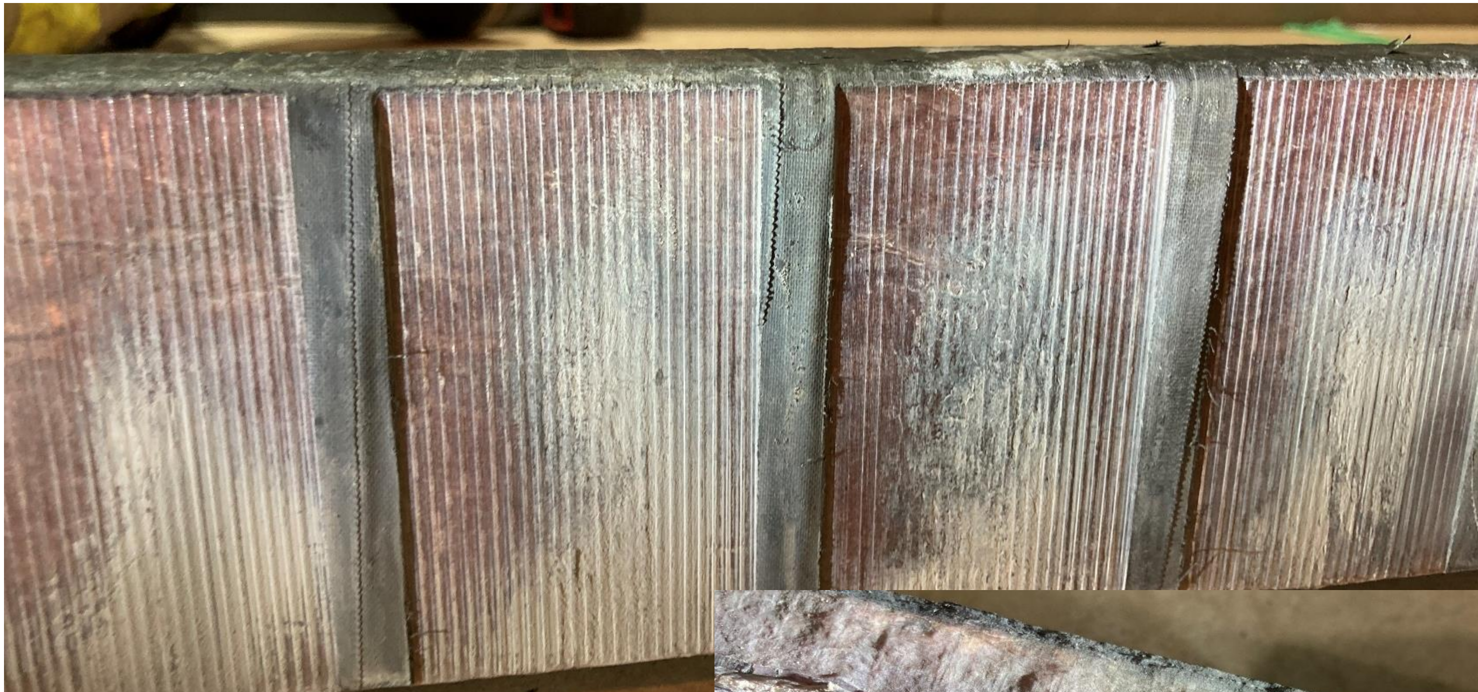
Case 1: 230 MVA air cooled turbo generator

- Demonstrates significant increase in off-line PD level , but **only several years after the first failure**
  - On-line PD level has been very high since the failure (was not measured before the failure, it may have been high)
- Demonstrates significant decrease in winding phase capacitance: year 2009 C = 712 nF / year 2021 C = 669 nF (- 6 %). This may be caused by gradual erosion of the slot corona protection in vibrating bars.
- No significant change in dissipation factor

PD nC	U 2018	U 2021	V 2018	V 2021	W 2018	W 2021
0,4 x U_N	0,3	7	0,3	14	0,4	9
0,6 x U_N	0,4	10	0,4	20	0,7	14
0,8 x U_N	0,6	40	0,8	45	1,0	29

Case 2:
85 MVA air cooled turbo generator

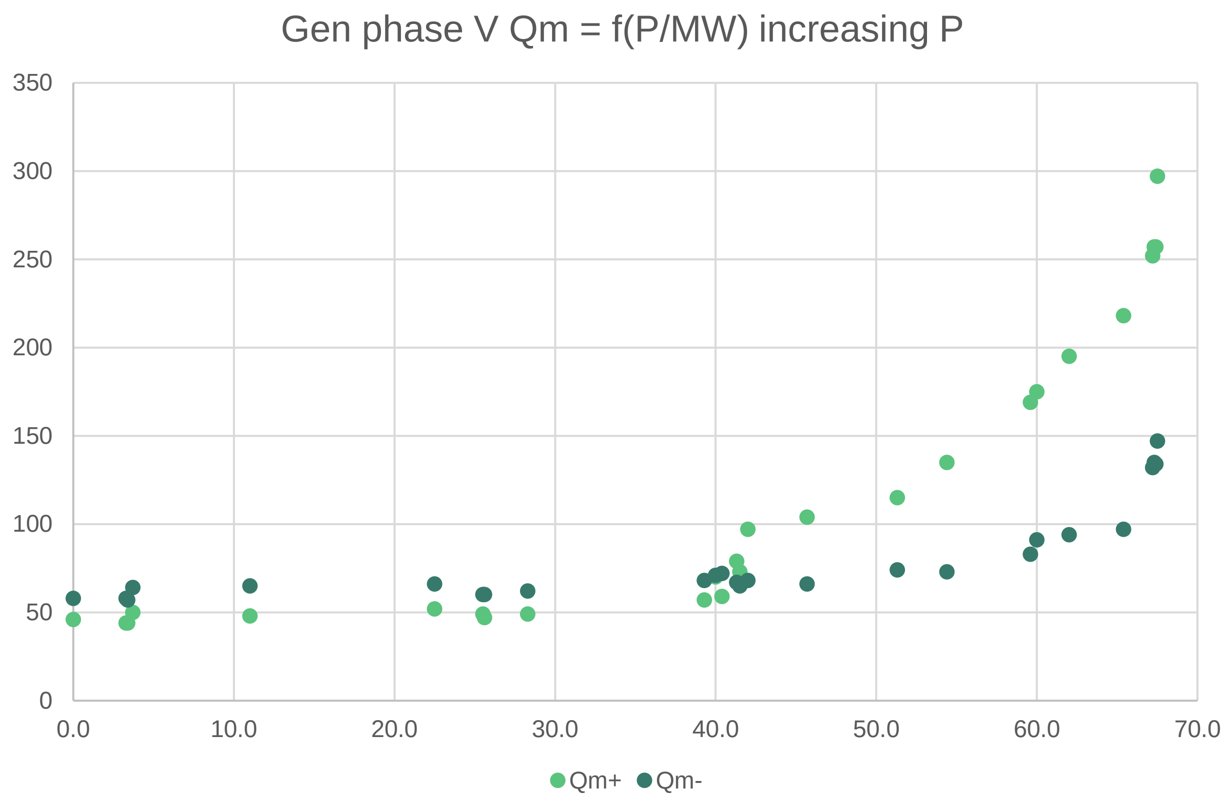
Damaged and failed bar Case 2



Bottom of the top bar was punctured

Case 2: 85 MVA air cooled turbo generator

- Has already failed once due to a vibrating top bar but was repaired
- Demonstrates clear activation threshold in on-line PD when power increased in start-up

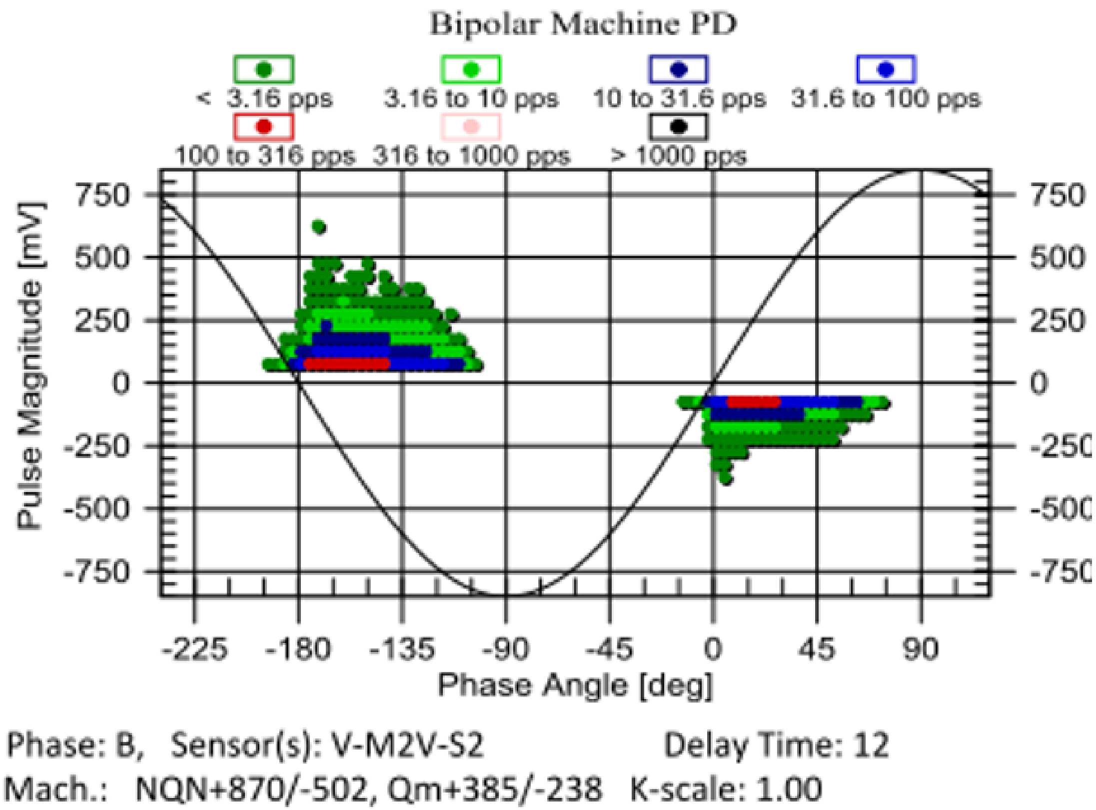


Measured with
Iris TGA-B system

Power
MW

Case 2: 85 MVA air cooled turbo generator

- Demonstrates now after the first failure high on-line PD level (here appr. 90 % power) and also clear dependence on output power (or current).
- Did not show significantly high on-line PD level before the first failure.



Measured with
Iris TGA-B system

Discussion

- Both Case 1 and Case 2 are made with global VPI technology, however quite differently.
- In both cases it was possible to replace the damaged top bar relatively easily, because it had vibrated itself totally free (it was not glued in place any more).
- No side packing in the slot or ripple springs under the slot wedges in neither of the two cases .
- Prevention of bar vibrations in global VPI machines relies heavily on the gluing of the bars on the slot walls by the (epoxy) impregnation resin. Normally a GVPI stator winding can’t be tightened by rewedging.
- However bar vibration problems are not limited to GVPI machines; we have seen them also in machines made with traditional resin rich technology.

Discussion Case 1

- Case 1 failed the first time some 5 years after commissioning. Therefore it is obvious that poor design or poor manufacturing quality was a significant factor.
- In Case 1 it is likely that the vibration started soon after commissioning and aging did not play any significant role.
- The failed bar location was 40 % from the line-end with some 5,5 kV voltage stress → possibly both traditional PD and some vibration sparking. The surface of the failed bar looked eroded by both mechanical wear and discharges.
- The fit in the slot seemed to be quite loose, which may have been a contributing factor preventing proper gluing effect of the stator bars in GVPI process.
- According to the information given by the manufacturer there is also a separation layer wrapped around the bars, therefore prevention of proper gluing effect may have been also intentional.

Discussion Case 2

- Case 2 served well some 30 years after commissioning before the failure. The failure took place soon after approximately 10 % power increase (causing increasing forces on bars), however within the original rating of the generator.
- It is obvious that the bar vibrations did not start soon after commissioning, but aging of the insulation system did play a significant role in the failure by separating the bar from the slot wall and enabling vibrations.
- The on-line PD level did not increase significantly before the first failure, but did show an increasing trend during the first year after the repair and recommissioning.
- The failed bar location was 57 % from the line-end with only some 3 kV voltage stress → likely no traditional PD but possibly some vibration sparking. The surface of the failed bar looked eroded mainly by mechanical wear; no crater-like appearance typical for heavy discharges.

Conclusions

- It may not be possible to detect dangerous bar vibrations early with on-line PD measurements alone without the possibility to compare results obtained at different power levels. This is well achieved with continuous monitoring.
- Measurement during start-up at increasing power level may help revealing the bar vibrations by showing sudden strong increase in PD at certain power level.
- If the vibrating bar(s) are far from the line-end, PD measurement may not give any warning at all.
- Main insulation puncture is caused by 1) mechanical wear possibly combined with 2) strong classic PD caused by the damaged slot corona protection (if the voltage stress of the bar is high enough) and/or 3) vibration sparking erosion (may take place in any bar independent of the voltage stress).
- Both GVPI windings and those made with traditional methods (resin rich, local VPI) may fail on bar vibrations.

Thanks for your time!