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Hydro Generator Rehabilitation Effects on Dynamic Modelling

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- Help describe how the machines and controls are changing.
- Define: What is Rehabilitation?
- Equipment & Operational Changes
- Discuss Challenges
- Questions & Answers







MOD-026/027 Wording (Deep Dive)







Rehabilitation



YouTube video preview from <u>https://www.youtube.com/watch?v=MrPzmhay_BE</u>. Video posted by user "Castanet News", "BC Hydro Mica Dam Upgrades".

• What is it?

- Asset renewal
- New stators, generators
- Replacement rotors
- New T&G
- Re-runnering of existing units
- Exciters
- Governors
- Plant Controls
- Increased Capacity





Repair or Replace



- The age of the digital treadmill.
- Analog systems are disappearing.
- Expertise is declining, and replacement is the low-risk option.
- Industry is replacing generation 1 and 2 digital controls beside original analog systems
- Cyclic loading
 - Machines are getting cycled
 - Changes in operating context





Risk Drives Change



- Liability is a form of risk, replacement is a universal option for all parties.
- Staff attrition and migration
- Deferred investments
- "Upgrade" or is it "conversion"
- Adding features or reliability concerns?
- Asset management is here.
- No easy answer





Rehabilitation



Need

- Asset renewal
- Turbine efficiency across all runner types.
- Plant discharge and fish friendly turbines.

Asset Life

- T&G still has the typical long life.
- Protection, excitation and governors have a lower replacement life (digital treadmill).
- 2nd and 3rd generation digital controls common.
- 1990's/2000's controls are being replaced side by side with original analog systems

Workforce

- Workforce has changed.
- Tolerance for analog controls declining.



Figure attained from "https://www.hydroreview.com/technology-and-equipment/using-cameras-for-online-generator-2/#gref" . Hydro Review article "Using Cameras for Online Generator Monitoring", 2011.



Like for Like Rehab?



Figure from Verification of Model Calculations for the Kaplan Turbine Design - Scientific Figure on ResearchGate. Available from: https://www.researchgate.net/figure/The-standard-4-K-69-Kaplan-turbine_fig2_322757647 [accessed 5 Apr, 2023]

- Rare.
- Efficiency and performance of runners have increased.
- Generators are being refurbished
- DC Exciters are disappearing
- Mass modernization





Prime Mover (Runner)



Change

- Some new runners are lighter, more power/efficiency or both
- Stay vanes, wicket gates, flow
- Draft tube reprofiling

Why?

- Asset Renewal
- Mechanical Retirement
- Forced civil embedded component rehabilitation
- Uprate, efficiency or flow

Model Effect

- Inertia
- Power versus Gate
- Significant change to gate timing
- Water Starting time



Figure from Simulation, Analysis, and Mitigation of Vortex Rope Formation in the Draft Tube of Hydraulic Turbines - Scientific Figure on ResearchGate. Available from: https://www.researchgate.net/figure/Vertical-cross-section-of-a-hydropower-plant-Modified-from-Henry-8_fig4_276847493 [accessed 5 Apr, 2023]



Same Generator, new MVA with Runner



Figure adapted from the cover of the "Small Vertical Waterwheel-Driven A-C Generators, Brochure", Westinghouse Electric & Manufacturing Company, 1944

Change

Increased MVA on the same generator

Why?

- New turbine within the capacity of an over-dutied generator.
- Affordable solution

Model Effect

- MVA base change affecting many parameters.
- New operation in regions of higher saturation online.
- Inertia changes & associated turbine governor changes.





Stator Changes



Change

- Various major components of the magnetic circuit
- Examples (core depth, slot count, tooth profile, iron magnetics, stainless clamping components, split removal, diameters, nominal air gap)

Figure sourced from "https://www.hydroreview.com/world-regions/majoroverhaul-boosts-performance-at-ludington-pumped-storage-plant/" *Hydro Review Article "Major Overhaul Boosts Performance at Ludington Pumped-Storage Plant"*, 2016

Thermal Aging

- Asset Renewal
- Core degradation
- Mechanical Retirement
- Uprate

Model Effect

Can be drastic





Stator Winding



Figure from Numerical Simulation of Discharge Activity in HV Rotating Machine Insulation - Scientific Figure on ResearchGate. Available from: https://www.researchgate.net/figure/Corona-protection-layers-in-Resin-Richtechnology-4_fig1_331702946 [accessed 5 Apr, 2023]

Change

- Rarely like for like copper cross section
- Roebel conversions
- Circuit Reconnections
- Usually MVA uprate
- Can be more scope than just winding
- Transpositioning

Why?

- Asset Renewal
- Opportunity Upgrade

Model Effect

- Vee Curve, OCC, D-Curve all change.
- Saturation limits changed, either improved or operating in a region of more saturation.





Stator Core (and or Frame)



Figure Adapted from "General Electric – Vertical Waterwheel-Driven Generators" by The General Electic Company, 1930, Bulletin GEA-820A Fig 1, Page 5. Retrieved from Google search query.

Change

- Magnetics pound for pound are better
- Can be change in slots
- Can be change in air gap
- Many leakage flux components changed to stainless
- Continuous pile

Why?

Asset Renewal

Model Effect

- Several
- It's really not the same machine





Pole & Rotor Modifications



Figure sourced from <u>https://www.hydroreview.com/world-regions/proactive-</u> <u>repair-of-the-helms-pumped-storage-plant/#gref</u>. Hydro Review Article "Proactive Repair of the Helms Pumped-Storage Plant", 2013.







Pole Position and Shape



Change

- Replacing the entire pole piece
- Moving the radial position of the pole (intentional)
- Mass and Inertia

Why?

- Original design defect
- Change in capability

Model Effect

- Direct change in field current requirements
- Direct change in magnetic saturation





Pole Winding



Change

- Replacing the entire pole winding
- Increasing copper cross section
- Reducing R_f
- Mass and Inertia
- Turn count

Why?

- Machine Uprate
- Temperature capability
- Cooling fins

Model Effect

- Saturation curve
- Direct impact to Inertia
- T'do is sensitive to R_f
- E_{fdbase} changes with R_f

Figure sourced from Google search query.for rotor pole reinsulation. Photo was publicly viewable from Wajax Delstar Energie, "https://delstarenergie.com/rotor-pole-manufacturer-and-refurbishing-services/"





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Generator Cooling System



Change

- Modified generator cooling
- Variance in prime mover windage losses.

Why?

 Improvement in cooling volume or ventilation design enhancement/deficiencies

Model Effect

• Inertia response and load rejection.

Figure sourced from "Redesigning the Rotor Fan Blades to Improve

the Cooling of Roxburgh's Hydro-Generators" by B. Liddell, A. Tucker, I. Huntsman, M. Manders and C. McDonald, 14th Australasian Fluid Mechanics Conference Adelaide University, Adelaide, Australia December 2001



Rotor Changes



move





Rotor Replacement Example

Change

- New Spider, rim and pole pieces
- Same pole winding design
- Change in dovetail attachment
- Uprated from 333 to 366MVA
- New Runner







Rotor Replacement Example

Parameter	New Rotor	Original Rotor
T'do	6.343	6.1
T"do	0.03	0.03
T'qo	0	0.078
Н	4.5	4.9
Xd	1.17	0.92
Xq	0.6375	0.58
X'd	0.29	0.31
X"d	0.23	0.17
XI	0.16	0.15
S(1.0)	0.09	0.13
S(1.2)	0.25	0.43



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Exciter Changes

- Physical Removals
- New AVR or Exciter
- Excitation of modal oscillation
- Need for PSS damping can become apparent





The Obvious



Change

- New Exciter
- New AVR

Why?

- Obsolescence, Reliability
- Modernization
- Conversion to Static
- Conversion to Brushless
- Remove one stage of Brushed Exciter

Model Effect

• Can be drastic





Pilot Exciter Reconnection/Upgrades



Change

- Reconnection of the pilot (shunt field) and the interpole series field with the installation of the static pilot AVR.
- New PID and forcing capabilities

Why?

• Static pilot AVR upgrade from a previous analog systems (such as Mag-Amp technology or mechanical AVR)

Model Effect

Figure obtained from Wikipedia searh for "armature (electrical)". Reference web address <u>https://en.wikipedia.org/wiki/Armature (electrical)</u>. Wikipedia photo source noted as By Hayward, Charles B. - Modern Radio Practice pg 47 https://archive.org/details/modernradiopract00hayw/page/47, Public Domain, https://commons.wikimedia.org/w/index.php?curid=85936098

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- Excitation model structure
- Exciter saturation curve
- Introduction of negative field forcing and limiters



Conversion to Static – Stub Shaft



Figure Adapted from "Westinghouse – Vertical Water Wheel Synchronous Generators Instruction Book" by Westinghouse Electric & Manufacturing Company, 1944, I.B. 7240 Fig 3, Page 8. Retrieved from Google search query.

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Change

- Retiring the rotating machine
- Retirement of one pilot stage
- Stub shaft replacement

Why?

- Obsolescence, Reliability
- Modernization
- Conversion to Static

Model Effect

- Excitation model structure
- Inertia
- Reliance from station service
- Independence from grid connection



Broken Damper Links



Figure from "DirectIndustry.com, Laminated Shunt". Retrieved from Google search query.

Change

- Some machines suffered crack links due to relative pole motion, or cyclic fatigue mechanisms
- Common to remove

Why?

Maintenance failure mode

Model Effect

• Change in the damping circuit (transient based impedances)





New Runners & Governors



Governor

- Perhaps you keep the original governor,
- New PID settings
- Change in SNL
- Gate timing
- Servo Cushioning

• Turbine

- New no load zones
- Power vs gate response
- Inertia





Mechanical to Digital Conversions





PLC Digital Control Head





Model Conversion (WSHYGP – HYG3)





Which one is the Digital Governor?

- Know your operational goal
- Ensure there is a focus on technical training.
- We can always model the response.
- In model validation, do not assume that NERC Testing equals good performance.







DCS/PLC Plant Controls



Change

- Plant level or unit level controls affecting governor frequency control.
- Addition Power Order controls antidrooping the station.

Why?

- Modernization controls
- De-staffing and automation
- "Upgrade"

Model Effect

- Implementation of load control model.
- May require a UDM to represent overall plant response.





What are the control options?

- Know your operational goal
- Meet interconnection governor control requirement
- Represent advanced control logic
- Consider your study time frame and if AGC or other advanced joint load controls are being modeled
- In some instances, HIL testing and validation.

Figure sourced from Google Patents, US Patent Number US2209987A, Irl C Martin, Thorell Helmer Walter, Woodward Governor Company, 1937

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Concluding Statements

- Equipment changes can affect your MOD model compliance.
- Rules previously did not exist, and model creation/validation was performed only by utility best practices.
- MOD-026/027 are capturing changes.







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Questions and Answers

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