MANITOBA HVDC RESEARCH CENTRE,
a Division of Manitoba Hydro International Ltd.

HVDC Life Assessment and Extension

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Agenda

- Introduction and background
- Documentation and records
- Root cause analysis
- Assessment team and preparation
- Performing the assessment

Agenda con't…

- HVDC cost analysis
- Life time of components
- Equipment analysis
- Environmental and regulatory
- Techno-economic analysis
- Conclusion / Q&A

Introduction

- Based on the 40 years of experience in the HVDC industry with associated areas such as operations and maintenance, performance, failure analysis, design and consulting.

- Also actively participated with the condition assessments of eleven HVDC Systems for all of, or parts of, the HVDC converter stations

Experience

- Nelson River Bipole 1: +/- 463.5 kV 1854 MW – Commissioned 1973 -1976 (Exp – 1975 to 2009)
- Nelson River Bipole 2: +/- 500 kV 2000 MW – Commissioned 1978 – 1985 (Exp – 1975 to 2009)
- Cahora Bassa – Mozambique +/- 533 kV 1800 Amperes – commissioned 1976 (Exp – 2007 to ongoing)
- Eight other HVDC projects – Part of a team or individual

Documentation and Records

- Need to decide what level of detail to retain as there are costs, this greater detail has significant benefits

- Need to decide how to retrieve the information in the forms required for maintenance, performance analysis and life assessment

- Need to consider Root Cause Analysis (RCA) – for accurate information and improved performance – Software (PROACT)

Root Cause Analysis (RCA)

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- Root Cause Analysis (RCA) – very important to drill down to the most detailed level to improve or sustain performance
- A higher level of records with less detail affects life assessment and the cost of extension or equipment replacement, but many times that all that is available
- Number of decisions have resulted in poor decisions because this was not done at a detailed level
- A lot of money was spent without a corresponding improvement in performance

Assessment Team

- Usually require a number of team members with a diverse background of skills, expertise and experience
- Converter transformers and reactors
- HVDC Controls and Protection (communications)
- Thyristor valves and cooling systems
- DC Switchyard
- AC switchyard

Assessment Preparation

- Best to prepare a list of information to ask for and review
- Likely not all requested information is available
- Site visit should be mandatory
- About 5 years of information at a detailed level should be reviewed
- Failure reports can be very valuable

Assessment Preparation

- Need to meet with the Client to get a clear understanding of their expectations, information available and deliverables
- Need to understand the process and approvals of the Client so that the assessment information is in the format required for company management, lenders, etc.
- Get as much information as possible from the Client before the site visit
- A second site visit may be necessary to get additional information or present the final report

Performing the assessment

- Take lots of pictures of equipment, nameplates and write a lot of notes

- Interview Operations and Maintenance staff with the focus on outages and cost of outages. Not all problems are documented on paper.

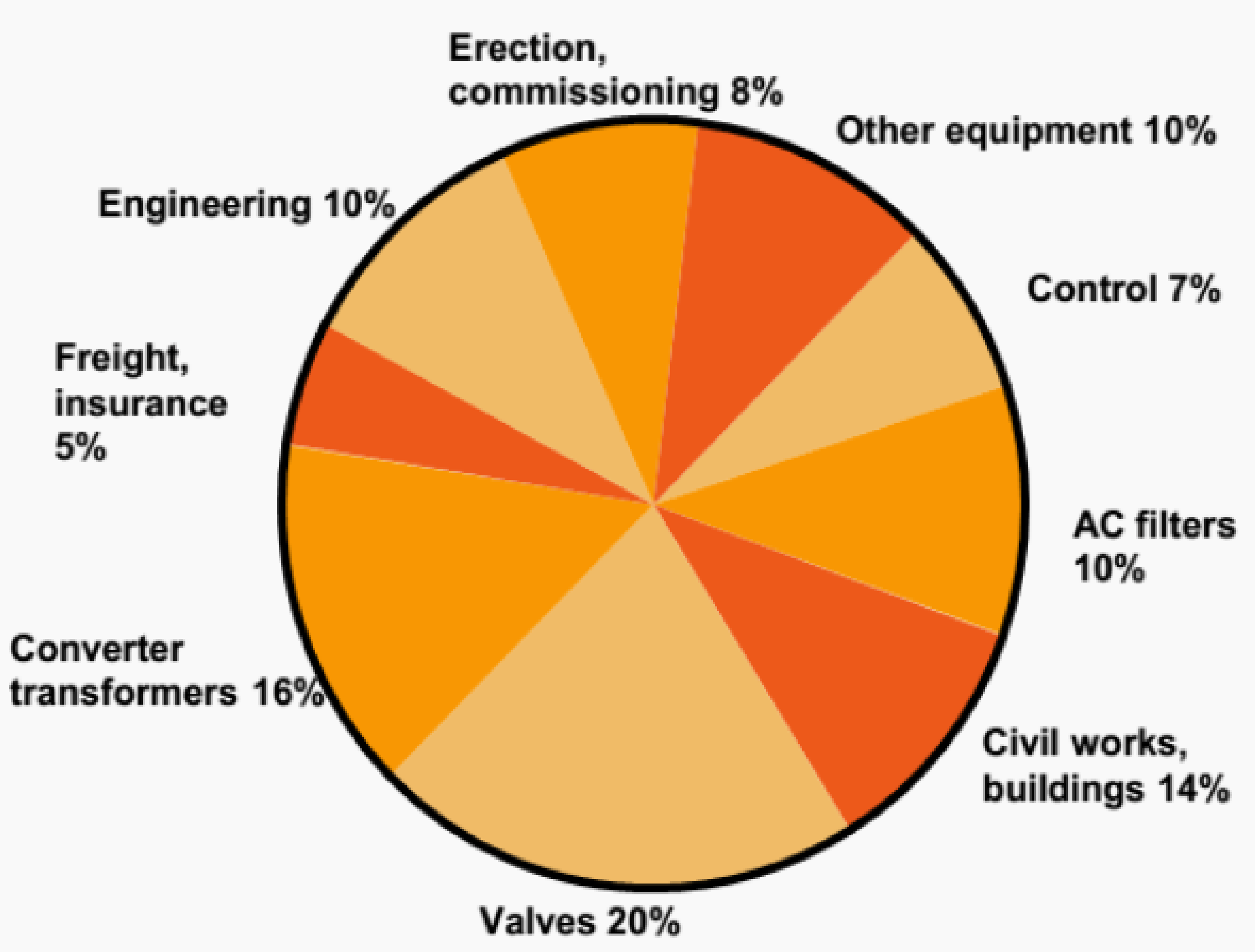
- Differentiate between “one-time failures” and systemic or design problems.

- Obtain as much information as required and especially any failures report (i.e. Transformers)

Performing the assessment

- Look for trends over a long period and be careful if only short term data is available (i.e. Thyristor failures)
- Consider critical spares and usability (i.e. DC bushings)
- Develop an evaluation criteria for each major piece of equipment or system (i.e. age, spares available, obsolescence, skills of staff to maintain)
- Look at equipment with good performance to see if a major drop off with age is possible. Cooling systems at 25 years are okay but will they last another 15 to 20 years?

Cost of HVDC


Erection, commissioning 8%
Other equipment 10%
Engineering 10%
Control 7%
Freight, insurance 5%
AC filters 10%
Converter transformers 16%
Civil works, buildings 14%
Valves 20%

Cost of Converter Transformers and Valves

- The Converter Transformers and Valves have the largest cost implications and thus the focus should be on these first
- The costs will vary from project to project, so are only representative
- If you add in the cost of engineering, shipping, erection and commissioning, the two make up about 50 % of the total costs

Converter Transformers

- Need to separate items that can affect the useable life versus items that can be readily available and inexpensive to replace (i.e. Core, windings and DC Bushings)

- Why DC bushings – Must be replaced with exact make and model above 150 kV, Replacements may not be readily available or very expensive.

- AC bushings, tap-changer coolers and controls are usually considered not a “Driver”

- May need to consider protection, cabling, oil spill containment
  - losses, original design flaws

Life Times of Components

- Life time does not mean end of life but means should be reviewed prior to see if there is any remaining life if no problems up until then
- Converter transformers - 35 to 40 years
- AC Bushings - 25 years
- DC Bushings - 30 years
- Tap-changer –350 000 operations or 30 years
- Coolers – 30 years
- Controls – 30 years

Core and Coils - DGA

- Rogers ratios, Duvals Triangle, Doernenberg
- IEC 61181, IEEE C57.104
- Manufacturers DGA - guidelines
- Large Company DGA – guidelines
- Which method does the Instrument test use (i.e. Morgan Schaffer)
- Trending Most important – increasing or stable, loading
- Analysis may be difficult as there may be multiple problems

Furan Analysis and Degree of Polymerization

- Degree of Polymerization 200 to 1000 (new) IEC 60450
- 2- FurFural correlation with cellulose degradation
- Correlation to CO2/CO ratio between 3 and 10
- Contaminants can really influence the results
- Again trending is important

Other Information

- Transformers failure reports
- Discussions with site staff (O&M)
- Visit to site
- Design issues as known

AC and DC bushings

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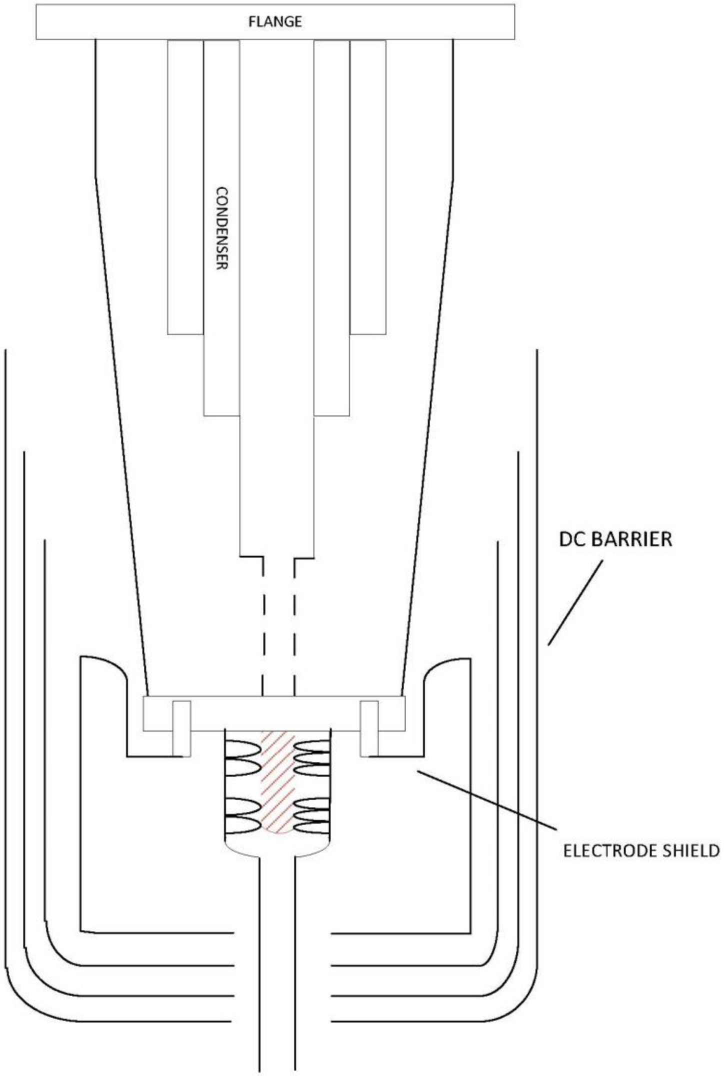
- Measurements of C1, C2 and Dissipation Factor with trending
- Above is a careening test only: If OK bushings can still fail dielectric voltage
- Oil sampling (OIP) – Nitrogen cap and contamination
- AC Bushings – Dielectric tests on two bushings– failure can rupture tank
- DC Bushings - Dielectric tests on two bushings – Spares if over 150 kV DC, Obsolescence
- DC Bushings may need to replace DC leads DC barrier, new RIP bushings, Costly

DC bushing Barrier



Decision Criteria – Number and Weighting

- Age
- DGA Results
- Furan analysis
- DC bushings Health and spares
- Design problems
- Failures
- Other may be site specific – Transport of replacements

Remaining Items - If transformers retained

- Tap-changer - 30 years or 350 000 operations (OEM analysis) - normal 6000 to 12000 operation per years
- Cooler – Efficient tests
- Control cabinet - Refurbishment – separation of power and control voltages
- Replacement of OTI, WTI, PDR with better versions, electronic
- Other problems and concerns – Oil leaks, etc.

Thyristor Valves - Custom equipment

Item to consider:

- Thyristors
- Cooling System Pipes
- Reactor Modules
- Damping Circuits (R/C)

Thyristor Valves - Custom equipment

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Item to consider:

- Valve Base Electronics including fiber optics
- Valve Arrestor
- Support Insulators
- Fire Design

Refurbishment

- Even though this is custom equipment most parts can be sourced if the general condition of the other parts is okay
- Example – One utility replaced the cooling pipes from a supplier for $ 6.0 M CAD whereas to replaced the valves was estimated at $ 200 M CAD at that time, payback ½ year. This extended the life by 18 years and counting
- Parts may be available from the OEM or other but some engineering is likely required
- Part of the assessment needs to be the risk versus the cost saving

Thyristors

- There does not appear to be a definite life for Thyristors subject to design and quality issues, Cahora Bassa Congo end since 1976 (40 years and tests indicate life left)
- Nelson River BP2 - 38 years and counting
- OEM will not likely supply after 20+ years so spares a large issue and costs
- Thyristor manufacturers have offered to custom supply and some have off the shelf replacements

Cooling Pipes

- Leaks, plugging and grading electrodes are concerns
- Cooling pipes, manifolds and fittings are made of PEX, and other types of plastics likely will have a life less than 40 years, 25 to 30 years require an evaluation
- Look for cracks, thinning, connectors, deposits and leak history
- Plastics suppliers or the OEM can generally supply replacements

Reactor Modules

- Limit di/dt and help commutation performance
- Plugging, overheating and iron core red dust are common causes
- Flow testing, ductoring connections and regular inspections, temperature strips for overheating
- OEM supply for 20 years but can custom supply after but costly – Nelson River BP 2 – 25 spares for $ 1.5 M CAD
- Additional spares can extend the life

Damping Circuit

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- RC damping circuit limits dv/dt and supplies power to the Valve electronics
- Resistor may be water cooled so plugging and overheating similar to reactor modules
- Should last 40 years if no design or quality issues
- Capacitors – Damping and valve voltage grading may be oil filled representing a fire hazard

Valve Base Electronics

- Provides communications to the Thyristor Valves for firing and monitoring of performance and failure
- Fiber Optics provide isolation from ground potential to high voltage
- Limited number of spares can technically limit the life of the VBE
- Replacements can be found for VBE parts from the OEM or others including the fiber optics but will be expensive

Valve Base Electronics

- Analogue VBE parts can still be sourced – can have 40 years life
- Digital VBE only from OEM and 12 to 15 years life
- Fiber optics – Failure of the protective outer jacket is common as well as the connector and electronics
- Cleaning of the fiber optic channel is a challenge and flashovers due to moisture or water leaks

Valve Arrestors

- Valve arrestors are similar to other DC arrestors and should have a 40 year life subject to design or quality issue and number of operations
- Zinc Oxide – can measure current leakage rate
- For a gapped arrestor you would need to high voltage test two units minimum
- Regular physical inspection for broken sheds, cracked discs if accessible.

Support Insulators

- Valve support and bus standoff insulators are subject to intense vibrations due to the valve reactors
- Grout failures, cracking of standoff insulators are areas of concern but most should last 40 years
- Spares are not an issues as there are many potential suppliers

Fire Design

- Many of the older valves did not have fire as a consideration in the design
- Fire barriers to reduce the chimney effect as well as self extinguishing materials were not considered
- It was thought the valves would not burn but several valve fire changed this thought process
- Need to be considered as part of the life extension assessment when replacing parts or if fire barriers can be added/retrofitted

Evaluation

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- Set up criteria as per the above with weightings and numbers for good or bad

- Weightings will depend on the criticality of the part causing the problems and the probability of obtaining replacement parts. May be different from link to link

Environmental and Regulatory

- Environmental issues are the same as any other project but the number of issues Scope and Costs may be greater
- Items such as asbestos, PCB’s, oil spills, Glycols, need to be considered
- Regulatory – for any major refurbishment or replacement there will like be many licenses and hurdle to face, at various levels of government.
- These costs need to be included in the Techo-economic Evaluation

Techno-economic Evaluation

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- Most difficult part of the process may to justify with Business Case analysis
- Need to involve Financial Specialists
- Banks may required financial models
- Determining the discount rate (interest minus inflation) and the refurbishment period (15 or 20 years versus new 35 to 40 years) can affect the outcome.
- Difficulty in determining the cost of forced and scheduled outages and increasing unreliability and unavailability
- May need to consult power sales marketers

Summary

- A good maintenance program such as Reliability Centered Maintenance (RCM) is essential to keep the equipment in condition for extension and provide records for review
- A Root Cause Analysis (RCA) process is essential to maintain high reliability and provide detailed information for cost effective life extension
- It is essential to have a highly knowledgeable team of specialists with expertise in the key areas as some life extension projects have not had a good outcome with the improvements to Reliability and Availability and Maintainability (RAM) not as effective as what is possible

Summary

- It is desirable to do a “lesson learned” a few years after the life extension to see what worked well and what could be improved.

References

- CIGRE Working Group B4.54 TB 649 Guidelines for the life extension of HVDC Systems February, 2016 – Convener L.D. Recksiedler
- EPRI – P162.001 Life Extension of Existing HVDC Systems

Questions? Thank you