MANITOBA HVDC RESEARCH CENTRE,
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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


• Cahora Bassa – Mozambique +/- 533 kV 1800 Amperes – commissioned 1976 ( Exp – 2007 to ongoing)

• Eight other HVDC projects – Part of a team or individual
• 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) – 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

- 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

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 replace 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
• 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

- 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
• 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
• 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 likely be many licenses and hurdles to face, at various levels of government.

- These costs need to be included in the Techo-economic Evaluation.
Techno-economic Evaluation

- 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.
• 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