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LIFE EXTENSION OF NELSON RIVER HVDC SYSTEM

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SUMMARY

Nelson River Bipole 1 was built as a mercury-arc valve scheme between 1970 and 1977. Bipole 2 was commissioned in 1978 (stage 1) and 1984 (stage 2) as a thyristor valve scheme. Nelson River Bipole 2 was the first commercial HVDC scheme with water cooled thyristors. The two bipoles transmit more than 70% of Manitoba Hydro's total power from remote northern generation to the load centre in the south.

Today's operational environment demands increased HVDC system performance, which in many cases exceeds the original equipment capabilities. This, coupled with equipment that is approaching the end of its design life, has presented additional challenges beyond the standard maintenance requirements facing the Nelson River HVDC system over the last thirty years. Equipment upgrades, replacements, and process improvements have enabled Manitoba Hydro to adapt to these demands and extend the life of the HVDC facilities.

Replacement of Bipole 1 mercury-arc valves, upgrading of Bipole 2 cooling system, purchase of spare converter transformers, replacement of Bipole 2 thyristor module tubing, replacement of Bipole 1 and 2 smoothing reactors, implementation of a reliability centered maintenance, staff training and condition based monitoring are examples of recent initiatives geared towards improving HVDC transmission system performance.

This paper provides a description of these measures and the reasons for implementing the upgrades. The impact of these improvements upon the system unavailability is also described.

KEYWORDS

Life Extension, HVDC, Valve Replacement

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1. INTRODUCTION

The Manitoba Hydro electrical system supplies the province of Manitoba. The peak load of Manitoba Hydro is approximately 4400 MW and the installed generating capacity is 5700 MW. Nearly 70% of this power is generated from three hydraulic stations on the Nelson River in northern Manitoba and is transmitted by two HVDC bipoles to southern Manitoba.

The Nelson River HVDC transmission system consists of two bipoles (Fig 1). Bipole 1 has a rating of 1854 MW at ±463kV and transmits the power from the northern terminal at Radisson Station over a distance of approximately 900 Km to the Dorsey terminal near Winnipeg. Bipole 1 originally went into service with mercury-arc valves, Pole 1 installed from 1970 to 1972 and Pole 2 followed with installation from 1975 to 1977. Pole 1 mercury-arc valves were replaced with thyristor valves from 1991 to 1993. The best performing Pole 1 valves were salvaged for use in Pole 2. This provided a surplus of spare parts, making it possible to defer replacement of the Pole 2 mercury-arc valves in until 2004.

Bipole 2 has a rating of 2000 MW at ±500kV and transmits the power from the northern terminal at Henday Station, approximately 40 km downstream from Radisson, to the Dorsey terminal. Bipole 2 went into service from 1978 (stage 1) to 1984 (stage 2 and 3) and consists of thyristor valves. Bipole 2 was the first HVDC system in the world to use water-cooled thyristor valves.

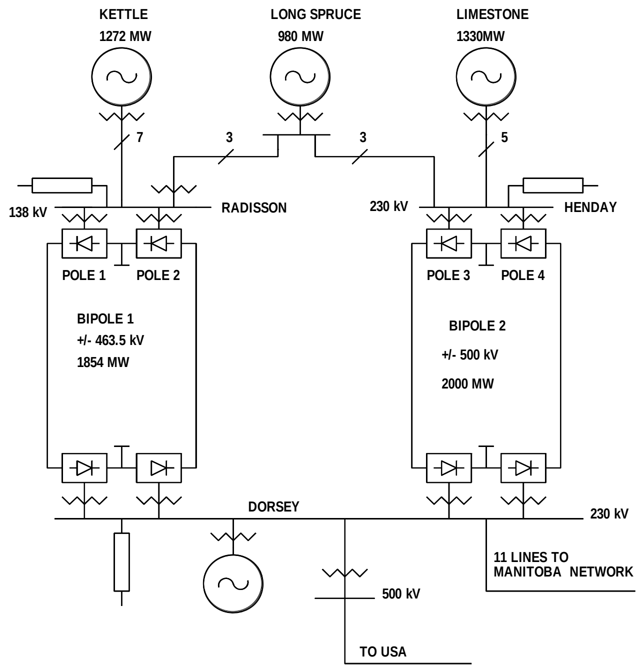

Figure 1: Nelson River HVDC System

Changes in the operating environment have imposed restrictions and increased demands on the HVDC system. Forced outages are very undesirable and scheduled outages for maintenance purposes are difficult to obtain. Major equipment, with projected life from 25 to 30 years, has already reached the end of life or is unable to meet the enhanced operating requirements. Safety and environmental issues were also major initiatives driving some equipment replacement.

2. OPERATING HISTORY

Prior to 1991, the Limestone Generating Station was not in-service and as a result the HVDC system was not fully loaded, thus making occasional forced outages and scheduled outages tolerable and less costly. When Limestone Generating Station came on line in 1991, the HVDC system was essentially fully loaded, with any HVDC outage creating a potential bottleneck for generation. As Manitoba Hydro's HVDC system transmits more than 70% of Manitoba's generation to the southern load centers,the availability and reliability of the system is very important.

Following the power industry deregulation (circa 1996), the operating environment for the HVDC system significantly changed. The HVDC system is experiencing increased utilization and is required to operate at a higher level of reliability. The higher price of energy also puts economic pressure on the HVDC operation.

3. SYSTEM IMPROVMENTS

In order to meet the continuous demands for high reliability and availability, a number of system improvements either have been implemented or are planned. The justification for these improvements was based on one or more of the following reasons:

- Equipment performance
- Equipment age (maintenance cost)
- Equipment maintainability (spare parts)
- Environmental issues
- Safety issues

The following system improvements have been completed or are currently underway:

3.1 Bipole 1, Pole 1 Mercury-Arc Valve Replacement

As the mercury-arc valves were prone to arc-backs, these valves required continuous refurbishing. It was also not possible to buy spare parts for these valves. As a result Pole 1 mercury-arc valves were replaced with thyristor valves in 1992/93. The parts from the valves removed from Pole 1 were salvaged and used to extend the life of the Pole 2 mercury-arc valves. The analog controls for the Pole 1 valve groups were also replaced with a new version of analog controls. The outage time for each converter changeout was 10 weeks.

3.2 Bipole 1, AC and DC Filter Reactors

The original AC and DC filter reactors supplied for the Bipole 1 were oil filled. In addition, these filters were self-tuning and used a hydraulic mechanism to rotate the core for tuning. The reactors were contained in porcelain housings, which was prone to cracking during sudden ambient temperature changes. This resulted in numerous oil and the hydraulic fluid spills. These reactors also required a cooling system to maintain the oil temperature at acceptable levels. To continue with oil filled reactors would require installation of fire barriers and an oil spill containment system. In order to eliminate these problems it was decided to replace the oil filled reactors with air core, air insulated reactors. This also eliminated all the maintenance problems.

3.3 Converter Transformers

Bipole 1 has 18 single-phase, three winding transformers at the inverter end and 18 single-phase, two winding transformers at the rectifier. Since 1993, six transformers have failed in service. Bipole 2 has 16 three-phase, two winding transformers. Eleven of these transformers have failed in service and an additional eight transformers were either replaced or repaired prior to actual failure (some units were repaired more than once). Initially there were no spare transformers available on site and as a result the converters were out of service for a long period (1.5 to 19 months) until the unit was repaired or replaced.

In an effort to minimize the outage duration associated with transformer failures, spare converter transformers have been purchased and significant work toward optimizing the change out process has been completed. Procedures, drawings, and modification packages are available for all transformers such that a transformer replacement can be achieved in nine days or less, a vast improvement to the initial thirty days or longer. Transformers are now moved into position full of oil and fully dressed.

Additional on-line monitoring of all transformers has been completed to evaluate the status and determine remedial action necessary to prolong suspect transformer life until spare transformers are available.

3.4 Bipole 2 Tubing and Header Replacement

As a result of increased failures, Bipole 2 thyristor module cooling tubes are currently being replaced. The original tubing was a polymide material, which started to fail after fifteen years. The replacement tubing is a Teflon based material, specified for a minimum of twenty-five years with a zero fire rating. Over the last four years, the headers in the modules have started to leak and these are also being replaced. The replacements are being carried out by taking short outages over weekends. The replacement program is expected to be completed in two years.

3.5 Bipole 2 Thryistor Firing Units

Beginning in 2000, after nearly 15 years of operation, the thyristor firing units started to overheat and in few instances caught fire. The cause of overheating was found to be cracked solder joints. A two week outage was taken on each converter to re-solder all of the firing units.

3.6 Wall bushings

The converter valves are connected to the transformer and the dc switchyard through wall bushings. The original design of these wall bushings for Bipole 1 and Bipole 2 were of the oil filled porcelain housing type. Initially these bushing had many flashovers during light rain. This problem was solved by installing booster sheds, which have worked successfully. In 1987 one wall bushing caught fire and the converter was out of service for 2 months. The bushings are now tested on a regular basis. As the Bipole 1 bushings were showing signs of deterioration they were replaced with the RTV type bushing.

3.7 Pole 2 Mercury-Arc Valve Replacement

Due to the continuous problem with spare parts for the mercury-arc valves and the excellent performance of the Pole 1 thyristor valves, it was decided to replace the Pole 2 mercury-arc valves in 2004. However, the original analog controls were not replaced. An interface to the valve base electronics was designed in-house. In order to reduce the outage time, single valves were pre-assembled and rolled on the same bases used for mercury-arc valves. The outage time was reduced from ten weeks to four weeks.

3.8 Bipole Outage Reduction

In 2000 a task force evaluated the root cause of bipole outages and recommended methods for prevention. The review was initiated based on the unacceptable performance of one bipole outage/year/bipole.

Recommendations have been prepared for separating and upgrading systems common to a bipole. The final design criteria will achieve separation of equipment on a pole basis similar to what would be provided for a new HVDC system. The bipole outage rate for the last ten years has been reduced to 0.2 bipole outages/year bipole.

3.9 Smoothing Reactor Replacement

Bipole 1 and 2 were supplied with oil filled smoothing reactors. These reactors are now more than 33 years old. As they have been subjected to many ac system faults and dc line faults, the core inside has become loose. In addition, the bushings are showing signs of insulation degradation. It has therefore been decided to replace the oil filled reactors with air core type. This eliminates not only the electrical problems but also the maintenance, fire risk and oil spill issues.

4. EFFECT OF LIFE EXTENSTION MEASURES ON SYSYTEM AVAILABILITY

Prior to 1998, the maintenance on each converter and pole equipment was performed annually. As a result the system was unavailable for 4.38% of the time for maintenance alone. In 1998 Reliability-Centered Maintenance (RCM) [1] was adopted as the maintenance program for the HVDC system. The objectives of the RCM program are to optimize maintenance costs, increase system availability, and improve system reliability. Optimizing maintenance processes directly affects scheduled outages and maintenance costs.

One of the key processes in an RCM living program is the analysis process. This process focuses on the maintenance effectiveness in the system operating context, which will support the decision of extending or replacing of assets. The RCM maintenance schedule was established as follows;

Valve Group Maintenance	Once every 4 years for 7 days
Pole Maintenance	Once every 4 years for 48 hours.

Using the above scheduling, the planned maintenance unavailability would only be 0.62%. **This would be the expected maintenance unavailability of a brand new HVDC system.**

However as the system was getting older, various components of the system had to be either replaced or refurbished in order to maintain the forced unavailability at an acceptable level. The life extension work described in section 3 was performed by either extending the normal maintenance outages or by planning a special outage. In addition to these planned outages, there were a number of deferred outages (as per CIGRE PROTOCOL [2]) required to make minor repairs to the system.
Table 1 shows how the Nelson River Bipole 2 unavailability is affected by the life extension and deferred maintenance work after 22 years of service and onwards.

The numbers show that in order to maintain the forced outage unavailability at acceptable levels, equipment must be taken out of service for periods longer than normally planned RCM maintenance to make additional repairs or replacements.

Table 1

Bipole 2 AGE	% UNAVAILABILITY			
YEARS	PLANNED	DEFERRED	FORCED	RCM
22	1.96	0.91	5.82	0.62
23	0.88	0.68	18.42	0.62
24	2.74	1.05	0.41	0.62
25	1.68	1.21	0.16	0.62
26	1.80	1.13	0.39	0.62
27	1.54	0.53	0.61	0.62
28	1.17	0.73	1.62	0.62
29	1.18	1.27	0.67	0.62
30	1.15	0.97	0.64	0.62
31	1.74	1.52	2.08	0.62

An EPRI report [3] on Life Extension of HVDC Systems provides a guide for the life time of various components of an HVDC system. Figure 2 shows the percentage of equipment with their expected life time as per [3]. In the figure 2, each component is treated as being the same regardless of the size of the equipment. For example, figure 2 shows that 16% of the components have a life time of 20 years and 14% of the components have life time of 25 years, etc.

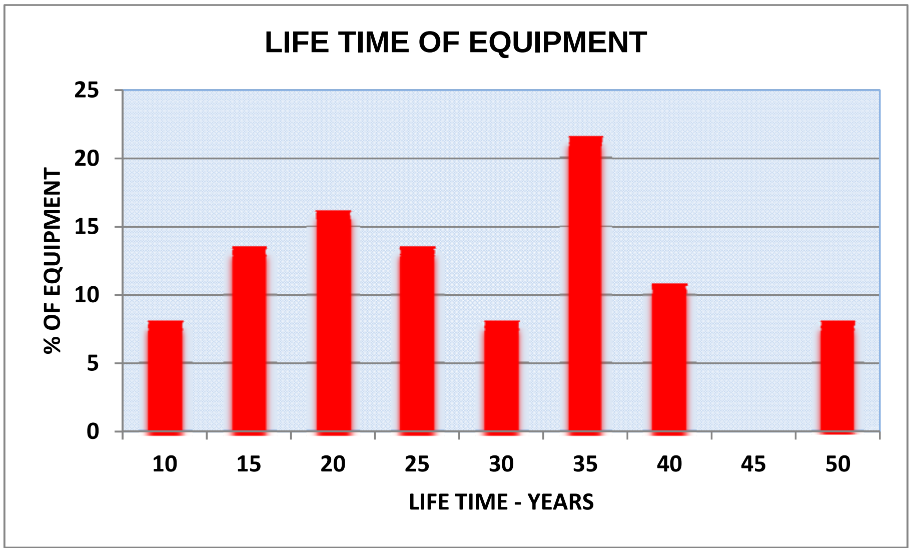

Figure 2 – Expected Life Time of Various HVDC Components

It can be concluded from figure 2 that life extension measures start after 10-15 years of service and would continue to be required periodically throughout the life of the project.

Figure 3 shows what percentage of the equipment would have to be replaced if the HVDC system was to operate for 50 years. It should be noted that during a span of 50 years some components with shorter life times (10-15 yrs) would be replaced more than once. Digital controls may fall into this category.

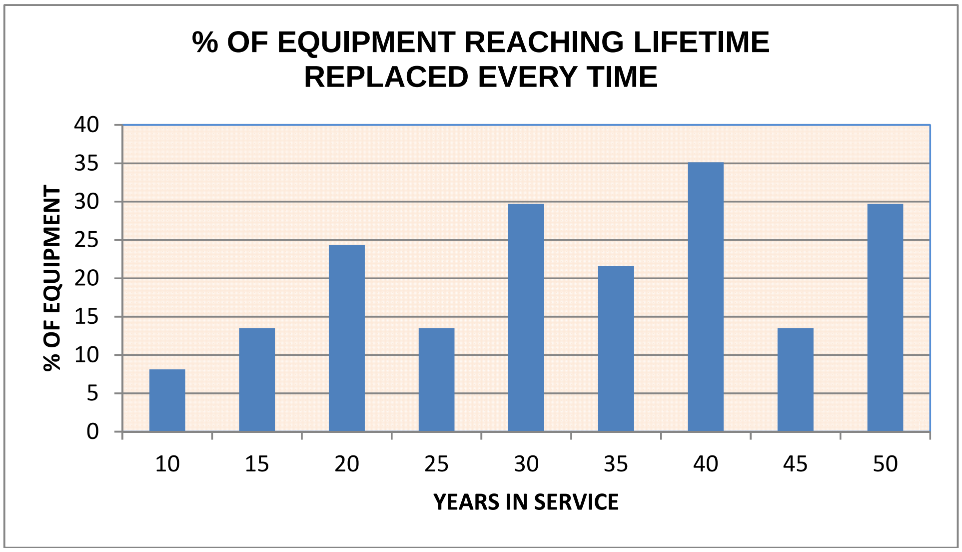

Figure 3 – Percentage of Equipment Replaced vs Years of Service

The increase in outage requirements for Nelson River Bipole 2 is consistent with what would be expected as per figure 3.

5. CONCLUSIONS

When the HVDC equipment is first commissioned, the planned/deferred outage requirements for repairing equipment other than regularly planned maintenance are very small or zero.

Once the equipment is 15 years old some components begin exceeding their expected life time and the requirement for additional outages starts to increase.

After approximately twenty years of service, major life extension measures may be required.

The effect of the additional outages on the system requirements and the life cycle cost should be taken into account.

6. REFERENCES

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[2] "Protocol for Reporting HVDC System Performance", SC14-04

[3] EPRI, Life extension guidelines of existing HVDC systems, EPRI Guideline 0682819-2, Dec 2007.