Question 14:
What are the pros and cons of the two different upgrade approaches? Which plans are there for mercury arc or thyristor based HVDC schemes upgrades, and how will these be implemented? Which components in thyristor based schemes will require upgrading/replacement and is this driven by manpower considerations, spares availability and/or reliability?

From the experience gained with three major HVDC refurbishment projects:

- Cahora Bassa – Apollo (based on thyristor valves, figure 1), first commissioned in 1975;
- Madawaska thyristor replacement;
- Celilo Mercury Arc Replacement Project (figure 2);
- Nelson River Pole 2 Mercury Arc Replacement;

a number of observations can be made with respect to Question 14. These observations would be valid regardless whether the schemes are thyristor based or mercury arc based (only two of which seem to be remaining worldwide).

**Figure 1:** Oil insulated and oil cooled outdoor thyristor valves in the ± 533 kV Apollo HVDC Station near Johannesburg, South Africa

The direct unit-by-unit replacement of converter valves would appear to be the lowest cost option. It is an excellent method to extend the useful life of a facility, provided the other equipment such as converter transformers, smoothing reactors, bushings, etc. can be made to last long enough also. The expenditure needed to refurbish those also can be spread out over a longer period of time, making this option more affordable in a difficult economic environment. Also, the existing control and protection systems may be kept in place with only minor adaptations as desired by the owner. It may be considered a drawback that any upgrades in terminal rating are tied to the capability of the remaining equipment.

The economics of the unit-by-unit replacement would be largely dependent on the availability of detailed design documentation for the existing station as well as the human factor: the success of both the Celilo and Nelson River Pole 2 replacement projects was possible because the respective owners had available in their organizations a competent and well trained engineering and operator/maintenance staff. The owners thus did all the infrastructure, assembly and commissioning work with just supervision provided by Siemens.
A major factor contributing to a short downtime as achieved in the Nelson River Pole 2 replacement would be the existing station layout. Given the extensive space required for handling, moving, and maintaining the original mercury arc valves, it was possible to pre-assemble all replacement valves for a group and roll them onto the existing valve stands (figure 2) within hours. Thyristor based installations in most cases do not afford nor require the same ample space. Still, given the power density of modern direct-light-triggered thyristor modules (the device shown in figure 2 of paper 203 can be made to serve as a complete valve of a 600MW twelve pulse group), and with the help of some temporary facilities at a small cost premium, it does not appear unrealistic to get close to the same downtime of 30 days for replacing the quadruple valves of early air insulated thyristor installations, should that be felt to be desirable.

Wholesale replacement of a complete converter station/converter pole may be the method of choice in two situations:

- When the life expectancy of equipment other than valves does not warrant the expenditure for replacing the valves only.
- When an existing transmission line/cable supports a substantially increased rating and the projected increased power sales justify the higher expenses spread over a short time period.

![Figure 2](image)

**Figure 2:** Six direct-light-triggered roll-on thyristor valves replacing one mercury arc valve group rated 133kV, 2000A at the Celilo Converter Station of the Pacific HVDC Intertie.

HVDC thyristor valves generally have an excellent reliability record as documented in the biannual reports of AG B4-04 (formerly WG 14-04). It would appear that in most cases they outlive the other components of the station, especially rotating equipment in the auxiliary services. HVDC thyristor valves are designed for off-site or on-site component replacement, should the need arise, and the manpower requirements and expenditures for maintenance typically are reported to have been minimal with a few exceptions.

In one case where the valves are based on a specific early thyristor technology, ageing of some part of the packaging of the wafers seems to have been the cause for increased failure rates resulting in high cost for replacement parts and manpower for maintenance, as well as decreased reliability. This was rather economically cured by just replacing the thyristor/heat sink pack with a different design and leaving all other components in the valve in place.

On the other hand, older designs of HVDC thyristor valves included a host of auxiliary components that experience statistical failures, especially in the gate electronics. It is not uncommon that after 30 years the
original manufacturers went out of business or have discontinued the respective production line so that it is becoming difficult to obtain replacement parts. One example would be the Cahora Bassa-Apollo system, the first contract using thyristor valves and the only one using oil insulated valves (figure 1). There, 30 years after manufacture, it was found that some manmade material used in the oil filled tank has mechanically degraded and new sources for replacement parts have to be found.

Few of the existing thyristor based HVDC stations are alike, as are the practices and strategies of their owners. Therefore, it would appear that no general answer can be given to the last part of question 14 in the Special Report. However, the human factor also comes in: as the operators/maintenance staff of the early thyristor based stations have signed on early in their professional lives when the facility was commissioned and are now about to retire taking their expertise with them, it may well be that some owners give second thought to purchasing modern technology for replacement of their ageing equipment.