

Konti-Skan 1 HVDC Pole Replacement

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Abstract--Konti-Skan's first DC link went in to service in 1965 connecting Sweden and Denmark. Its utilisation has been high and with new cables laid in the 1990s, replacement converters for one pole with higher rating are now being installed. The new pole replaces the existing Pole 1, increases the transmission rating and will permit bipolar operation with the existing Pole 2. The new Pole 1 equipment will be housed alongside Pole 2 at both Vester Hassing, Denmark and Lindome, Sweden. This paper describes the two installations. Thyristor valves, each containing 36 x 125mm thyristors for 285kV, will be used. Control arrangements for reduced DC voltage to allow for conditions of poor overhead line insulation, whether in monopolar or bipolar operation and for various overload conditions are described. Very stringent ambient noise limitations are a special feature of this scheme compared to others and the alternative approaches to this question will be discussed.

Keywords - Interconnection (power), HVDC, Valves - suspended, Audible noise, Frequency control.

1. INTRODUCTION

Konti-Skan has been in service for almost 40 years [1]. It forms an essential link between the energy resources of Sweden and Denmark, as well as one of the asynchronous interchange paths between the NORDEL and UCPE systems. A new cable for Pole 1 was commissioned in the 1990s. It allows for higher ratings than the existing Pole 1 converter equipment which being mercury-arc requires high maintenance. A completely new converter station at each end is therefore now under construction, located adjacent to the existing Pole 2 converters, but within the existing station's boundary and due to go into service in 2005.

A single-line diagram is shown in Figure 1. The link has lengths of submarine DC cable totalling 87km and of overhead line totalling 61km. There are existing electrodes, connected via cables and overhead lines, none of which are being altered from the existing installation. Formerly the two pole converters were separate geographically at the Swedish side.

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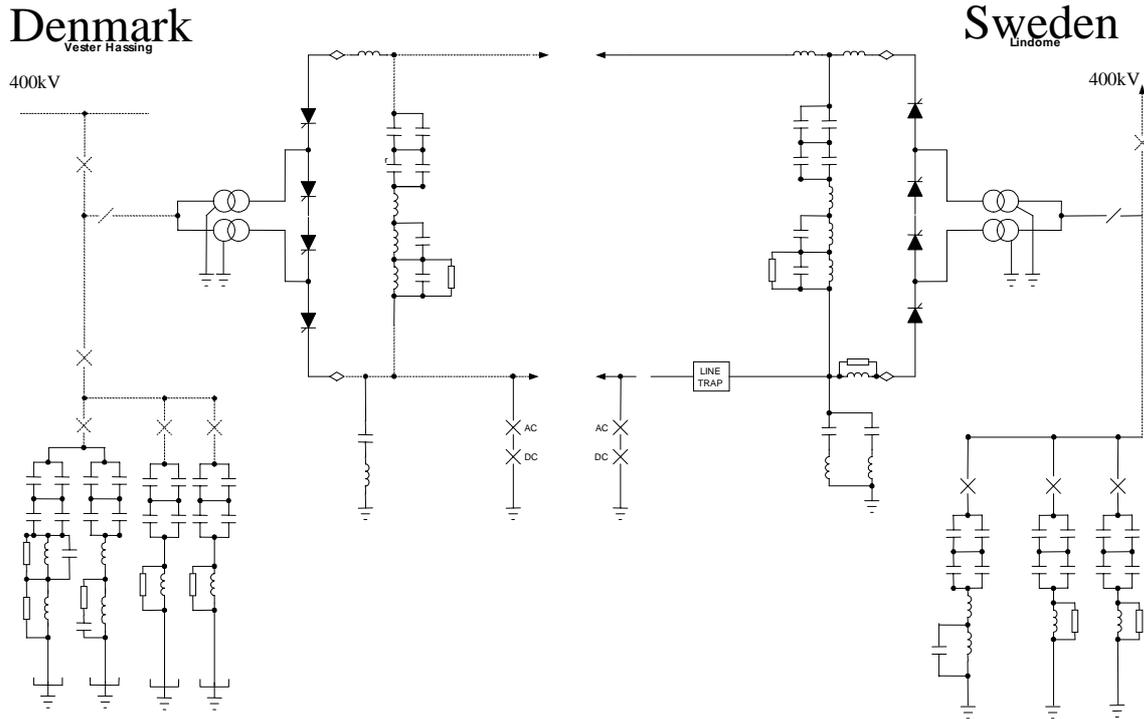


Figure 1 Single line diagram

2. SCHEME PARAMETERS

The former Pole 1 of Konti-Skan was rated 250kV at 1000 amperes, but since new cables of higher rating have been installed the new pole will be rated 285kV at 1350 amperes, 380MW. Power is reversible. At both ends of the cable lengths (87km total) there are sections of overhead line of 52 and 10km. To allow for poor insulation conditions, the DC voltage can be reduced to 80% at full current and for short periods at full power (requiring in this case all cooling to be available).

The AC systems on each side are at 400kV and relatively strong. The lowest extreme fault level is a drop to 1000MVA, giving an ESCR of 2.16. To minimise the step change when power direction is reversed, a minimum direct current of 3% can be carried continuously. When changing direction, there is a short delay between blocking current at 3% and restarting at 3% at inverse voltage, to give an effectively continuous rate of change of power through zero.

Independently of these various conditions, the new pole will have a Forced-outage rate of no more than 5 events per year.

The scheme is rated to offer a reactive power exchange at the converter station busbars of ± 65 Mvar on the Danish side and ± 40 Mvar on the Swedish side or a little more at low power levels. To limit the step change in voltage when a filter is switched, the reactive power change on switching under normal operating conditions is limited to 65Mvar. Filter sizes have therefore been selected as 3 x 60Mvar on the Danish side and 1 x 45Mvar and 2 x 66 on the Swedish side. The filters are listed in Table 1. At each station there is both an open-loop control to ensure sufficient filters are in service for the power being transmitted and a closed-loop control to give either automatic AC voltage control or Operator-controlled exchange of reactive power with the AC system. The open loop control has priority.

Switching Sequence	Danish Side		Swedish side	
	Mvar	Filter type	Mvar	Filter type
First	60	3 rd /27 th double damped plus 11 th /13 th double-tuned	45	11 th /13 th double damped
Second	60	12 th damped	66	11 th damped
Third	60	12 th damped	66	11 th damped

Table 1: AC Filters for Konti-Skan Pole 1 Replacement

3. VALVE DESIGN

A recently modernised design of liquid-cooled valves, denoted as the H400 series, is being installed. Following the well-established H300 “banded pair” technology [2] in which two thyristors were clamped by glass-fibre bands to their heatsinks, the same principles have been applied. In the H400 technology, up to six thyristors and heat sinks are clamped by similar glass-reinforced plastic (GRP) tension bands, see Figure 2.

These provide the high clamping load necessary for good electrical and thermal contact between thyristor and heatsink. The straps also maintain adequate dielectric strength to support the voltage stresses experienced during the off-state intervals of the valve. The clamping system facilitates replacement of a thyristor without opening any power or coolant connection.

Adjacent to each clamped assembly are the damping resistors (also liquid-cooled), damping capacitors and gating electronics, and the electrical circuit is completed by a rate-of-change (di/dt) limiting saturating reactor. The six thyristors in a clamped assembly together with their grading components, gating electronics and di/dt reactor, are known as a ‘valve section’ and form the electrical building block in the circuit (Figure 2). Two such electrical valve sections are housed within a module. The mechanical support for the sub-assemblies within the module is provided by flame retardant GRP beams and aluminium end frames, the latter also forming part of the low-resistance power circuit. The valve section can be fully tested as a package in a new valve-test facility.

Each thyristor will be a 125mm 8.5kV (forward or reverse repetitive withstand potential) electrically triggered device. Each has its own damping and grading circuits so that all electrical stresses are shared between thyristors as closely as possible. Each thyristor is also protected by an electronic over-voltage protection that fires it if the forward voltage or its rate of change (dV/dt) exceeds a threshold characteristic. The primary purpose is to protect the thyristor if a firing signal is not received due to a failure of a fibre-optic or a signalling device. An additional benefit gained by the local electronic protection being integral with each thyristor level is that the protection settings are dynamic. They can be made compatible with the actual operating parameters of the individual level, rather than a gross approximation for the entire valve.

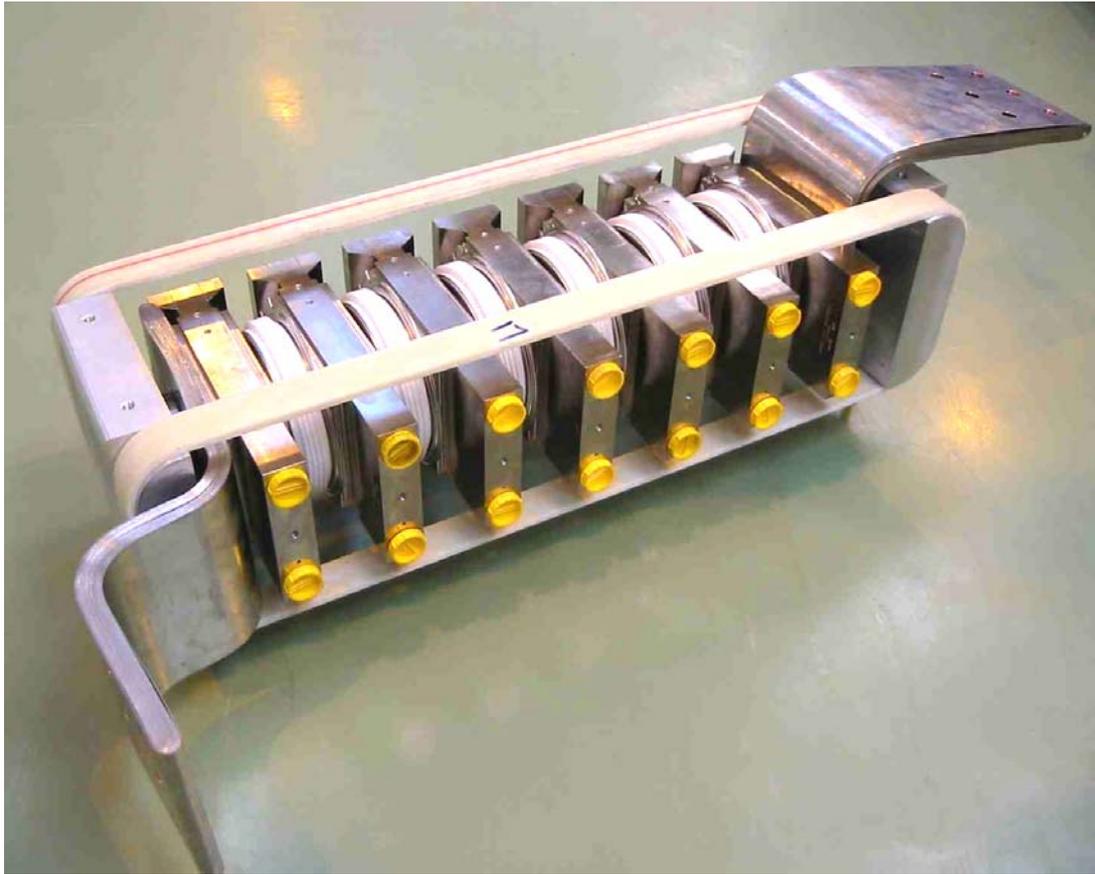


Figure 2: Hex group of 6 thyristors with bands, heatsinks and power connections

Continuous operation is possible at any power level when such a failure exists, with a failure in one or two thyristor levels within a valve, including the situation of power throughput as low as 3%. Component ratings are sufficient for the extra stress of this continuous firing via electronic protection at low current, ensuring good reliability of the scheme between scheduled maintenance periods. In addition the reliability principles below have been applied in the design of the valves.

- To provide adequate protection of all thyristors under all credible main power-circuit fault and disturbance conditions by using a worst case limit approach (i.e. a protective system at its worst tolerance limit must adequately protect those thyristors which, because of the normal production spread in characteristics, are most vulnerable).
- To incorporate in each valve sufficient thyristor levels in excess of the minimum number required for safe operation to allow valves to remain in service in the presence of component faults. Hence two additional “redundant” thyristors are added to the minimum requirement of 34 in each valve for this project.
- To ensure, so far as possible, that no single component failure affects more than one thyristor level nor causes loss of, or reduction in, transmission capability.
- Any fault or failure is inherently safe, i.e. it does not lead to fire, explosion or other phenomenon which could have consequential effects on the valve or other equipment.
- If the occurrence of the fault affects the voltage withstand capability of controllability of the valve, it is properly indicated.

- At the maintenance outage, the faulty component can be identified and replaced in-situ without the need for removing large sections of the valve.

The design philosophy with regard to redundancy is that no component (other than the module structure, cooling water manifolds and di/dt reactor) is common to more than one thyristor level. That is, every thyristor is equipped with its own electronic gating and protection equipment and grading components. Therefore valve component failures do not affect more than one thyristor level.

To design the system to be 'fail safe' often means deliberately to contrive for some component faults to cause the thyristor to fail. This is because, even in its failed state, the thyristor itself remains the only current path through a thyristor level which can carry normal load and fault currents. Overvoltage firing protection is provided at each thyristor level and the circuit is designed for continuous repetitive operation with triggering in this mode. This protection can be electronic as opposed to the use of discreet components such as break-over diodes (BOD) at each level. The electronic protection provides the same safeguards to the thyristor as the BOD but with greatly reduced stress as it can detect the position earlier before the voltage across the device voltage is high.

Consideration has been made to safety by minimising the flammability of the valve. No component such as the damping capacitors contains free oil that could leak or combust in the presence of heat. In addition all components are generously rated, both electrically and thermally to minimise overheating. There is no potential to spread a fire among the materials and components used in the H400 valve.

4. CONTROL SYSTEM REQUIREMENTS

The stations will not be manned under normal conditions and all control and monitoring will be made at the remote operating points of the two power companies.

The existing Pole 2 has its own Master Control, but must now act in concert with Pole 1 when in bipolar mode, in order to minimise the balancing current passing through the electrodes in steady-state conditions and to share emergency power control action. There is an over-ride of the Pole 2 Master Control from the new Bipole controller associated with the Pole 1 station control.

Studies are in progress to verify the stability of the new pole and its controls in relationship both to the existing Pole 2 and to the Skagerrak HVDC system located some 75 km distant. These studies follow the principles of those reported before for the Western Indian system [3]. Stability is also being checked in relation to the recent large wind farms connected to the Danish system. These machines are induction generators. There are in Denmark combined-heat-and-power (CHP) plants that are subject to trip if the voltage falls below a given threshold. Control strategies will be sought to minimise any disturbance to these facilities caused by the DC or, for example, by a fault or interruption of power in the Swedish system. Eigenvalue analysis will examine the stability of the Danish network in all relevant frequency bands between Konti-Skan and Skagerrak, whether at full load, light load, or light load with high production from renewable generation nearby. If necessary, control strategies will be developed to counteract any instability.

Transient stability will be examined, particularly recovery following AC system faults and disturbances. Under certain faults or outages elsewhere in either AC system it may be necessary to run back the DC power order rapidly to maintain the AC voltage and the stability of either system. Power modulation in response to the frequency or rate-of-change of frequency of either system may have benefits to the two systems, for example in unusual conditions of very low short-circuit level or islanding after a major disturbance. The selection of parameters and the range of frequencies over which modulation is effective will be determined by stability studies. Similarly the possibility of a blackout, requiring that Konti-Skan HVDC to contribute to the recovery of one system, the other being healthy, will be determined.

In addition the control system must handle a variety of overload conditions, power flowing in either direction, for example:

- At 80% DC voltage and full power for one hour max (no voltage exceeding rated values) when all cooling is available at rated temperature
- 100% DC voltage, 113% DC power, emergency overload at rated temperature.
- 100% DC voltage, up to 130% DC power, at below rated ambient temperature with redundant cooling available
- Long-term emergency power direction cycling to 100% power with the ambient at 20°C or lower and to 114% power at 0°C or lower.

The DC control principles used for all these conditions will conform to the following basic concepts.

- a) Under steady-state conditions the rectifier will control DC current by firing angle (alpha) variation. Should the normal limits of alpha be reached the rectifier tap-changer will operate to change the valve-winding voltage of the converter transformer. At the inverter the same current control applies but with a current margin, so that the rectifier is normally the controller of the direct current.
- b) The inverter will control the DC voltage at the rectifier to a target value and while maintaining stability keep the extinction angle (gamma) at a minimum for economic reasons (both losses and reactive power needs). The target value is calculated by compounding the inverter DC voltage and current through the known DC resistance of the interconnection.

The control system will use Series V equipment, where separate building blocks allow the future replacement of any block with new equipment and its acceptance by the other blocks. All controls are duplicated for reliability.

5. AUDIBLE NOISE

The site at Vester Hassing in Denmark is close to a number of residential dwellings and the operator is required to minimise any noise disturbance to them. There are 8 residences ranged about 250m distant in a ring around the site in a flat area. The site itself is about 750m square. The audible noise permitted from the new equipment is only 28dB(A) at the residences, in order to meet the statutory requirement of no more than 35dB(A) at the residences. This can be compared to the reported normal ambient in a library of 40dB(A). Effectively the existing Pole 2 makes as much noise on its own as can be permitted.

Very careful measures will be necessary to deal with a diverse set of noise sources within the station. A first indication of the methods under consideration to be selected is:

- Heaped banks of landscaped earth; eyesores and probably requiring too much space
- Active noise reduction methods were considered but not found practical
- Chambers of acoustic paneling around oil-filled transformers
- Shields or shrouds built up and around air-cored smoothing reactors; must be made of a non-magnetic material (such as glass fibre which traps air for sound absorption) and not interfere with the natural convection cooling
- Shields around filters, also non-magnetic, with wall-bushings for electrical connections and ducts for air flow to remove heat
- A barn-like structure over all the filters; probably unrealistic for cost and visual impact
- Special designs of filter capacitors so that each can experiences less than normal levels of electrical stress or has a shield or jacket placed around it
- Noise suppression of cooling fans, such as slow speed operation, and passing the air through tubes or between baffles at the entry and exit to the fans to silence the transmitted noise.

6. CONCLUSION

The new pole at Konti-Skan will have the first application of a world-leading design of thyristor valves. It will act in concert with the existing pole. This project offers a technical challenge to reduce the audible noise from such a facility to a level not hitherto achieved.

7. ACKNOWLEDGEMENT

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8. REFERENCES

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