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COMPENDIUM OF HVDC SCHEMES THROUGHOUT THE WORLD

Working Group 04
of
Study Committee 14 (DC Links)

1987

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Convener : O. Hauge

1987

C O N T E N T S

Preface:

The history of Electric Power begins with d.c., and it is only for about 100 years that electricity has served mankind. Also d.c. transmission has engaged scientists and engineers from the beginning.

The first electrical central station of the world designed by Thomas A. Edison in New York, began operation in 1882 and supplied part of the city within a radius of approximately 1.6 km. This was the beginning of distribution of electrical power over limited distance.

However, soon a.c. superseded d.c. in generation, transmission and utilisation because a.c. generators are simpler and a.c. is easy to transform from one voltage into another for chosing suitable voltages for generation, transmission and distribution of power. Also a.c. was easy to convert to low voltage d.c. applications by means of rectifiers. Particularly the development of the 3-phase system merited the a.c. system further.

However some engineers were still convinced about advantages of d.c. for long distance transmission. The need of one or two conductors in stead of three simplifies the transmission line and a French engineer M. René Thury developed and designed a high voltage d.c. transmission system, about 1883, using series connected d.c. generators at the sending end and at receiving end there was a comparable number of series connected d.c. motors for driving of low voltage a.c. generators. Thus, 1983, may be considered as the 100th anniversary of HVDC transmission.

The most famous of the Thury plants was the Moutiers-Lyon system, commissioned in 1906. Its rated power was 4.5 MW which was transmitted at 60 kV d.c. and 75 A. The length of the transmission line was 180 km, and some extension was made in the period until 1912, to a total capacity of 19.3 MW whereby the voltage could be increased to 125 kV d.c. The system was in operation up to the mid-30s. When in 1922 a link across the Skagerrak between Norway and Denmark was discussed for the first time, the Thury system was considered as a possible solution for the d.c. link with a rated power of 42 MW at 110 kV d.c.

Anyhow, research into HVDC transmission was carried out in other parts of the world too, and even though the Thury principle was a proven application, direct conversion of a.c. into high-voltage d.c. and vice versa, if possible, was seen as a better solution. For such conversion by statical means, but at low voltages the mercury arc valves became practicable by end of the 1920:s. During the 30s a young Swedish engineer, later Dr., Uno Lamm, developed the mercury arc valve for higher voltage which prepared the way for further applications of HVDC transmission and led to the decision to build the Gotland link - the first modern HVDC scheme in the world.

Before the final decision was taken in 1950 an experimental HVDC transmission line was constructed in Western Sweden between Trollhättan and Mellerud, a distance of about 50 km. Many tests and experiments were made on this line which proved that the technique and principle were right. A larger experimental facility for the valves was then built adjacent to the Trollhättan power station.

Many incidents could be related from those early days. On one occasion a superintendent from the Mellerud station, when approaching the station one evening after he had been away on vacation, was surprised to see that there was no light on in the station. When arriving there, he found the walls all sooted and on his desk a note reading, "How long time to restore? - Please call me" signed B.F. (Birger Funke, the leader of the experiments).

The design and construction of the Gotland link took place from 1951 to 1954. Admittedly, there were many disturbances in the beginning, but the problems were solved, and the subsequent experience has indicated that the decision taken in 1950 was right. The Gotland scheme was the pioneer project within HVDC transmission and technology. Many schemes since then have built on the experience gained from it, also from its innovative system engineering.

Since these early days the thyristor valve has been developed and, together with the further development of control and protection systems, valve design e.t.c. the reliability and availability have increased.

Today HVDC systems are contributing to a better utilization of electric power within many areas and in my opinium minimizing the conflict or competition between a.c. and d.c. Individualy they have both their advantages and disadvantages in modern power transmission systems. From a technical or economical point of view there will, of course, still be cases where a.c. is the right solution, and there will be some where d.c. is the better or even the only solution.

Finally I would like to thank everybody who has contributed with data and information to make this compendium possible.

April 1983

With my compliments to a valuable HVDC encyclopaedia / Uno Lamm

[signature]

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Introduction

The compendium wants to give a survey of the HVDC-systems all over the world in detailed fashion.

Many datas are required for these descriptions and we were able to get them for many systems. Those systems, of which not all data wanted are available, are described as far as possible.

You will find the universal scheme, which should be used for the descriptions, after the introduction. This sheme was written by J. Knudson, who started the compendium in 1982.

When making the compendium the single line diagrams appear to be a problem because in literature and references they are often drawn in different ways. We would like to use the IEC 117 symbols for the single line diagram of all schemes, and we are using it as far as possible.

The compendium can only be updated if all recipients support the work and inform about the latest data available. Furthermore they are asked to correct and to complete the compendium.

Please send your information concerning the compendium to

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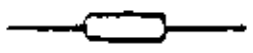
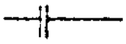
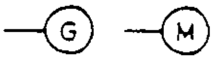
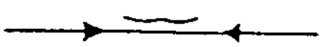
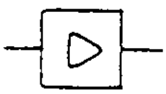
Am Hof 6 A
A-1010 Vienna
Austria

(Wolfgang Haimbl is the member of Cigre WG 14-04 who works at the compendium.)

IEC 117

NO.	SYMBOL	DESCRIPTION
74		Resistance, resistor (if it is not necessary to specify whether it is reactive or not)
84		Capacitance - capacitor
86		Earth (ground)
112 113		Generator/Motor
154		Transformer with two separate windings
155		Transformer with three separate windings
156		Auto-transformer
169		Transformer with on-load tap changer
189		Coil, choke coil, inductor, inductance or (inductive) reactor
192		DO. variable
216A.		Circuit breaker
217A		Disconnector (isolator)
220		Switch-disconnector (on-load isolating switch) i.e. bypass- or metallic return switches
428 430		Line with submarinecable
		Converter unit

DATA WANTED FOR THE COMPENDIUM

1) Name of the HDVC installation.

2) Geography situation.

3) Between area's or countries.

4) Owners - power companies.

5) Manufacturer.

6) Commission date for commercial operation.

7) Main purpose.

8) Main data for the HVDC plants, including description of overload capacity (continuous and seasonal).

9) Main data of the a.c. networks including description (one- or three phase) of the converte transformers, MVA-data, voltages on a.c. and d.c. sides and the tapchanger range.

10) Short circuit ratio: Here there have been some confusion because we have not defined what we mean. I propose we ask for two conditions defined from:

$$ESCR = \frac{\text{Short Circuit MVA - MVA of filters and capacitors}}{\text{HVDC Power}}$$

where 1) the normal SCR level of the a.c. network at normal network configuration incl. installed MVAR.

2) the min. SCR level of the a.c. network at the lowest thinkable network configuration included installed MVAR at the station.

We then must give information of as well installed filter capacity as installed SVC or synchronous compensators, so that people who want to calculate the SVR in another method are able to do this.

A.C. Filters: Describe design (tuned, damped, etc.) and fill in data in proposed table.

Harm.	MVAR	C = uF	L = mH	R = ohm

11) HVDC system: describe line data (ACSR, dimension etc.), Length, Shielding, insulator leakage based on the line to ground d.c. voltage.

Land- or submarine cables: Describe type (solid- or oil-filled), dimension and conductor area, Armouring (single, double etc.), Length.

Electrode: Describe station arrangement (sea or land) no. of electrodes and design (for instance graphite, back-filling etc.), total resistance for the electrode station.

DC filters: If d.c. filters are used describe design incl. data of C, L and R.

HVDC valves: Describe valve design (quadruple/single) valve arrangement (6 pulse or 12 pulse), no. of moduls; no. of thyristors in series or parallel per modul/bridge arm).

Cooling system: Descripe design (total and per valve)

Smoothing reactor: Descripe design, placement and data.

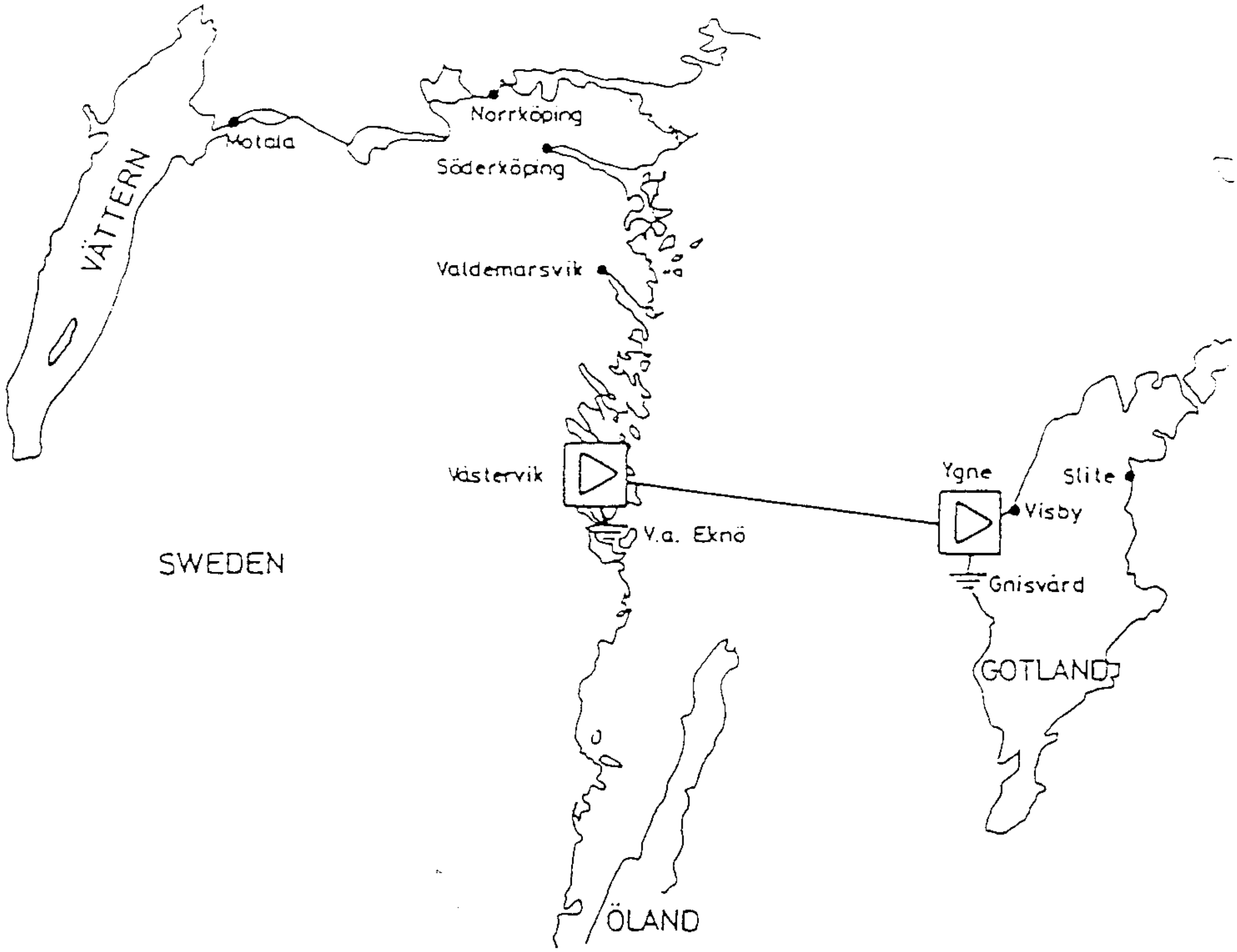
References: Mention possible technical papers.

According to table 14-86
(WG 04)-03.1

Table 1: HVDC systems in Service

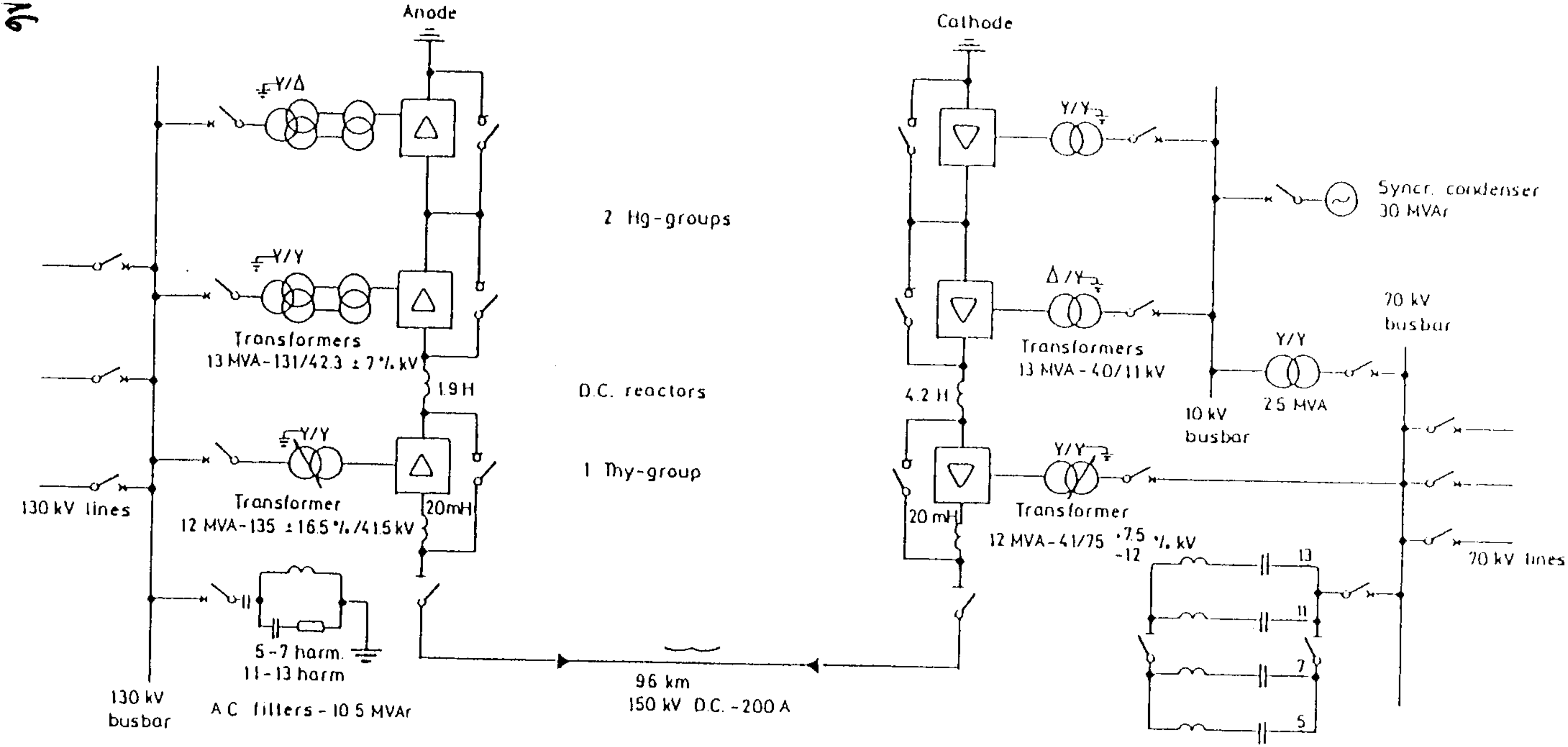
No.	HVDC systems	Transmiss. Distance km	Rated voltage kV x no. of circuits	Nominal capacity MW	Commis-sioning date	Comments
A	Mercury-Arc Valve Systems					
1	Gotland-Swedish Mainland	96	± 150	30	1954/70	
2	Cross Channel 1 (GB-F)	65	± 100	160	1961	out of service from 1984
3	Volgograd-Donbass (USSR)	470	± 400	720	1962-65	
4	Konti-Skan (DK-S)	180	250	250	1965	
5	Sakuma (J)	50/60 HZ tie	125x2	300	1965	
6	New Zealand (NZ)	609	± 250	600	1965	
7	Sardinia-Italian Mainland	385	200	200	1967	
8	Vancouver Pole 1 (CDN)	74	+ 260	312	1968/69	
9	Pacific Intertie (USA)	1362	± 400	1440	1970	
10	Nelson River Bipole 1 (CDN)	890	± 450	1620	1973-77	
11	Kingsnorth (GB)	82	± 266	640	1974	
B	Thyristor Valve Systems					
12	Eel River (CDN)	As	80x2	320	1972	
13	Skagerrak (DK-N)	240	± 250	500	1976/77	
14	David A. Hamil (USA)	As	50	100	1977	
15	Cahora Bassa-Apollo (MOC-ZA)	1414	± 533	1920	1977-79	
16	Vancouver Pole 2 (CDN)	74	- 280	370	1977/79	
17	Square Butte (USA)	749	± 250	500	1977	
18	Shin-Shinano (J)	50/60 HZ tie	125x2	300	1977	
19	Nelson River Bipole 2 (CDN)	930	± 250	900	1978	
20	CU Projekt (USA)	710	± 400	1000	1979	
21	Hokkaido-Honshu (J)	168 As	250	300	1979/80	
22	Acaray (PY-BR)	50/60 HZ tie	26	50	1981	
23	EPRI Compact Station (USA)	0.6	100/400	1000	1981	
24	USSR - Finland	As	± 85x3	1070	1982	
25	Inga Shaba (Zaire)	1780	± 500	560	1982	
26	Dürnrohr (A)	As	± 145	550	1983	
27	Gotland 2-Swedish Mainland	98	150	130	1983	
28	Eddy County (USA)	As	82	200	1985	
29	Itaipu (BR) Bipole 1	783	± 600	3150	1985	
30	Chateaguay (CDN)	As	140	1000	1984	
31	Pacific Intertie, upgrade (USA)	1362	± 500	400	1985	
32	Highgate (USA)	As	56	200	1985	
33	Oklaunion (USA)	As	82	200	1985	
34	Blackwater (USA)	347.6 As	56	200	1985	
35	Miles City (USA)	As	82	200	1985	
36	Madawaska (CDN)	As	144	350	1985	
37	Sidney (USA)	As		200	1986	
38	Cross Channel 2 (GB-F)	72	± 270x2	2000	1985/86	
39	Intermountain (USA)	794	± 500	1600	1987	
40	Quebec-New England (CDN(USA)	1000	± 450	2000/2090	1986/92	

As...Asynchronous tie



THE GOTLAND I HVDC SCHEME
Geographic map

15



VÄSTERVIK
(mainland)

YGNE
(isle of Gotland)

THE GOTLAND I HVDC SCHEME
Simplified single line diagram

The Gotland HVDC scheme.

Between:	The Swedish mainland and the isle of Gotland
Power Co.:	The Swedish State Power Board, Stockholm
Manufacturer:	ASEA Sweden
Commissioned:	July 1954 (Hg-valves) April 1970 (Thy.valves)
Main purpose:	Supply to the island with power from the mainland for support to the local electricity production. Power reversal is possible.
Main data:	Monopole: 20 MW at + or -100 kV d.c. and 200A. Earth return with electrode stations on both sides. In 1970 the system was extended by adding a thyristor valve group, increasing the capacity with 10 MW and the d.c. voltage with 50 kV thus the present data are: 30 MW at + or -150 kV d.c. and 200 A. Overload capacity: + 10 % continuously.
A.C. networks:	At both terminals is used one 3-phase converter transformer per 6-pulse converter unit.

<u>Mainland:</u> Two transformers 13 MVA
131/42.3 kV ± 7 %
One transformer 12 MVA
135 ± 15.5 %/41.5 kV

The three transformers are connected to the 130 kV a.c. system.

Short circuit capacity: min. 500 MVA. (former data)

<u>Island:</u> Two transformers each 13 MVA for the Hg-valve groups.
40/11 kV

The two transformers are connected to the 70 kV bushbar by a transformer 25 MVA-

One transformer 12 MVA for the thyristor valve group 41/75 kV ± 7.5%/12%

Short circuit capacity (70 kV bus) min 261 MVA.
A synchronous condenser, 30 MVAr is connected to the 10 kV bushbar.

<u>HVDC System:</u> Route length: 96 km.
No overhead lines are used.
<u>Submarine cable:</u> Solid type with oilimpregnated paperinsulation.

Conductor: 90 mm^2 Cu
Length: 96 km
The cable has a single steel armouring of 30 x 4..0 mm.

Electrodes: The electrodestations are situated at the shores on both sides.
They are designed as sea electrodes placed in the sea and at the mainland side behind a break water.

Resistance	mainland:	0.3 ohm.
	island:	0,5 ohm.

No d.c. filters are used.

HVDC valves: Air cooled mercury arc valves are used. Each valve has two anodes in parallel connection and each 6 puls converter unit gas 6 main valves and a bypass valve for 50 kV d.c. and 200 A.

In each terminal there are two series connected HG-valve groups and in 1970 a thyristor valve group was installed in series connection with the two Hg-valve groups.
The thyristor valves are aircooled and housed indoor in the same valvehall. The valves are designed as a double valve structure and each valve arm has 60 thyristors in series connection which makes a total of 360 thyristors for one 6 pulse converter unit for 50 kV and 200 A.
The smoothing reactors are placed on the high voltage side and are on the mainland designed for 1.9 H + 20 mH and on the island designed for 4.2 H + 20 mH at 200 A.

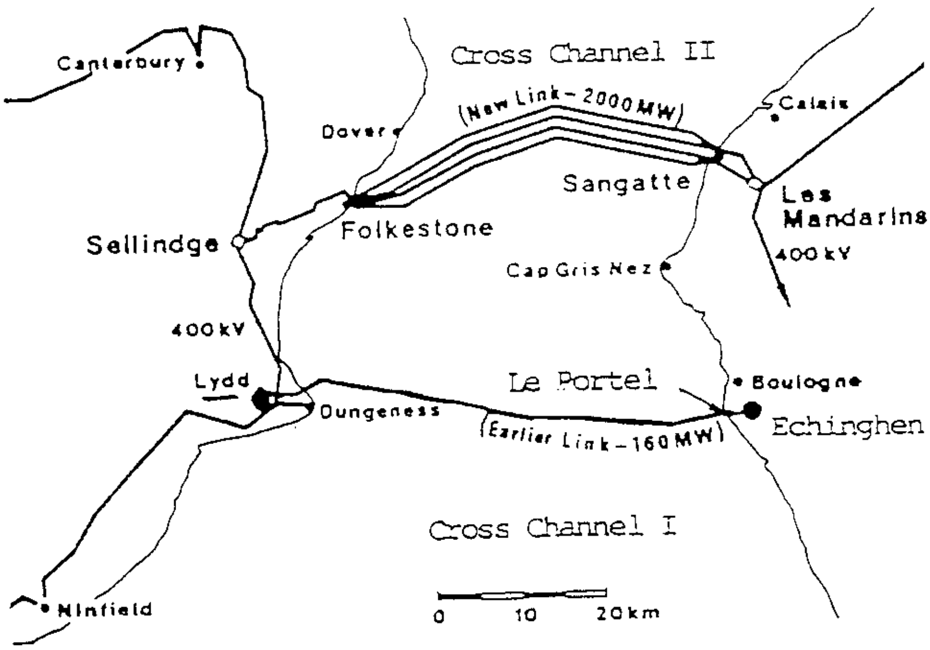
A.C. Filters: Harmonic filters are provided at each terminal:

Västervik: 10.5 MVAr; C = 2x1.83 F; L= 120 mH and R= 148 ohm

Ygne:

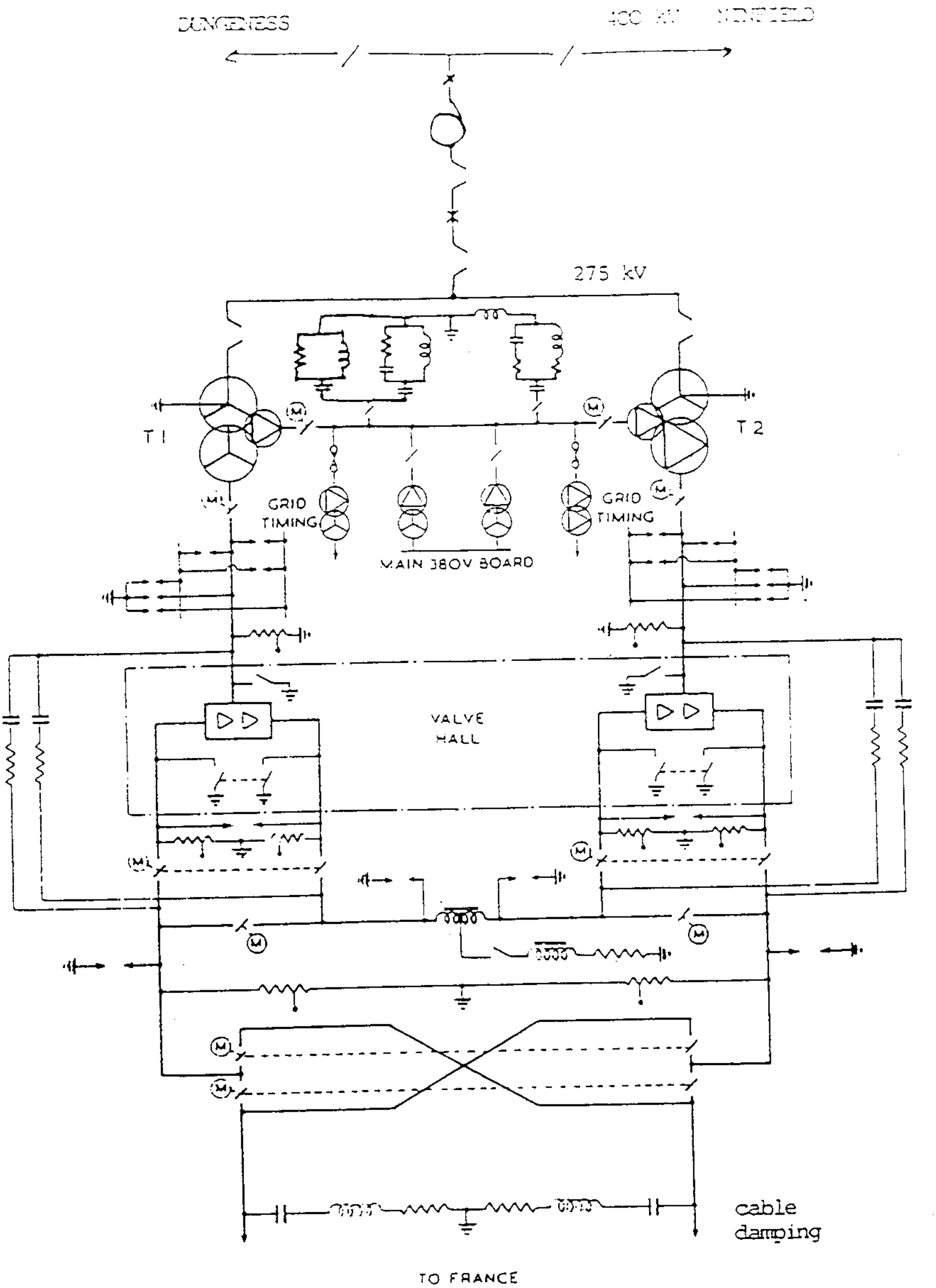
Harm.	MVAr	C=uF	L=mH	R=ohm
5.	5	2.6	156	
7.	2.5	1.33	156	
11.	2.6	1.4	60.9	
13.	1.9	1.0	60.9	

References: "Electra" no. 63, 1979 - "A.C. harmonic filters and reactive compensation for HVDC" by SC14-WG 03.



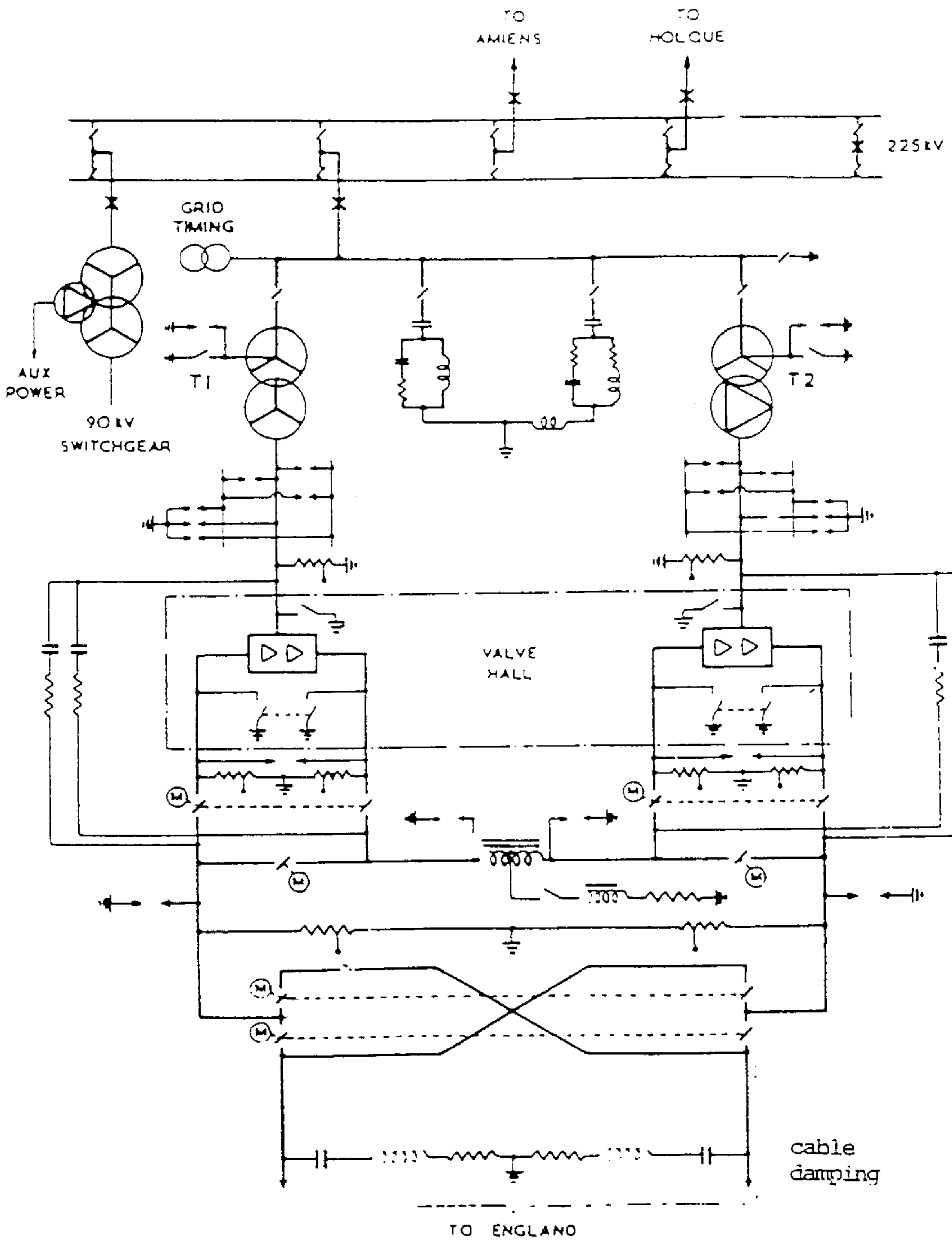
CROSS CHANNEL I

GEOGRAPHIC MAP



SINGLE-LINE CIRCUIT DIAGRAM OF LYDD.

23



SINGLE-LINE CIRCUIT DIAGRAM OF ECHINGHEN.

CROSS CHANNEL CONNECTION 1

Between:	Lydd, England and Echinghen, France
Power Co:	Central Electricity Generating Board and Electricite de France
Manufacturer:	ASEA, Sweden
Commissioned:	8 December 1961 - decommissioned 1984
Main Purpose:	Interchange of bulk power to take advantage of differential costs at the margin
Main Data:	Bipole, 160 MW ± 100 kV d.c. Single pole operation with metallic return permissible, no provision for earth return. Overload capacity: 20% for 30 min (cable limitation)
A.C Networks:	At both terminals one 3 phase converter transformer per 6-pulse converter unit.

Lydd:	Converter transformer 95/95/65 MVA, 284 ± 15%/83.6/33 kV originally connected to 275 kV system. At the system uprating to 400 kV connection was made through an auto transformer 750/750/60 MVA, 400/275/13 kV. Short circuit capacity: 900 MVA min

Echinghen: Converter transformer 97.6 MVA, 232 ± 15%/86.3 kV

HVDC System: Route length 65 km, completely cabled.

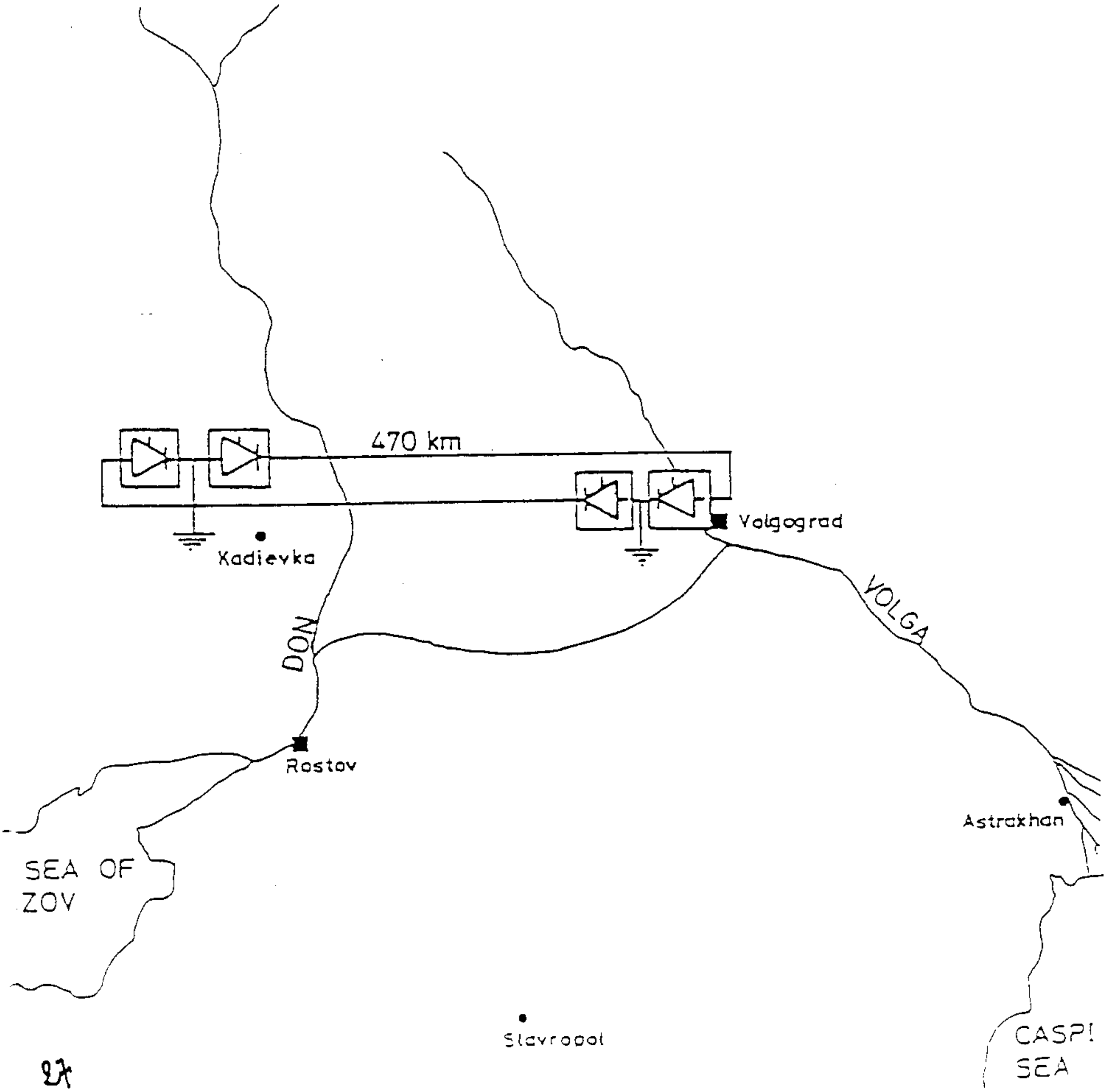
Submarine cable length 50 km

HVDC Valves: Mercury-arc valves. The valves have 4 air-cooled anodes and an air-cooled cathode. 6 main valves and one bypass valve form a 6-pulse converter unit for 100 kV 800 A. The d.c. reactor, rated 0.95 H at 800 A, is connected at the earth end, and is common to the two poles with a mid point system earth made at only one substation.

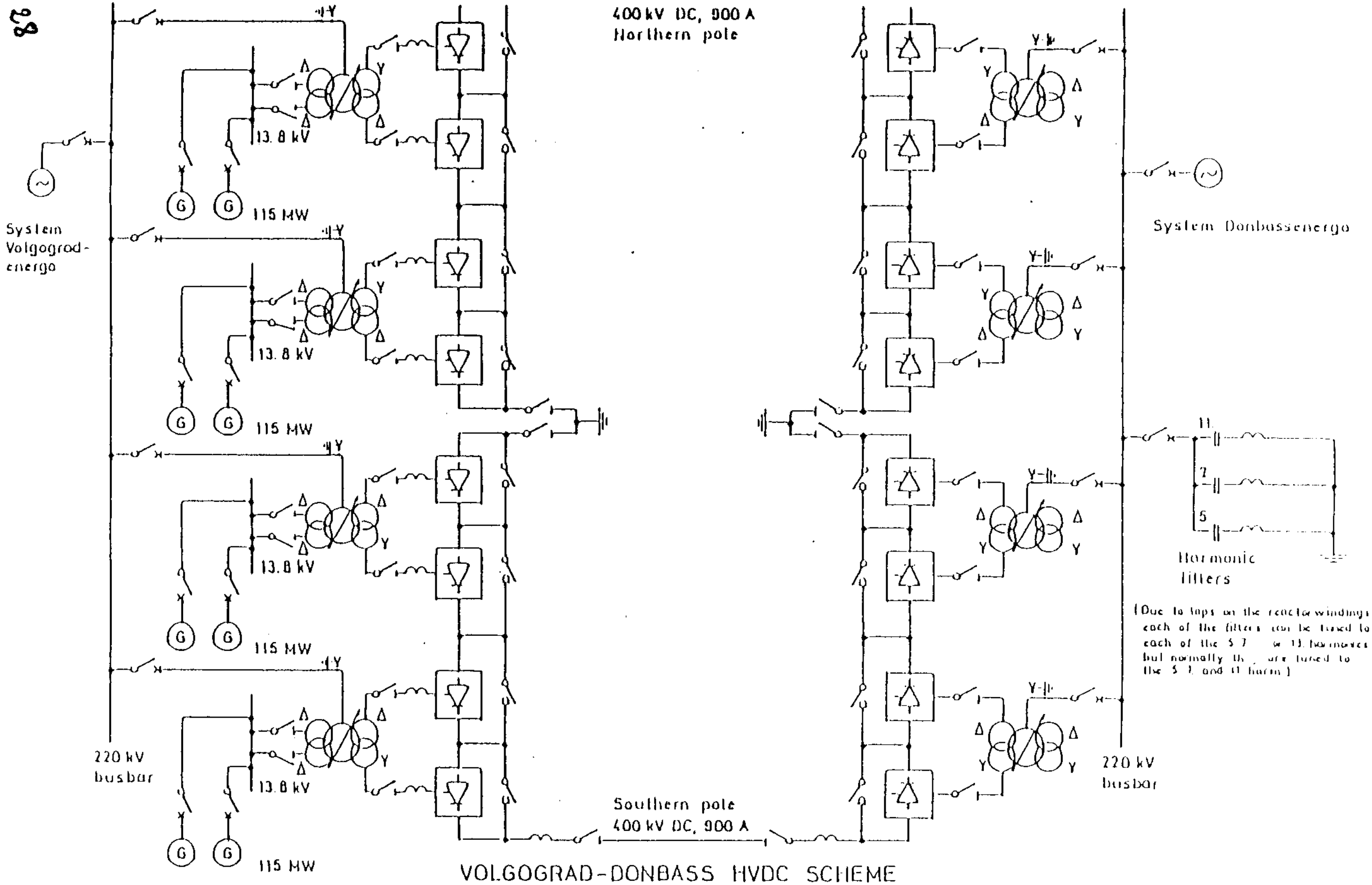
At Echinghen bridge No 1 (YY) was replaced by an air-cooled thyristor valve bridge in 1974 (manufacturer CGEE - Alsthom). Each valve is made up of 12 modules, aech module has 10 levels of two thyristors in parallel (240 thyristors per valve). The firing circuit comprises 2 light guides from earth potential to each module and pulse transformers from the pulse generator to each thyristor. Shunting of the bridge is by means of a bypass pair and a circuit breaker.

Moskva

VOLGOGRAD-DONBASS HVDC-SCHEME
Geographic map



27



VOLGOGRAD-DONBASS HVDC SCHEME
Simplified single line diagram

The Volgograd - Donbass HVDC scheme:

Between: Volgograd (Volzhskaya) and Donbass (Mikhailovskaya).

Power comp.: Volgogradenergo and Donbassenergo.

Manufacturer: Ministry for Electrotechnical Industry of USSR.

Commissioned: I Stage in October 1962
II Stage in May 1965.

Main purpose: Interconnection between two 220 kV a.c. systems, joir also by some weak a.c. lines.

Energy supply predominantly to the Volgograd area, but power reversal is possible depending on the wate: flow in the Volga river basin, and power demand in e: system.

Main data: Bipole, 720 MW at ± 400 kV d.c. and 900 A. Earth ret: is possible with only one pole in service.

Overload capacity: 15% continuously.

AC Networks: The convertor transformers used at both terminals ar: single phase units with four secondary windings. Two windings, one in star- and the other in delta connec· tion are supplying one 12 pulse convertor unit, and two windings are at the Volzhskaya terminal connecte· to two 115 MVAr hydro generators at 13.8 kV.
The fifth winding is connected to the 220 kV a.c. s: stem.

Volzhskaya: 90 MVA, 252 ± 10 %/89/13.8 kV

min. short circuit capacity: 8340 MVA

Mikhailovskaya: 90 MVA, 233 ± 10 %/89/13.8 kV

min. short circuit capacity: 2700 MVA.

At Mikhailovskaya, only two valve windings and one l winding of the transformer are used for supplying th converter units.

HVDC system: Route length = 473 km.

Overheadlines: 2 x 600 mm^2 ACSR conductors/pole

Line towers: Self supporting, lattice steel structures designed as T-towers.

Shieldings: 70 mm^2 ACSR

Insulator leakage: 1.8 - 2.56 cm/kV (on 400 kV).

Electrodes: The electrode stations are situated at a distance of 24 km from the Volzhskaya terminal and 32 km from the Mikhailovskaya terminal. They are designed as land electrodes each with one single steel rod, with a diameter of 30 mm. Coke backfill is used.

Volzhskaya: R = 0.08 ohm (excl. electrode lines).

Mikhailovskaya: R = 0.13 ohm (excl. electrode lines).

Electrode lines: 2 x 240 mm^2 ACSR are used, supported on steel towers as separate overhead lines.

DC filters: No special d.c. filters are used.

HVDC valves: When the system was constructed in 1962 and 1965, mercury arc valves were installed, using two valves in series, each for 50 kV d.c. and 900 A, i.e. 12 main valves and two bypass valves per 6 pulse convertor unit for 100 kV d.c. and 900 A, and a total of four 6 pulse convertor units in series per pole for 400 kV d.c. and 900 A. The mercury valves have one air cooled anode and the tank is oil cooled.

Later on, during the time from April 1974 to April 1977, two 6 pulse convertor units have been replaced by thyristor valves.

The thyristor valves are designed as indoor valves in a 6 pulse valve structure for 100 kV d.c. and 900 A. Each valve section has 6 modules in series connection. Each module has 36 thyristor levels in series and each thyristor level has 3 thyristors in parallel connection.

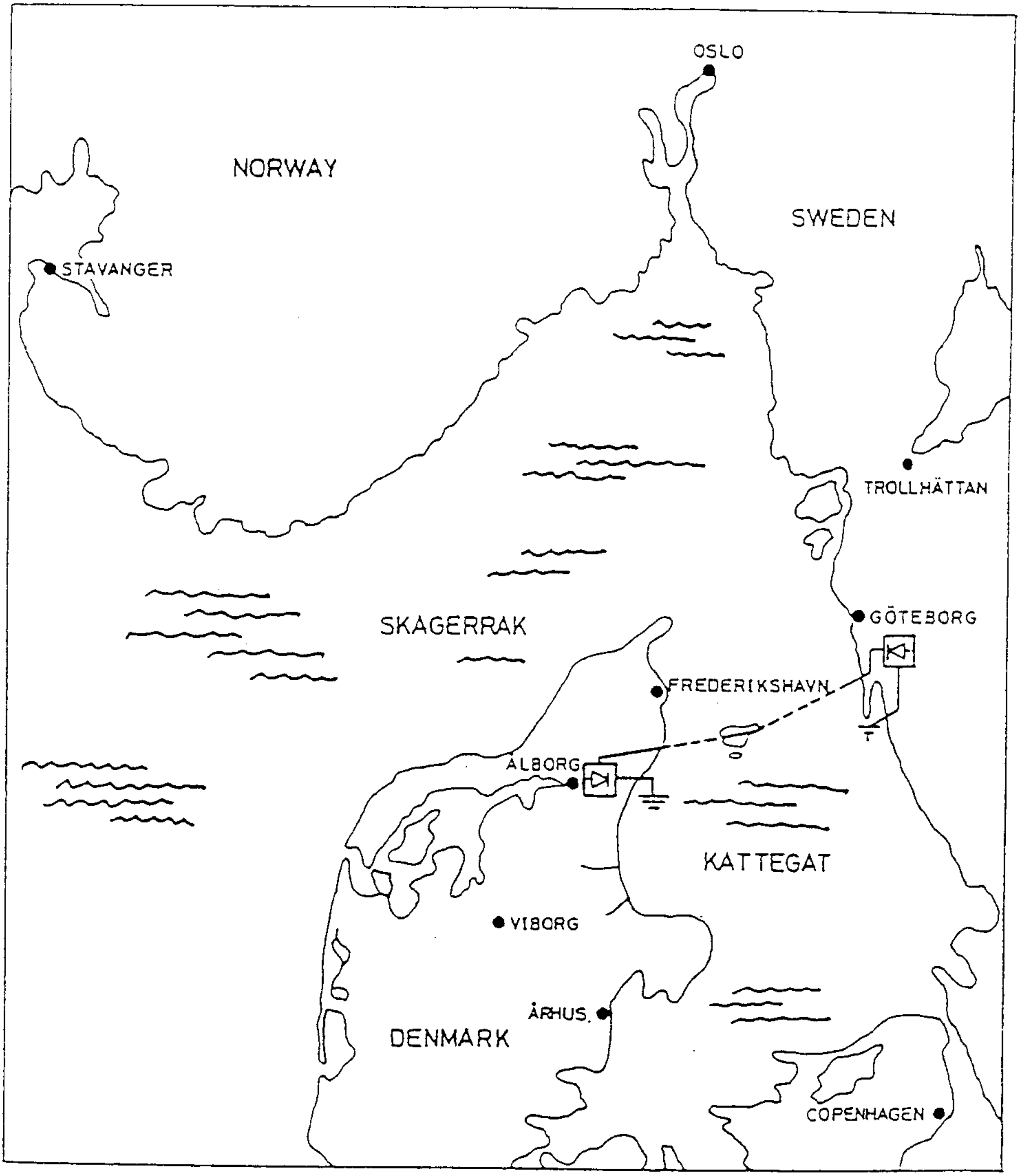
This makes a total of 648 thyristors per valve arm or 3888 thyristors per 6 pulse convertor unit.

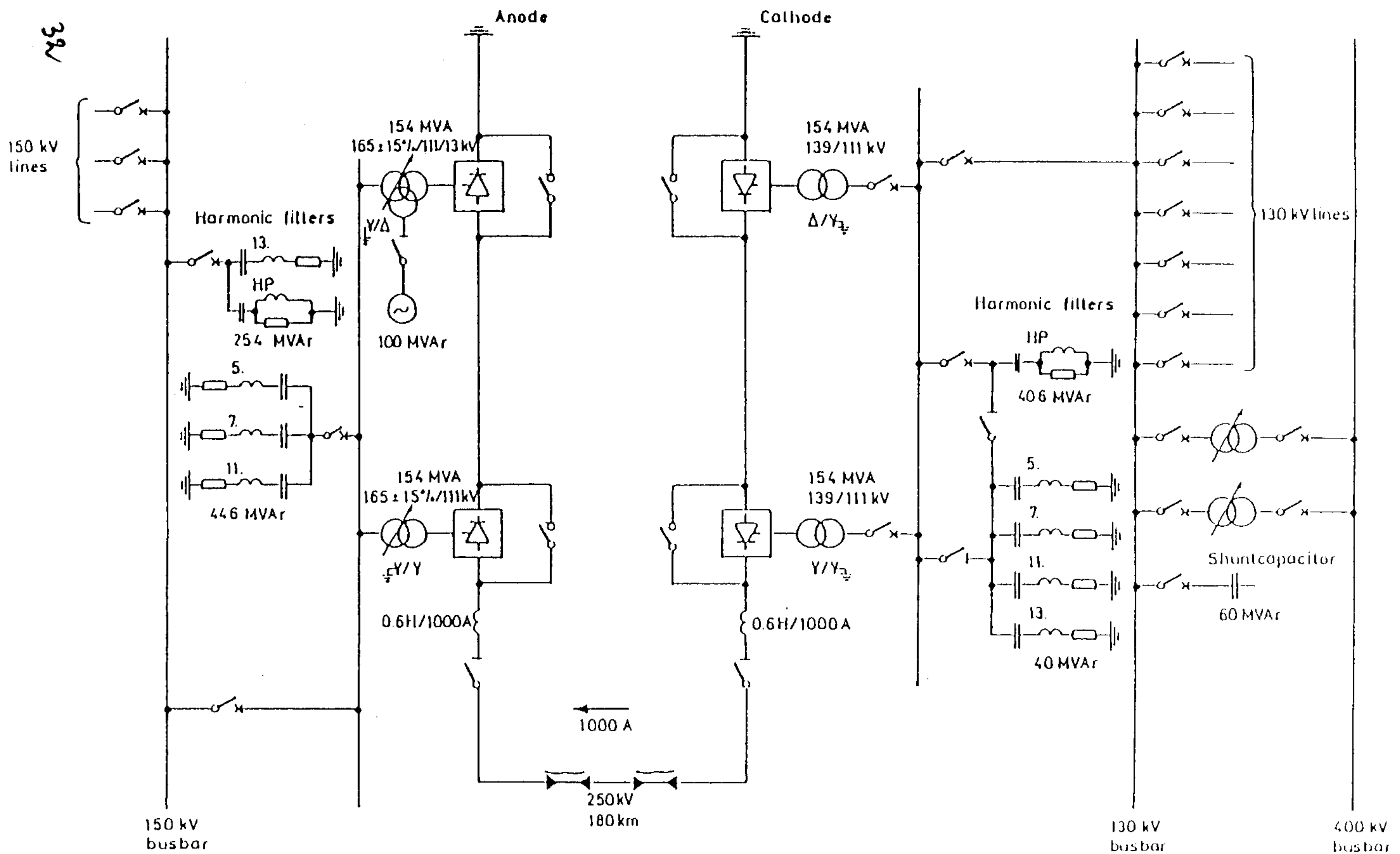
One module has a weight of 1000 kg.

The thyristors are air insulated and water cooled. For bypass path, air blast breakers are used in parallel with bypass valves.

The smoothing reactors are placed on the high voltage side and they are designed for 400 kV and 1 H at 900 A.

KONTI-SKAN HVDC TRANSMISSION





THE KONTI SKAN SCHEME
Simplified single line diagram

The Konti-Skan HVDC scheme:

Between: Denmark (V.Hassing) and Sweden (Gothenburg)

Power Comp: The Jutland-Funen Power Pool ELSAM, Fredericia and The Swedish State Power Board, Stockholm

Manufacturer: ASEA, Sweden

Commissioned: 10th September 1965

Main purpose: Peak power reserve for both countries
Excess energy supply
Energy supply during emergency situations to support the AC system in both countries in case of network disturbances.

Main data: Monopole: 250 MW at + or - 250 kV DC and 1000 A.
Earth return with the anode situated on the Danish side. (DC current flow always in the direction Sweden → Denmark).

Overload capacity: 10% continuously.

AC Networks: At both terminals one 3-phase convertor transformer/ 6-pulse convertor unit is used.

V. Hassing: a) one 154 MVA, 165 ± 15%/111/13 kV with a synchronous condenser (100 MVAr) connected to the tertiary winding at 13 kV.

b) one 154 MVA, 165 ± 15%/111 kV
Both transformers are connected to the 150 kV AC system.
Short circuit capacity: min. 2500 MVA

Gothenburg: Two 154 MVA, 139/111 kV. Both transformers are connected to the 130/400 kV AC system. No tap changers are used on the Swedish transformers.
Short circuit capacity: min. 6500 MVA

HVDC system: Route length = 180 km.

Overhead lines: length in Denmark = 40 + 15 km.
(15 km on the island of Laesoe)
length in Sweden = 40 km.

Line towers: In Denmark self supporting lattice steel structures are used.
In Sweden guyed lattice aluminium structures are used, and in angle towers, self supporting lattice steel structures are used.

Conductors: 1 x 910 mm^2 ACRS (Falcon).

Shieldings: Only approx. 3 km out from the convertor-stations and 15 km on the island are shielded by a single steel wire.

Insulator leakage: In Denmark = 2.7 - 3.2 cm/kV (on 250 kV
In Sweden = 2.2 - 2.7 cm/kV (on 250 kV

Submarine cables:

Denmark: between main land and the island of Laesoe:
2 oilfilled cables (flatcable) in parallel connection, each with 2 Cu-conductors: 2 x 310 mm^2
length = 25 km.

Sweden: between Sweden and the island of Laesoe:
one cable, solid type with oilimpregnated paper insulation and a single Cu-conductor = 625 mm^2.
length = 60 km.
Both cables have a single steel armouring (4 mm).

Electrodes: Because the current is decided always to flow in the direction Sweden → Denmark, the anode electrode station is situated on the Danish coast.
The station is designed as 25 graphite electrodes, connected in parallel. Each placed in a wooden structure, where coke backfill is used.
Resistance = 0.03 Ω total.
The cathode is situated approx. 3 km from the Swedish coast and consists of a Cu-busbar on the sea bed at a depth of 10 m. Resistance = 0.02 Ω.
The cathode is connected to the electrode line by approx. 5 km of PVC cable.

DC filters: No spec. DC filters are used.

HVDC valves: Mercury arc valves are used. The valves have water cooled cathodes and air cooled anodes.
There are 4 anodes/valve, and 6 main valves and 1 bypass valve for each 6-pulse convertor unit for 125 kV DC and 1000 A.

Each terminal has 2 series-connected 6-pulse convertor units and 6- and 12-pulse operation is possible.

The smoothing reactors are placed on the high voltage side, designed for 250 kV DC and 0.6 H at 1000 A.

A.C. Filters: Harmonic filters are provided at each terminal:

Denmark:

Harm.	MVAr	C=uF	L=mH	R=ohm
5.	18.5	2.08	195	6.12
7.	9.3	1.06	195	8.57
11.	16.8	1.97	42.5	2.94
13.	12.0	1.41	42.5	3.48
HP	13.4	1.57	12.2	96

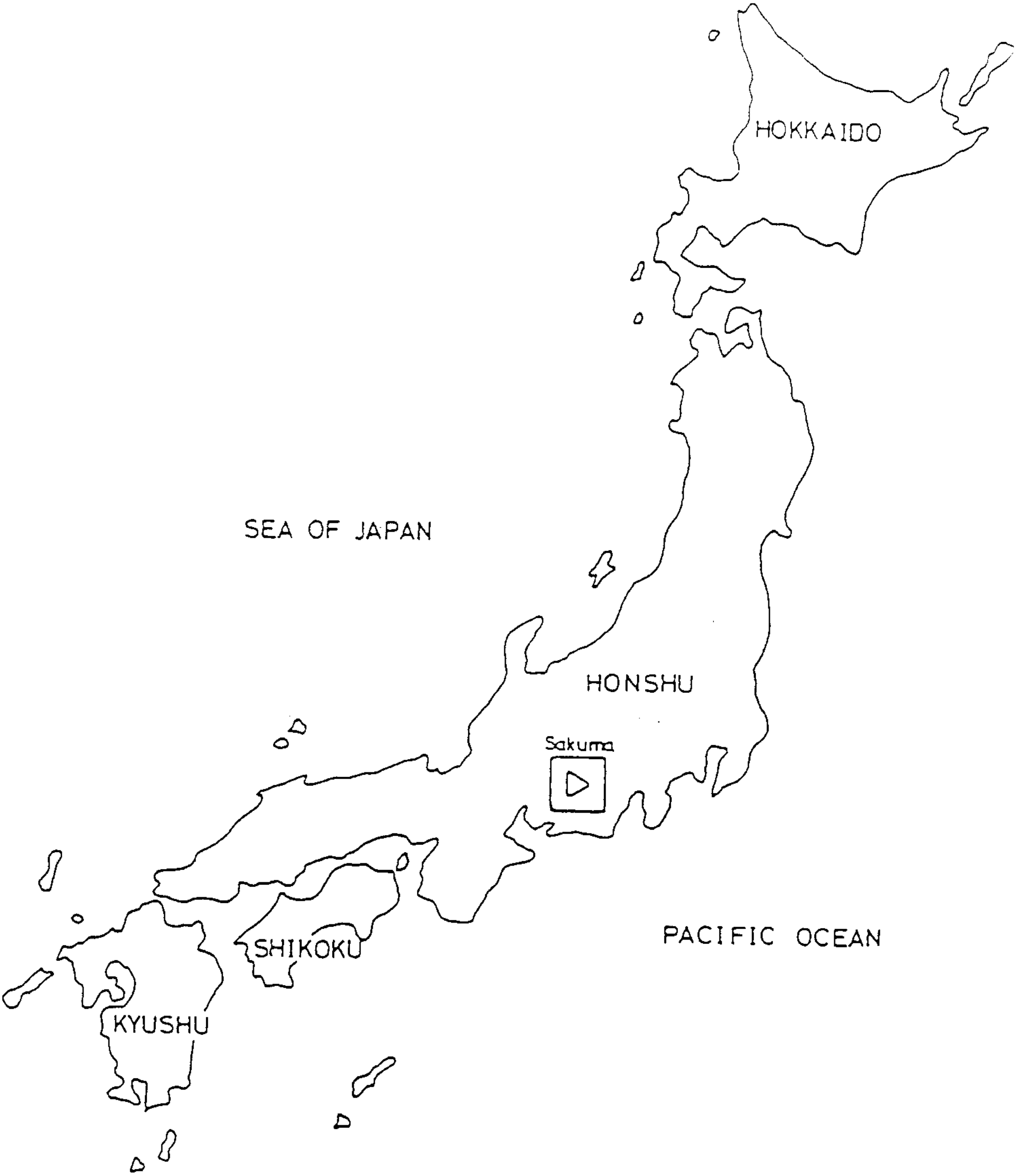
Sweden:

Harm.	MVAr	C=uF	L=mH	R=ohm
5.	13.15	2.08	195	6.12
7.	6.65	1.06	195	8.57
11.	11.96	1.97	42.5	2.94
13.	8.85	1.41	42.5	3.48
HP	40	6.63	3.5	21

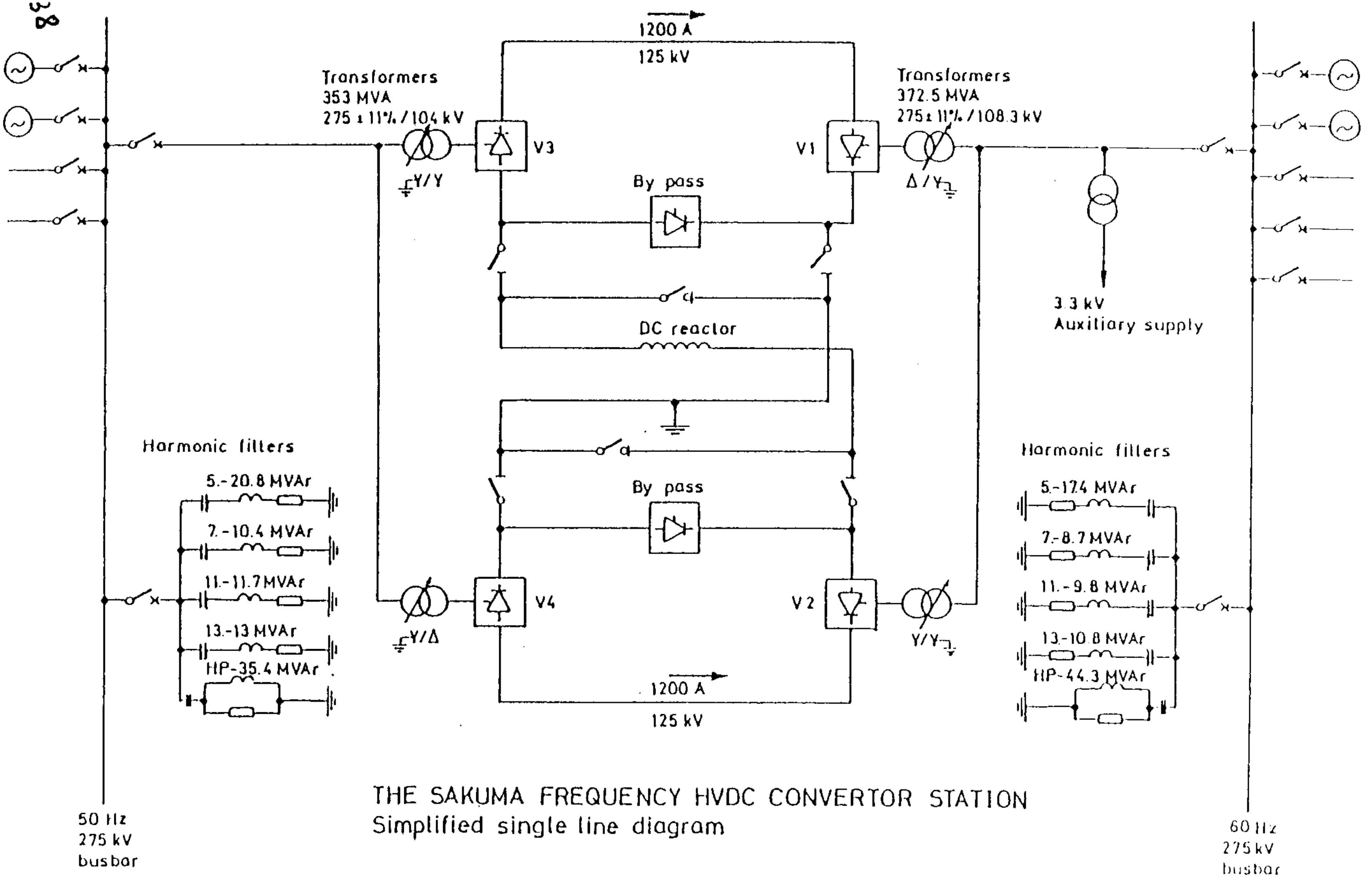
References:

Cigré 1964 paper 408: The Konti-Skan HVDC project
G.von Geijer, S. Smedsfelt, L. Ahlgren and E. Andersen

"Electra"-1979 no 63, A.C. harmonic filters and reactive compensation for HVDC." - A general survey by SC14 -WG03.



SAKUMA
Frequency converter station



THE SAKUMA FREQUENCY HVDC CONVERTOR STATION
Simplified single line diagram

The Sakuma Frequency HVDC Convertor station.

Between:	The 50 Hz 275 kV and the 60 Hz 275 kV AC system at Sakuma, Japan.
Power Comp:	Electric Power Development Co., Tokyo.
Manufacturer:	ASEA, Sweden for the valve equipment incl. the smoothing reactor. Mitsubishi Electric Co., Japan for transformers etc. Nisshin Electric Co., Japan for the AC filters.
Commissioned:	10th October 1965
Main purpose:	Supply of energy between the two AC systems in case of AC network disturbances or lack of energy in either of the systems.
Main data:	300 MW at ± 125 kV DC and 1200 A. Overload capacity: none
AC Networks:	The convertor station is situated about 1 km from the Sakuma Power Station. This station is connected to the 60 Hz, 275 kV AC network via Nagoya with interconnections to Osaka and the Western area. The station is also connected to the 50 Hz network via Nishi-Tokyo with interconnections to the Northeastern area.

Main transformer no. 1: 60 Hz, 372,5 MVA
2 x 184 MVA, 275 ± 11%/108.3 kV
one 4.5 MVA, 275/3.3 kV for auxiliary supply.
The three transformers are housed in one tank and they are ordinary 2 winding transformers with separate transformer cores.
Min. short circuit capacity = 4200 MVA

Main transformer no. 2: 50 Hz, 353 MVA
2 x 176.5 MVA, 275 ± 11%/104 kV
The two transformers are housed in one tank.

Min. short circuit capacity = 3400 MVA

The transformer tanks have a sound absorbing cover.

HVDC system: Due to the station design (back to back) there are no transmission lines. The BIL is 750 kV for all DC equipment.

DC filters: No DC filters are used.

HVDC valves: Mercury arc valves are used. The valves have water cooled cathode and tank, and air cooled anodes.
Each valve has 4 anodes, and 6 main valves form a 6-pulse convertor unit for 125 kV and 1200 A.

Only one bypass valve - and one bypass switch are needed for each of the two "poles".

The smoothing reactor is designed for 125 kV, and 0.4 H at 1200 A.

A.C. Filters: Harmonic filters are provided at 50 Hz - and 60 Hz side

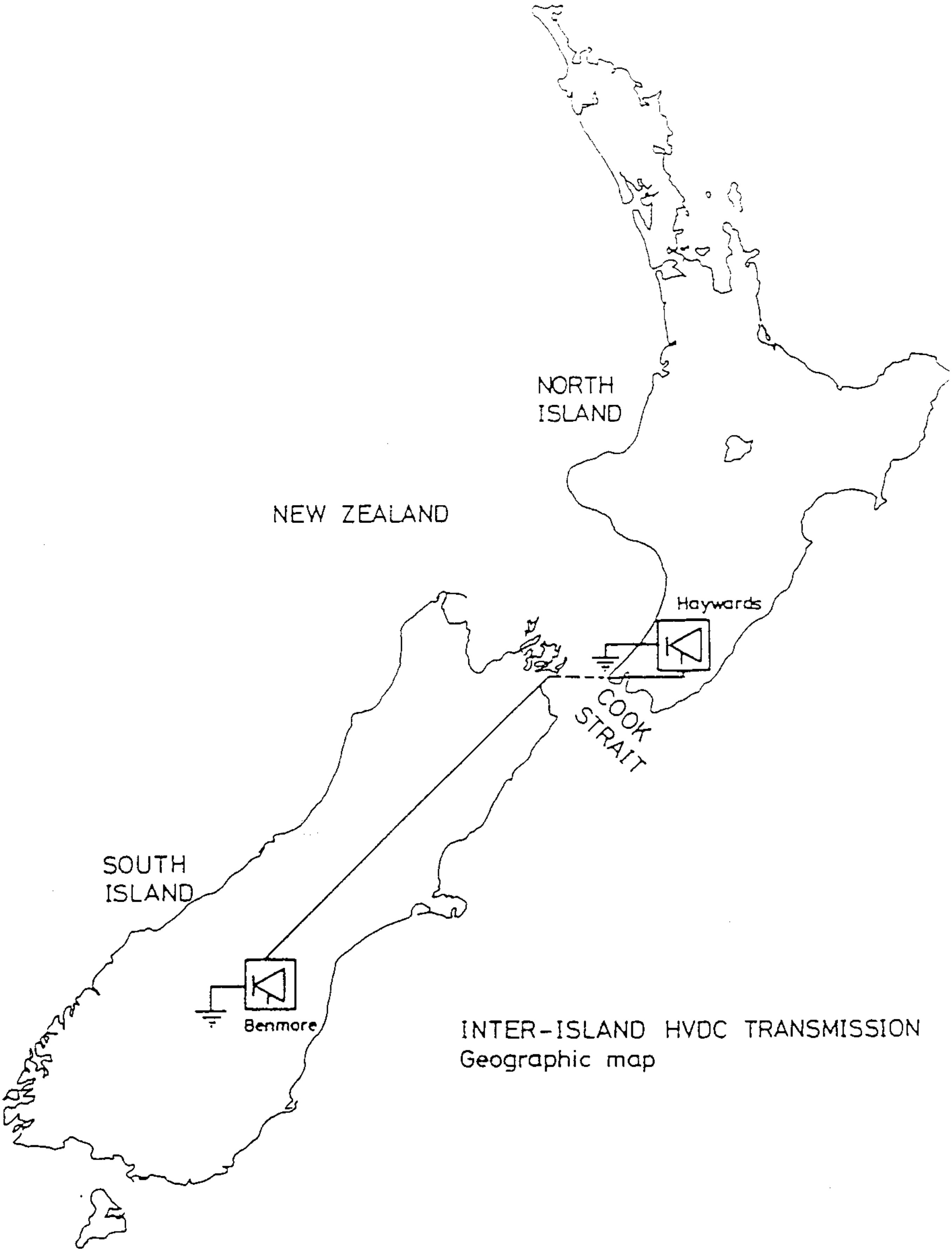
50 Hz side:

Harm.	MVAr	C=μF	L=mH	R=ohm
5.	20.8	0.842	480	15.1
7.	10.4	0.429	480	21.2
11.	11.7	0.488	171	11.9
13.	13.0	0.541	111	9.1
HP	35.4	1.49	14	100

60 Hz side:

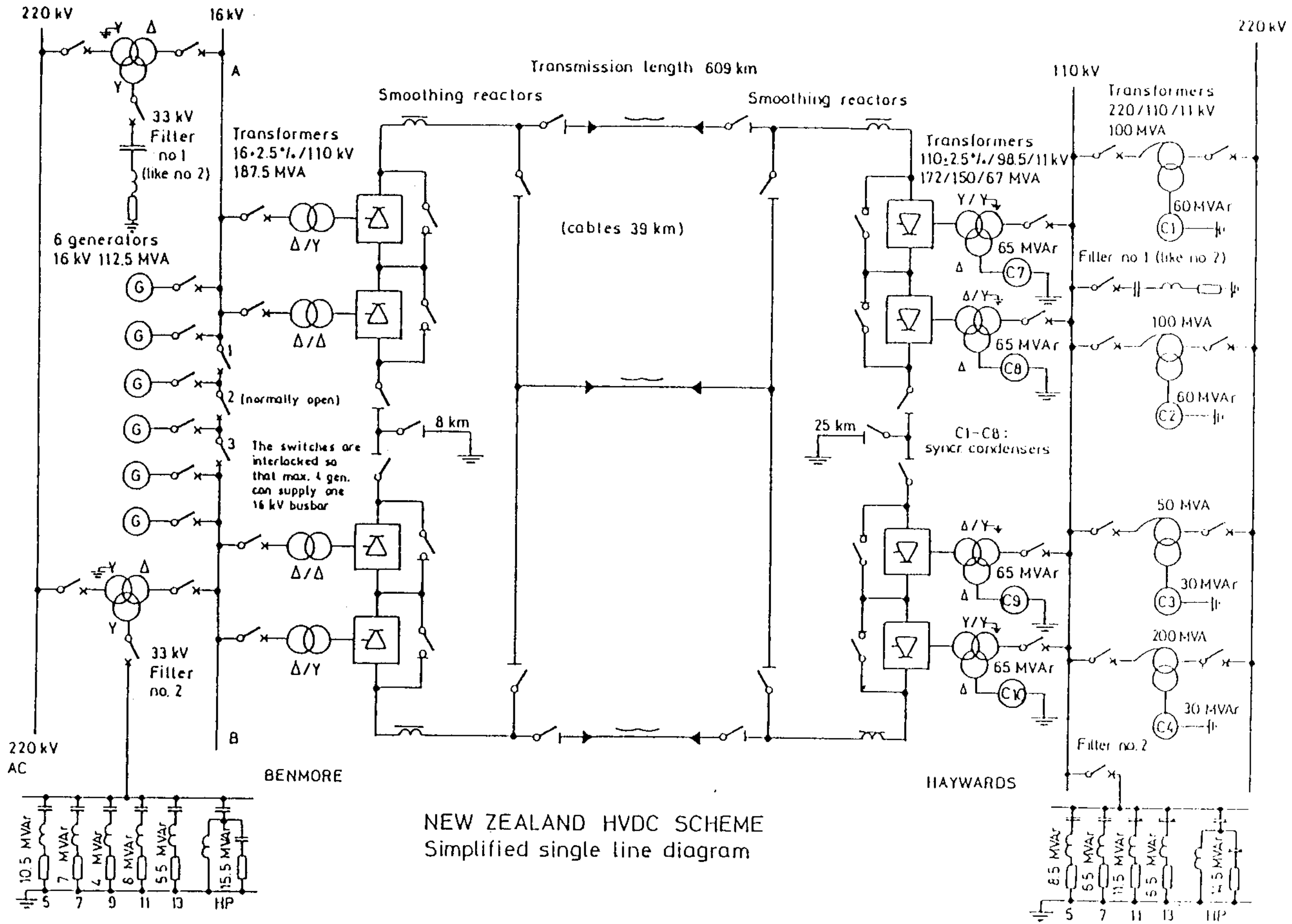
Harm.	MVAr	C=μF	L=mH	R=ohm
5.	17.4	0.585	480	18.1
7.	8.7	0.3	480	25.3
11.	9.8	0.34	171	14.2
13.	10.8	0.375	111	10.9
HP	44.3	1.55	14	100

References: "Electra" no. 63 1979)
"AC Harmonic filter and reactive compensation for HVDC"
A general Survey by SC14 - WG 03.



INTER-ISLAND HVDC TRANSMISSION
Geographic map

41



NEW ZEALAND HVDC SCHEME
Simplified single line diagram

The New Zealand HVDC scheme

Between:	Benmore, South Island and Haywards, North Island.
Power Comp.:	New Zealand Electricity Department.
Manufacturer:	ASEA, Sweden.
Commissioned:	April 1965.
Main purpose:	Bulk power transmission from Benmore to Haywards. Power reversal is used occasionally.
Main data:	Bipole, 600 MW ± 250 kV d.c. and 1200 A/pole. Earth return is possible with only one pole in service. Overload capacity: 0 %.
a.c. Networks:	At both terminals three single phase convertor transformer per 6-pulse convertor unit are used. Haywards: Four transformers designed with tertiary windings for supplying four 65 MVAr synchronous condensers at 11 kV. Data: 172/150/67 MVA, 110 ± 2 1/2 %/98.5/11 kV connected to the 110/220 kV a.c. system. Short circuit capacity: min. 3390 MVA (on 110 kV). Benmore: 187.5 MVA, ± 2 1/2 %/110 kV. The four transformers are connected to the 16 kV generator bushbar, supplied from six 112.5 MVA generators. Short circuit capacity: min. 1560 MVA (on 16 kV).
HVDC system:	Route length = 609 km. Overhead lines: North Island 35 km South Island 535 km

Line towers: Self supporting lattice steel structures.

Conductors: 2 x 794 mm^2 ACSR.

Shieldings: Single earthwire, outside diam. = = 11.05 mm (7 x 3.68 mm)

Insulator leakage: 2.2cm/kV - inland)
5.0cm/kV - costal) on 250kV

<u>Submarine cables:</u> Three gas-filled cables are used for the Cook Strait crossing, and one is a spare cable. Each cable is designed with a single Cu conductor of 500 mm^2 and a single steel armouring of 5.89 mm.

Length = 39 km, weight = 44 kg/m (in air)

<u>Electrodes:</u> The anode station is situated at a distance of 25 km from Haywards convertor station and located at the Oteranga Bay.

The station is designed as a sead electrode with 25 silicon iron electrodes in parallel connection.

R = 0.23-0.3 ohm, depending on tidal conditions.

The cathode station is situated at a distance of 8 km from Benmore convertor station.

The station is designed as a land electrode with R = 0.22 ohm.

<u>d.c. filters:</u> No special d.c. filters are used.

<u>HVDC valves:</u> Mercury arc valves are used. The valve has 4 air cooled anodes and a water cooled cathode.

6 main valves and one bypass valve form a 6-pulse convertor unit for 125 kV d.c. and 1200 A. Each pole has 2 series connected convertor units for 250 kV d.c. and 1200 A.

The smoothing reactors are placed on the high voltage side, designed for 250 kV d.c. and 0.8 H at 1200 A.

6

A.C. Filters: Both terminals are provided with harmonic filters:

Benmore: 2 filters each with:

Harm.	MVAr	C=uF	L=mH	R=ohm
5.	10.5	30.9	13.1	0.412
7.	7	20	10.3	0.454
9.	4	12.1	10	0.56
11.	8	23.2	3.6	0.249
13.	5.5	16.1	3.75	0.305
HP	15.5	45(x2)	0.6	4.5

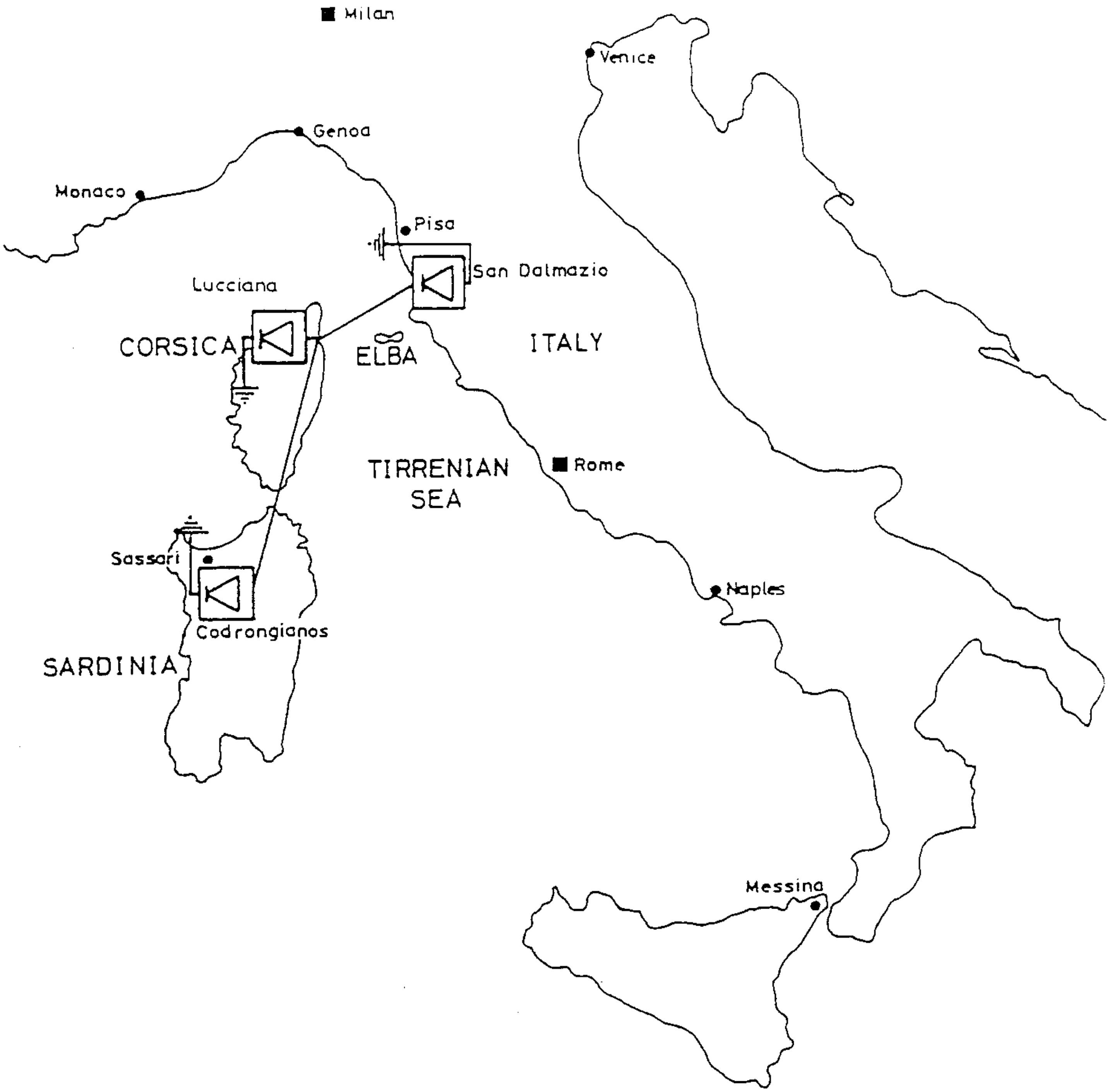
Haywards: 2 filters each with:

Harm.	MVAr	C=uF	L=mH	R=ohm
5.	8.5	2.33	173	5.46
7.	6.5	1.79	115	5.08
11.	11.5	3.06	27.2	1.89
13.	6.5	1.77	33.7	2.77
HP	14.5	3.79(x2	5.05	36.5

References:

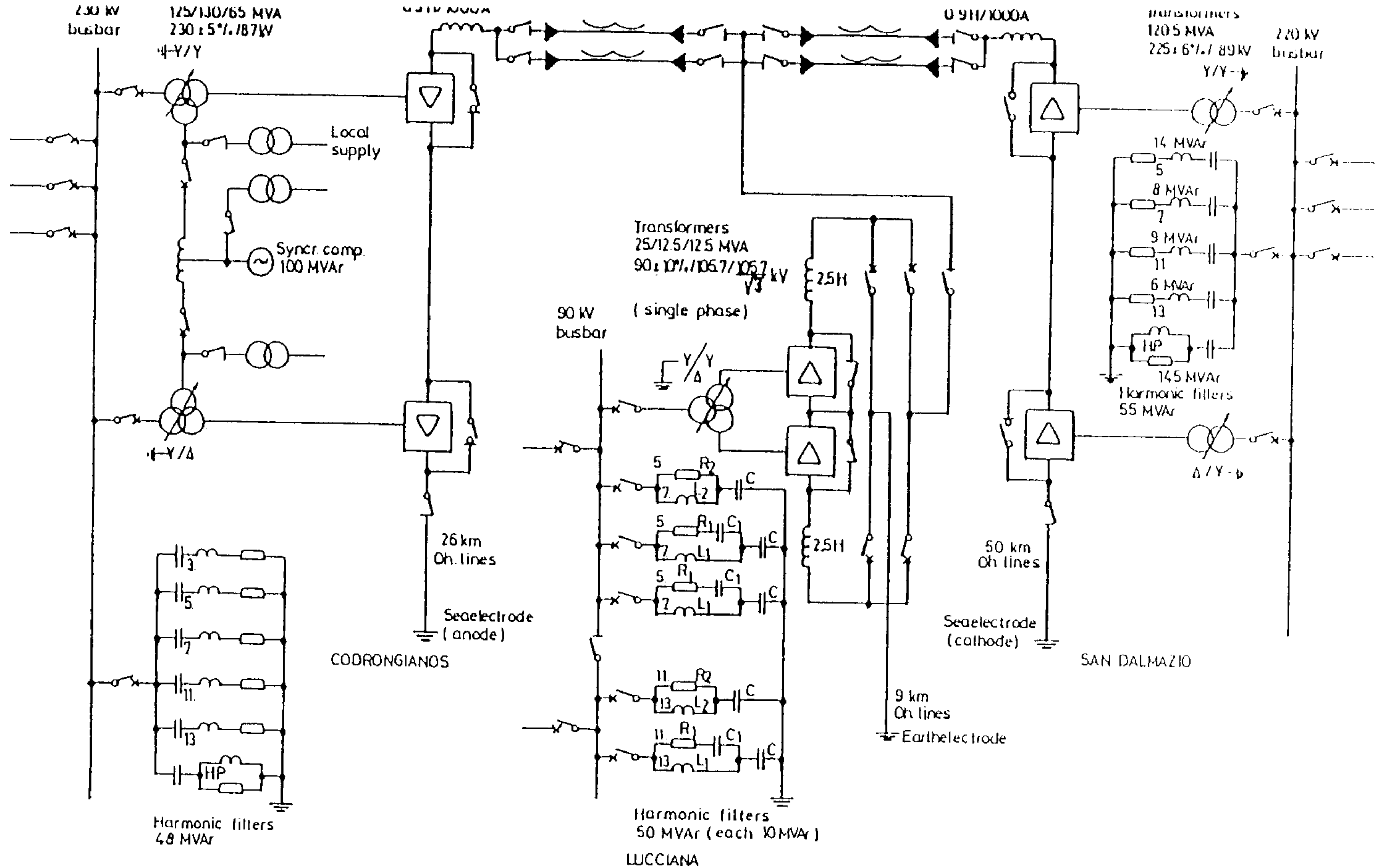
"Electra" no. 63 (1979)
"A.C. harmonic filters and reactive compensation for HVDC"
A general Survey by SC14-WG03.

HS



THE SARDINIA HVDC-SCHEME
SACOI
Geographic map

47



THE MULTITERMINAL HVDC SCHEME "SACOI"

Simlified single line diagram.

The three-terminal HVDC Scheme "SACOI".

Between:	Codrongianos, in the Sardinia Island, Lucciana (Bastia) in Corsica, and San Dalmazio (Pisa) on the Italian Mainland.
Power Co.:	ENEL (Ente Nazionale per l'Energia Elettrica) Rome. EDF (Electricité de France).
Manufacturers:	Codrongianos and San Dalmazio: English Electric with ASEA, Sweden, as sub-contractor for valve and control equipment. Lucciana: CGEE-ALSTHOM and ALSTHOM ALTANTIQUE as sub-contractor, France.
Commissioned:	Codrongianos and San Dalmazio: June 1967 Lucciana: October 1985 (scheduled)
Main purpose:	Frequency support to the Sardinian a.c. network by power/frequency control of the d.c. line. In Corsica, energy supply, frequency control and static "spinning reserve". The direction of the power flow between the two main stations, Codrongianos and San Dalmazio, imposes the polarity of the d.c. line voltage. The direction of the flow on the a.c. Corsican network is made independent of this

polarity by reversing the connection of the Corsican convertors by high-speed isolating switches. Automatic power reversal between main stations is still possible by a sequence eliminating Corsican convertors for 500 ms.

Main data: The three stations are connected in parallel on a line which is operated at the rated voltage + or - 200 kV; earth- and sea return are used.

Codrongianos: 200 MW, at ±200 kV d.c. and 1000 A. Anode situated on the Sardinian coast.

San Dalmazio: 200 MW, at ±200 kV d.c. and 1000 A. Cathode situated on the coast.

Lucciana: 50 MW, at ±200 kV d.c. and 250 A. Earth-electrode on the shore used as an anode or a cathode.

Overload capacity: 7,5 % from Codrongianos to San Dalmazio only.

a.c. networks: At both main terminals one 3-phase converter transformer per 6-pulse convertor unit is used. In Corsica, three single-phase transformers + 1 spare with two secondary windings supplies one 12-pulse convertor, with possible operation of each 6-pulse valve group.

50

San Dalmazio: 120,5 MVA; 225 ±6%/87 kV.
The two transformers are connected to the 220 kV a.c. system Min. short circuit capacity: 1250 MVA.

Codrongianos: 125/130/65 MVA;
230 ±5 %/87/13 kV.
The two transformers are connected to the 230 kV a.c. system and the tertiary winding connections at 12,85 kV are brought out of the transformers to provide a coupling point for a 100 MVAr synchronous condenser via a compensating reactor.
Min. short circuit capacity: 550 MVA.

Lucciana:
25/12,5/12,5 MVA; 90 ±10 %/105,7 $\frac{105,7}{3}$3 kV.

The winding on the 90 kV network side is star connected, while the windings on the valve side are on star- and the other delta-connected.
Min.short circuit capacity: 120 MVA.

HVDC System: Route length = 413 km.
One the whole route two circuits of the same polarity are used. For each circuits overhead lines and submarine cables are used. The two overhead lines conductors are supported by the same line towers.

Overhead lines: Sardinia l = 86 km
Corsica l = 156 km
Italian mainland l = 50 km

SA

Line towers: Selfsupporting lattice steel structures are used both on the and on the Islands.

Conductors: 755 mm^2 A.C.S.R.

Shieldings: 94,7 mm^2 A.C.S.R.

Insulator leakage: 4,2 cm/kV (on 200 kV)

Submarine cables: The two submarine cables used are both solid type with oilfilled paper insulation and CU-conductor of 420 mm^2.
The cables are armoured by a single layer of steel wires of 7 mm diameter.

Italian Mainland Corsica: l = 105 km

Corsica Sardinia : l = 16 km

Electrodes: In Sardinia the anode electrode station is designed as a sea electrode with 30 electrodes arranged in a little quiet bay, protected from the sea by a concrete breakwater. The single electrode is made of platinum coated titanium pipe with cable connections to a busbar.
Total resistance = 0,6 ohm (including cable connections).
On the mainland side, the cathode electrode is made of simple bare copper conductors supported by concrete blocks located 3 km from the shore where the depth of the water is about 28 m.
Total resistance = 1 ohm (including cable connections). In Corsica, the earth electrode, acting as an anode or a cathode, is located 9 km from the convertor station, near the sea.

52

It consists in a line of 50 ferro-silicium-chrome electrodes, placed horizontally every 5 meters.

Total resistance: 0,16 ohm.

<u>Electrode lines</u>:

Sardinia	l = 26 km
Italian Mainland	l = 50 km
Corsica	l = 9 km

Conductors: 683 mm^2 A.C.S.R. in Italia and in Sardinia.

On the mainland the electrode line is supported by the overhead line towers for 42 km and also acting as an earth wire.

The remaining 8 km are designed as a separate overhead line to the cathode location, on the Italian coast.

On Sardinia, the electrode line is designed as a separate overhead line to the anode location, about 30 km from the convertor station.

The Corsica earth electrode line is designed as a conventional 20 kV line but with 2 conductors.

<u>d.c.filters:</u> At both main stations, d.c. filters are used for 300, 600, 900 and 1200 Hz harmonics. In Corsica, there are no d.c. filters planned in the present project in construction.

<u>HVDC valves:</u> <u>Codrongianos and San Dalmazio:</u>

Mercury arc valves are used. The valve has air cooled anodes and tank. Each valve has 4 anodes; 6 main valves and 1 bypass valve form a 6-pulse converter unit for 100 kV and 1000 A.

Each terminal has two series connected units, and either 6-pulse or 12-pulse operation is possible.
The smoothing reactor is placed on the high voltage side, designed for 200 kV d.c. and 0,9 H at 1000 A.

Lucciana:
Air cooled thyristor valves are used. The converter consists of 6 double-valves designed in a wholly symetrical manner, to have the full insulation with respect to the earth on both the anode and the cathode. Each double-valve is formed by 24 modules connected in series and one module has 10 thyristor levels in series each with one thyristor.
The 6 double-valves form a 12-pulse converter unit for 200 kV and 250 A.
Two smoothing reactors are placed at both ends of the converter. They are both designed for 200 kV d.c. and 2,5 H each at 250 A.

A.C. Filters: Harmonic filters are provided at each of the three terminals:

San Dalmazio: Total installed: 55 MVAr

Harm.	MVAr	C=uF	L=mH	R=ohm
5.	14.-	0.89	452.-	14.2
7.	8.-	0.512	404.-	17.8
11.	9.-	0.562	149.-	10.3
13.	6.-	0.372	161.-	13.2
HP	14.5	0.909	28.4	250.-

Codrongianos: Total installed: 48 MVAr

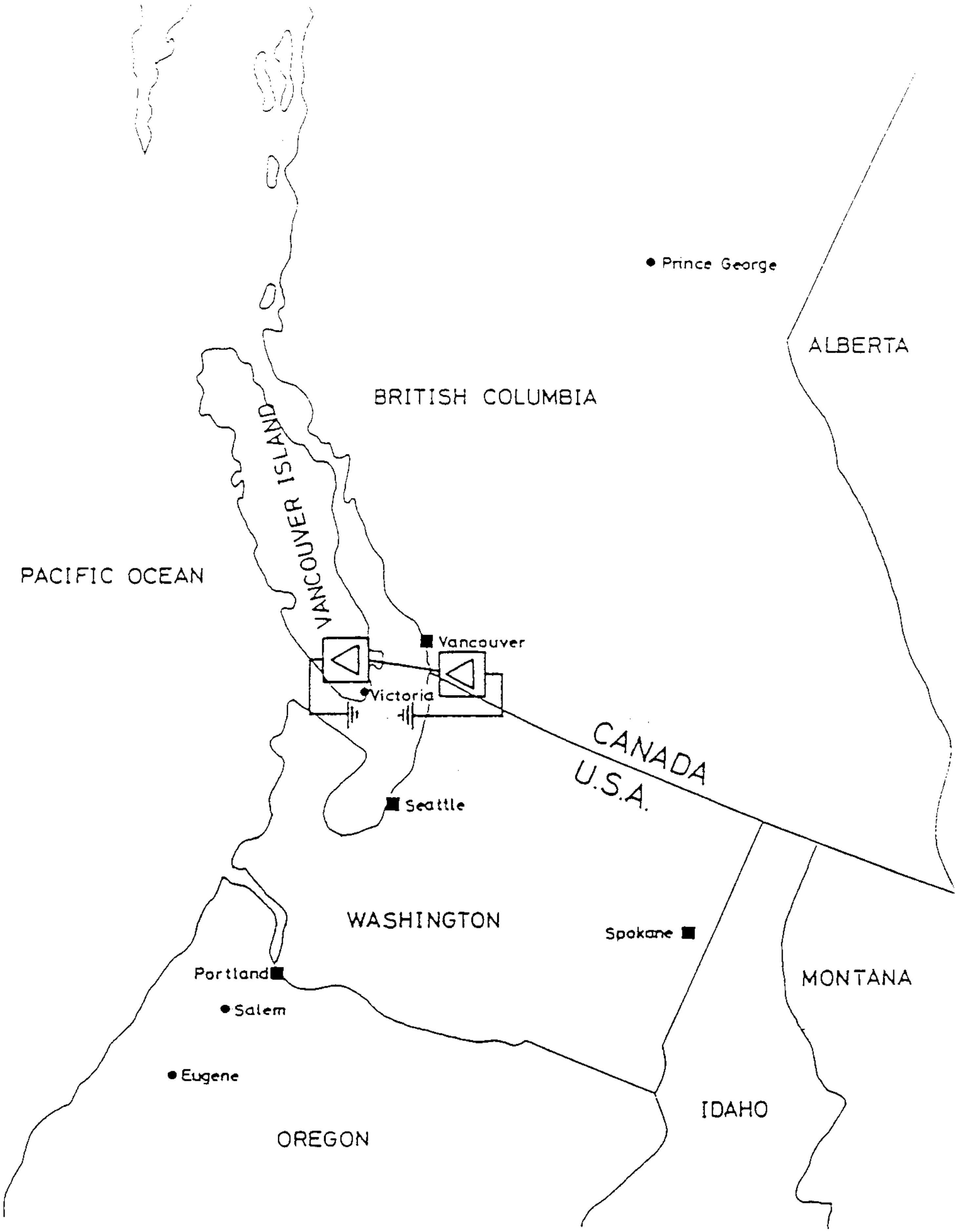
Harm.	MVAr	C=uF	L=mH	R=ohm
3.	2.83	0.683	7036	244
5.	13.3	0.20	502.8	21.7
7.	6.28	0.507	448.6	25.3
11.	1043	0.461	165.2	14.6
13.	3.15	0.806	299.8	31.7
HP	6.43	0.16	29	29.3

Lucciana: Total installed 5 filters each 10 MVAr of the damped type designed as

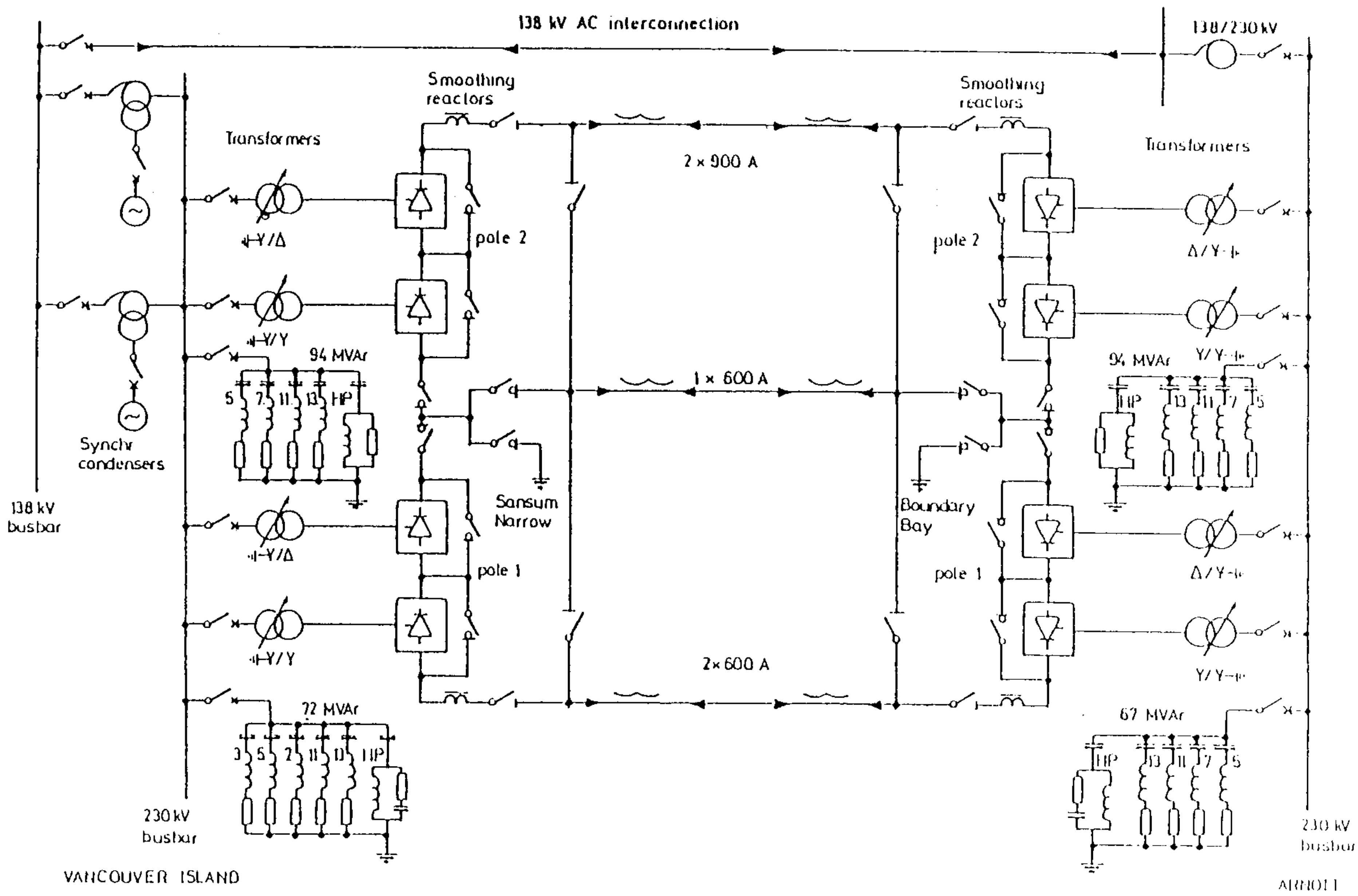
3 combined filters for 5.- and 7. harm. and

2 combined filters for 11.- and 13. harm. each with

C=μF	C_1=μF	L_1=mH	L_2OmH	R_1ohm	R_2=ohm
3.784	4.73	82.2	18.5	3.30	146.2



VANCOUVER ISLAND HVDC-SCHEME
Geographic map



VANCOUVER ISLAND HVDC SCHEME
Simplified single line diagram

Vancouver Island HVDC scheme.

Between: Vancouver Island at Duncan and the mainland at Delta.

Power comp.: B.C. Hydro and Power Authority, Vancouver, Canada.

Manufacturer: ASEA, Sweden for pole 1.
General Electric, USA for pole 2.

Commissioned: Pole 1: Stage I in July 1968
Stage II in October 1969

Pole 2: Stage I in April 1977
Stage II in April 1979

Main purpose: Energy supply, predominantly to Vancouver Island, but power reversal is possible.
The two DC terminals are also interconnected by two AC 132 kV submarine cables.

Main data: Bipole, 312 MW (pole 1) + 370 MW (pole 2) = 682 MW
at: Pole 1: + or - 260 kV DC, and 1200 A
overload capacity: 2 hours daily at 1320 A

Pole 2: + or - 280 kV DC, and 1320 A
overload capacity: Wintertime: x) 1700 A
x) temperature below 0 °C.

Both 6- and 12-pulse operation is possible.

Earth return: During for instance monopolar operation normally metallic return is used by means of one of the DC submarine cables, but earth return is used when return current exceeds 600 A.

AC Networks: At both terminals single phase convertor transformers are used, connected to the two 230 kV AC systems.

Arnott: Pole 1: 62.7 MVA, 236^{+23}_{-11} %/111,1 kV
Pole 2: 83.1 MVA, 236^{+15}_{-13} %/119,2 kV
short circuit capacity: min. MVA.

Vancouver Island:
Pole 1: 62.7 MVA, 236^{+23}_{-11} %/111,1 kV
Pole 2: 83.1 MVA, 236^{+15}_{-13} %/119,2 kV
short circuit capacity: min. MVA.

HVDC system:

Route length = 73.6 km.

Overhead lines: Three sections. Total length = 41.1 km.

line towers: Self supporting lattice steel structures are used.

conductors: 2 x 402,8 mm^2 ACSR

shieldings:

insulator leakage: 2.75 cm/kV (on 260 kV)
2.55 cm/kV (on 280 kV)

Submarine cables: Two sections. Total length = 32.5 km.

Pole 1: Three 260 kV DC cables (one spare). Solid type with oilimpregnated paper insulation and a single Cu-conductor of 400 mm^2. On land a short length is 650 mm^2.

Pole 2: Two 280 kV DC cables, high pressure oil filled with impregnated paper insulation, and a single Cu-conductor of mm^2.

The cables have a single layer of steel armouring of 6,0 mm, and they are buried about 60 cm down in the extensive tidal flats

Electrodes:

The anode station is designed as a sea electrode at Sansum Narrows on Vancouver Island.
It consist of 28 graphite electrodes connected as 4 x 7 electrodes in parallel.
Total resistance (excl. overhead lines) is about 0.1 ohm

The cathode station on the mainland at Boundary Bay is designed as a land electrode. It consist of 40 copperweld ground rods, divided in 2 groups, each with a length of about 9.2 meters.
Total resistance (excl. overhead lines) is about 0.01 ohm.

The electrode stations are connected to the DC system by overhead lines with 2 x 470 mm^2 ACSR conductors.

DC filters: No D.C. filters are provided.

HVDC valves: In pole 1, mercury arc valves are used.
Each valve has 4 air cooled anodes.
The tank and cathode are water cooled. Six main valves and one bypass valve form a 6-pulse convertor unit for 130 kV and 1200 A.

There are 2 series connected convertor units.
In pole 2, thyristor valves are used. The valves are housed indoor and they are designed as double valves. with 2 valves in series connection per valve structure. Three double valves form a 6 pulse convertor unit. Each valve has 15 modules, connected in series. One module has 12 thyristor levels in series and each thyristor level has 2 thyristors in parallel, giving the total of 360 thyristors per valve arm or 2160 thyristors per 6 pulse convertor unit for 140 kV and 1320 A.
Vacuum switches are used for the bypass path.
The smoothing reactors are placed on the high voltage side for both pole 1 and pole 2. They are designed

for pole 1: 260 kV and 0.5 H at 1200 A

for pole 2: 280 kV and 0.68 H at 1320 A.

A.C. Filters: Harmonic filters are provided at each terminal and pole.

Vancouver Island - Pole 1

Harm.	MVAr	C=uF	L=mH	R=ohm
3.	4.7	0.195	4000	80.2
5.	19.35	0.86	330	10.5
7.	9.65	0.44	327	15.1
11.	7.7	0.354	164	11.9
13.	5.5	0.254	164	14.1
HP	25	1.16 (x2)	11.5	

Pole 2

Harm.	MVAr	C=µF	L=mH	R=ohm
5.	21.5	1.04	271	4.1
7.	11	0.53	271	5.7
11.	15.5	0.756	76	2.5
13.	11	0.55	76	2.3
HP	35	1.73	7.1	161

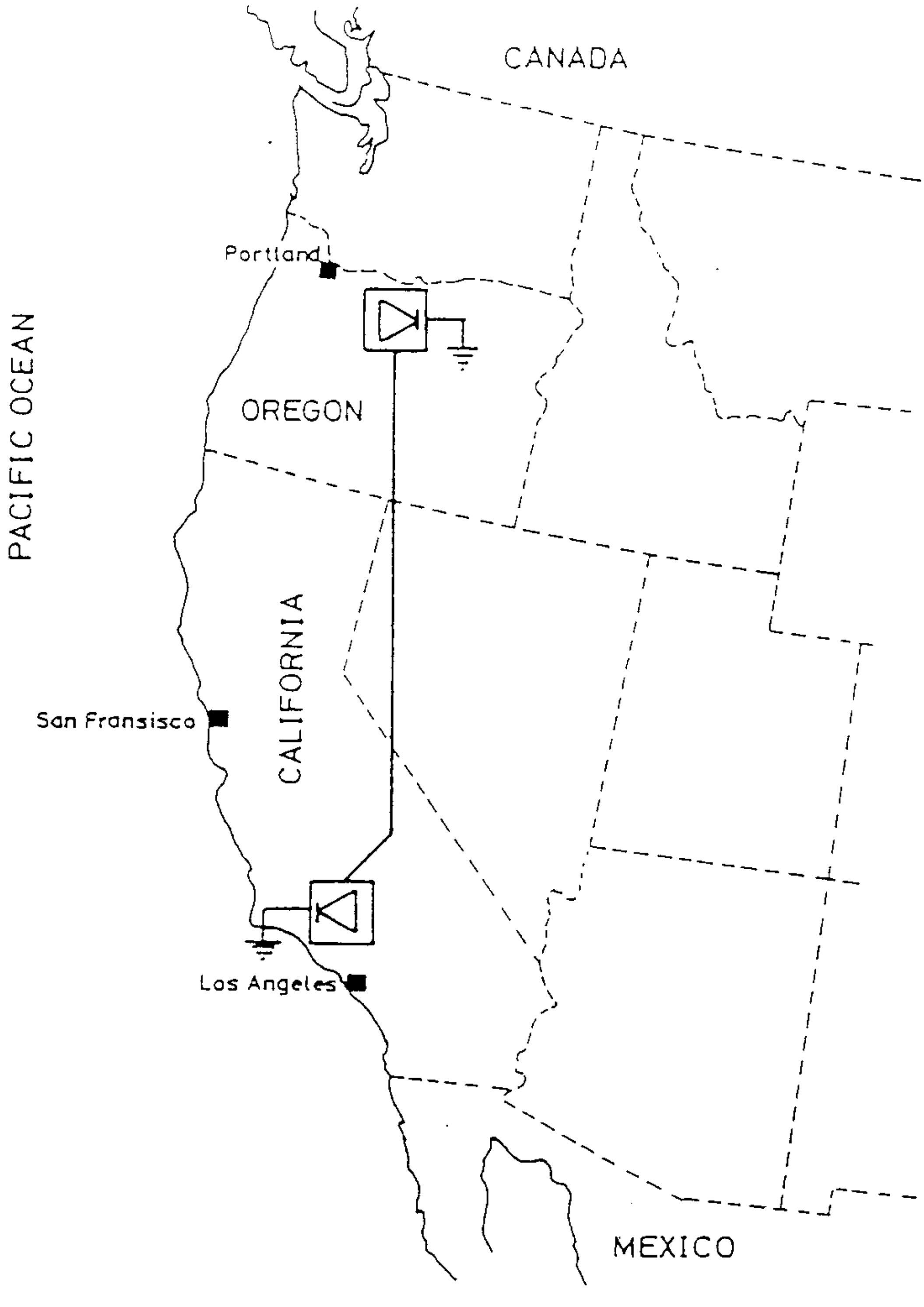
Arnot - Pole 1

Harm.	MVAr	C=µF	L=mH	R=ohm
5.	19.35	0.86	330	10.5
7.	9.65	0.44	327	15.1
11.	7.7	0.354	164	11.9
13.	5.5	0.254	164	14.1
HP	25	1.16	11.5	99.5

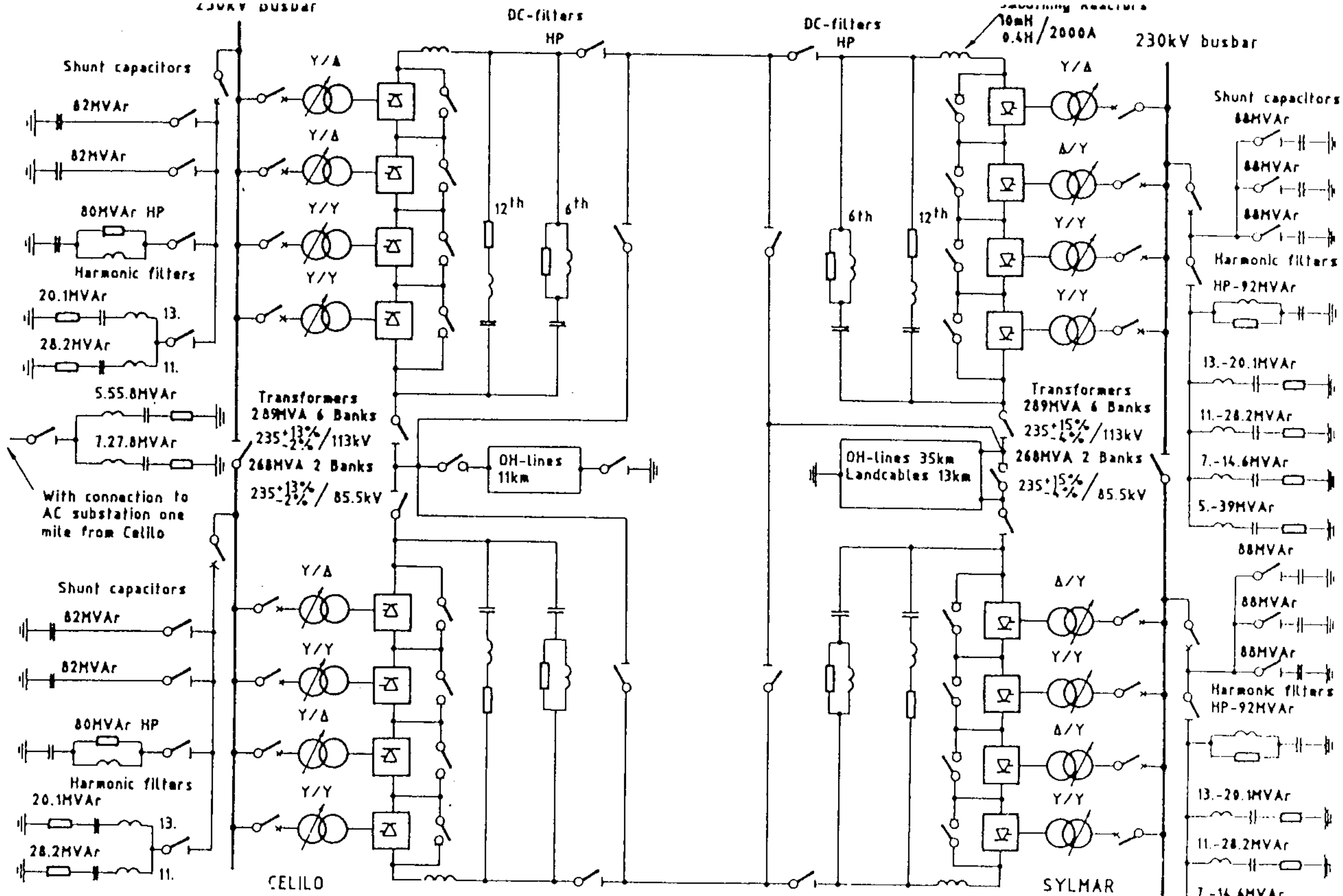
Pole 2

Harm.	MVAr	C=µF	L=mH	R=ohm
5.	21.5	1.04	271	4.1
7.	11	0.53	271	5.7
11.	15.5	0.765	76	2.5
13.	11	0.55	76	2.3
HP	35	1.73	7.1	161

References: Cigré 1976, paper 14-08
"System design features of pole II for the Vancouver Island HVDC link using thyristor valves" by S.C. Kaspoor, W Chin & L.A. Zimmermann
Electra no. 63 (1979)
"A.C. Harmonic filters and reactive compensation for HVDC' A general survey by SC14 - WG03.



PACIFIC HVDC INTERTIE
Geographic map



PACIFIC HVDC INTERTIE SHEME

Simplified single line diagram

The Pacific Intertie Scheme

Between:	Celilo, The Dalles, Oregon and Sylmar, California
Operated by:	Celilo, Bonneville Power Administration, Portland Sylmar: Los Angeles Department of Water & Power
Manufacturer:	ASEA, Sweden, and General Electric Company
Commissioned:	May 1970, upgrade 1985 (by adding a thyristor bridge in serie)
Main Purpose:	The generation resources of the Northwest are made available to the Southwest during peak load periods. In return, the Northwest is provided with energy during offpeak period (Capacity-Energy Exchange). The transmission of surplus hydro power from Northwest when available.
Main Data:	Bipole: 2000 MW at $\pm$ 500 kV and 2000 A/pole. Monopolar: 1000 MW with earth return or with metallic return.
AC Networks:	At both terminals, three single phase convertor transformers are used for each of the four 6-pulse convertor groups/pole.

Celilo: 6-banks 289MVA, 3phase, $235\ ^{+13\%/}_{-\ 2\%/}113.3\,kV_{LL}$

2 banks, 268 MVA, 3 phase $235\ ^{+15\%/}_{-\ 2\%/}85.5\ kV_{LL}$

The transformers are connected to the 230 kV a.c. System.

Short circuit capacity: min. 6750 MVA

Sylmar: 289 MVA, $235\ ^{+15\%/}_{-\ 4\%/}113\ kV_{LL}$;

2 banks - 268 MVA, 3 phase, $235^{+15\%/}_{-\ 4\%/}85.5\ KV_{LL}$

The transformers are connected to the 230 kV a.c. system. Short circuit capacity: min 10,000 MVA

HVDC-system:

Route length = 1361 km

Overhead lines:

Conductors: 2 x 1171 mm^2 ACSR/pole.

Note: Conductor cross-sectional area does not include steel reinforced core.

Line towers: Self-supporting and guyed towers are used. All self-supporting towers are steel structures. Guyed towers for the Southern section are steel and for the northern section aluminium.

Shieldings: The northern section has a single steel shielding wire of 127 mm^2. The southern section has 2-steel shielding wires each of 97 mm^2.

Insulator leakage: varies from 1.8 to 2.6 cm/kV (for 500 kV)

Electrodes:

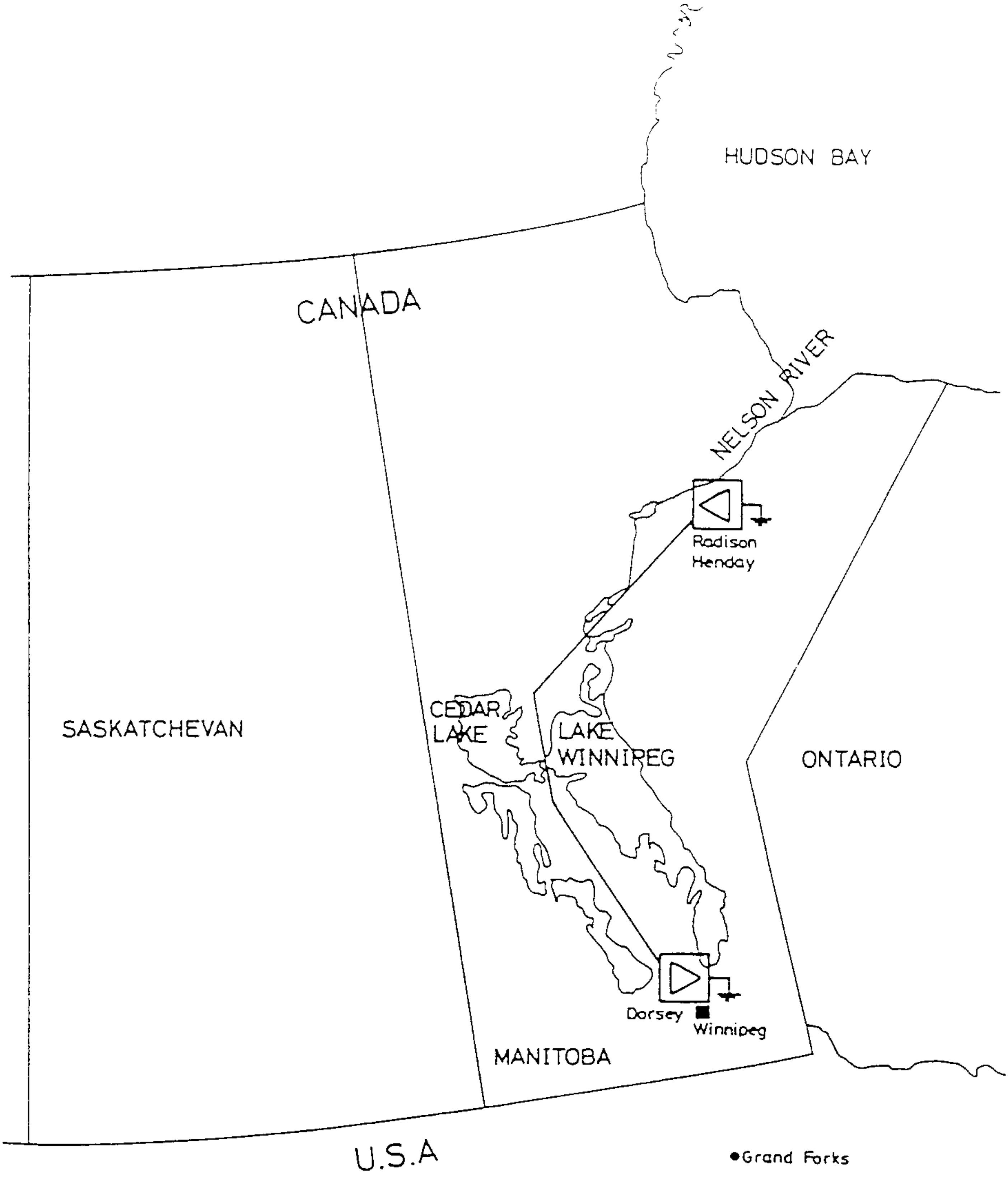
At Celilo: the ground electrode is located 10.6 km from the convertor station, in Rice Flates. The electrode is designed as a ring type 3255 m circumference, 1067 cast iron

anodes, and 2′ x 2′ coke backfill is used. Total resistance in 2 parallel electrodelines and ground electrode = 0.43 ohms.
At Sylmar: the sea elektrode is located 48 km from the convertor station, in the Pacific Ocean and consists of a linear array or 24 horizontal electrode elements made up of silicon-iron alloy rods suspended 0.5 to 1 m above the ocean bottom and located within concrete enclosures. Total resistance in 2 parallel electrode lines and sea electrode = 1.13 ohms.
Electrode lines: At Celilo: 2 x 644 mm^2 ACSR conductors in parallel supported by the d.c. line towers.
At Sylmar: 2 x 644 mm^2 ACSR conductors in parallel are used for the first 35 km, supported by the 230 kV line towers. For the remaining 13 km, two parallel paper-insulated underground cables are used, each with a 633 mm^2 Cu-conductor.

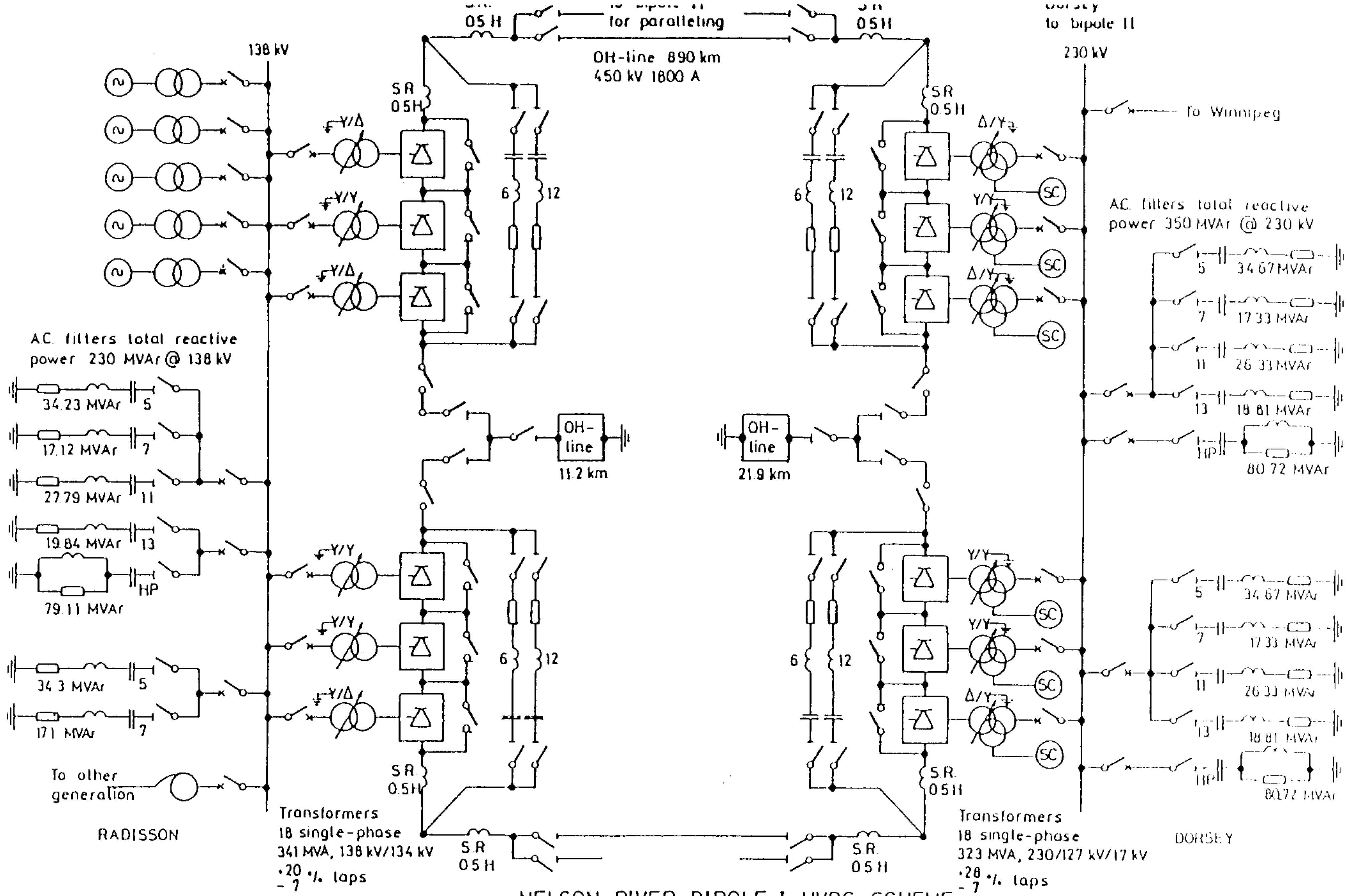
DC Filters: Each pole has one double-tuned HP-filter and one single-tuned filter tuned to the 6th and 12th harmonics. The filters are connected between the pole and the electrode lines.

HVDC-Valves: Mercury arc valves are used for 6 of the converter groups. In 1984 two additional solid state thyristor groups were added at the highest kv-BIL level. The valves have air-cooled anodes and a water-cooled cathode. There are 6 anodes/valves. The thyristor groups are water cooled valves. Six valves and one bypasse-valve form a 6-pulse mercury-arc

convertor group for 133 kV; the thyristor groups operate at 100 kV.
Each pole has 4 series connected 6-pulse convertor groups. The smoothing reactors rated at 2000 A are placed on the high voltage side, designed at 0.4 H at 400 kV d.c. and 10 mH at 500 kV d.c.



NELSON RIVER HVDC SYSTEM
Geographic map



NELSON RIVER BIPOLE I HVDC SCHEME
Simplified single line diagram

The Nelson River Bipole 1 HVDC Scheme

Between: Radisson near Gillam and Dorsey near Winnipeg, Manitoba.

Power Co: The Manitoba Hydro-Electric Board, Manitoba, Canada

Manufacturer: G.E.C. (English Electric), England.

Commissioned: 1973.

Main purpose: Bulk power supply from isolated hydro-electric generation in the north to a large load center in the south. No power reversal is required. The system is run on a varying daily load cycle of full out for load peaking and export and almost shut down at night.

Main data: Bipole, 1668.6 MW at the rectifier
at ± 463.5 kV d.c. and 1800 A
Overload capacity: (short term): 10%.

A.C. networks: At both terminals, three single phase converter transformers with tertiary windings are used for each of the three 6-pulse converter units per pole. The tertiary windings at Dorsey only supply the synchronous condensers.

Radission:

Transformers: 341 MVA, 138 kV $^{+\ 20\%}_{-\ 7\%}$ /134 kV (three phase)
connected to the 138 kV a.c. system.

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Short circuit capacity: min. = 1100 MVA
(3 generators)
A.C. Filters: 2 x (5,7) and one 11,13 and HP.

Dorsey

Transformers: 323 MVA, 230 kV + 28% / - 7% /134 kV/14 kV
(three phase)
connected to the 230 kV a.c. system
Short circuit capacity: min. = 5000 MVA
(4 synchronous condensers, no. 500 kV tie).
Synchronous condensers:
Six at + 160 MVAR capacitive,
- 80 MVAR inductive
connected to the 17 kV tertiary
A.C. Filters: 2 x (5,7,11,13 and HP).

HVDC System: Route length = 890 km

Overhead lines

Conductors: ACRS; Duplex 974,3 mm^2
(each 1.6 " dia., 1843.2 MCM 72/7)
457,2 mm (18") sub spac. 3600 amps/pole
DC resistance/pole is 13.89 ohms at 20°C.
Shielding: 34.93 mm (1 3/8") dia., 7 strands
Grade 180 steel.
Towers: Tangent and light angle guyed single mast type towers are used and also heavy angle and dead end towers of the self-supporting type.
Insulator leakage: 2,3 to 2.35 cm/kV.

Electrodes:	Radisson: It is located 11.2 km from the station and is of the ring type 381 metres in diameter. It is comprised of a steel rod and is installed in a low sulphur coke bed. Resistance: 0.16 - 0,37 ohms. Dorsey: It is located 21.9 km from the station and is of the ring type 305 metres in diameter. It is comprised of a steel rod and is installed in a low sulphur coke bed. Resistance: 0.37 to 0,6 ohms. The Dorsey electrode is designed to accomodate both Bipoles 1 and 2. Electrode line: ACSR, 2 - 795 MCM, 54/7. This is mounted on a separate wood pole structure.
D.C. Filters:	Each pole has one sixth and one twelfth harmonic filter. The filters are connected between the pole and the electrode line.
HVDC valves:	Mercury arc valves are used. The valve has air-cooled anodes and a water-cooled cathode. There are six anodes per valve. Six valves and a bypass vacuum switch form a 6-pulse converter unit at 150 kV. Each pole has three series connected 6-pulse converter units. The smoothing reactors are placed on the high voltage side. There are two smoothing reactors per pole per station with the d.c. filters between them.

Operation is possible with only one smoothing reactor per pole. The smoothing reactors are 0.5 henry each.

A.C. Filters: Both terminals for bipole are provided with harmonic filters:

Dorsey: 2 filters each for:

Harm.	MVAr	C=uF	L=mH	R=ohm
5.	34.7	1.67	168	3.17
7.	17.3	0.852	168	4.43
11.	26.3	1.31	44.4	1.84
13.	18.8	0.938	44.4	2.17
HP	80.6	4.04	4.07	42

Total reactive power installed = 350 MVAr.

Radisson

Harm.	MVAr	C=uF	L=mH	R=ohm
5.	34.3	4.58	61.4	1.08
7.	17.1	2.34	61.4	1.52
one 5.+7.+11. harm filter with:				
5.	34.23	4.58	61.4	1.08
7.	17.12	2.34	61.4	1.52
11.	27.8	3.84	15.2	0.75
one 13. harm + HP filter with:				
13.	19.84	2.75	15.2	0.89
HP	79.11	11	1.45	21

Total reactive power installed = 230 MVAr.

74

References:

1. BATEMAN, L.A., BUTLER, L.S., HAYWOOD, R.W. The ± - kV Direct Current Transmission System for the Nelson River Project. (CIGRE 1968 session, paper no. 43-02).

2. ESTEY D.S., HAYWOOD R.W, Rolland J.W., Willis D.B. Nelson River HVDC System Commissioning and initial operating experience (CIGRE 1974 session paper 14-02)

3. "Electra" NO. 63 (1979) "A.C. harmonic filter and reactive compensation for HVDC". A general survey by SC14-WG03.

4. Cigré 1984, paper 14.04 Responses of the Nelson River HVDC system to disturbances on the receiving end a.c. network by SC14: R.W. Haywood and J. Chand

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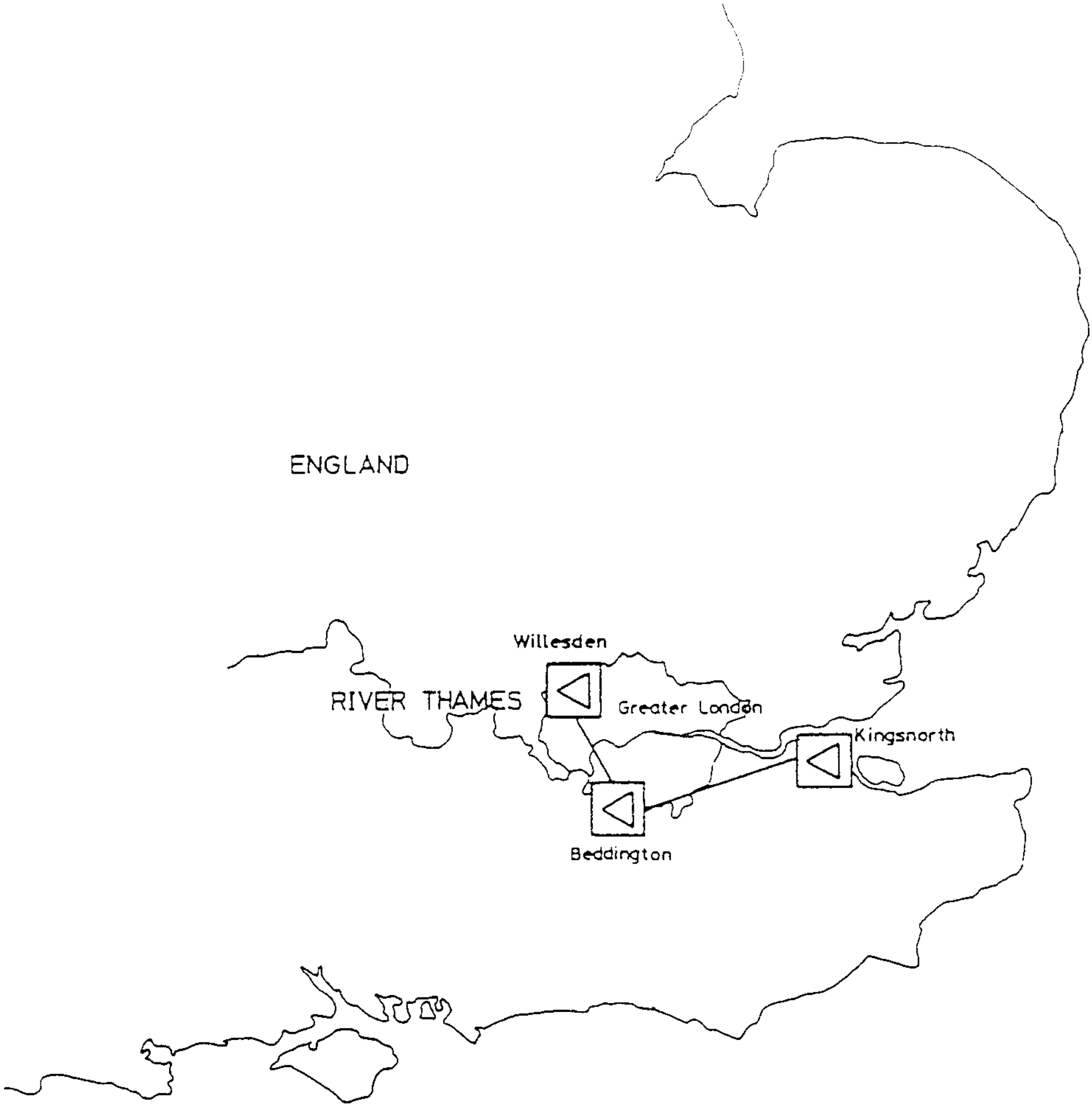
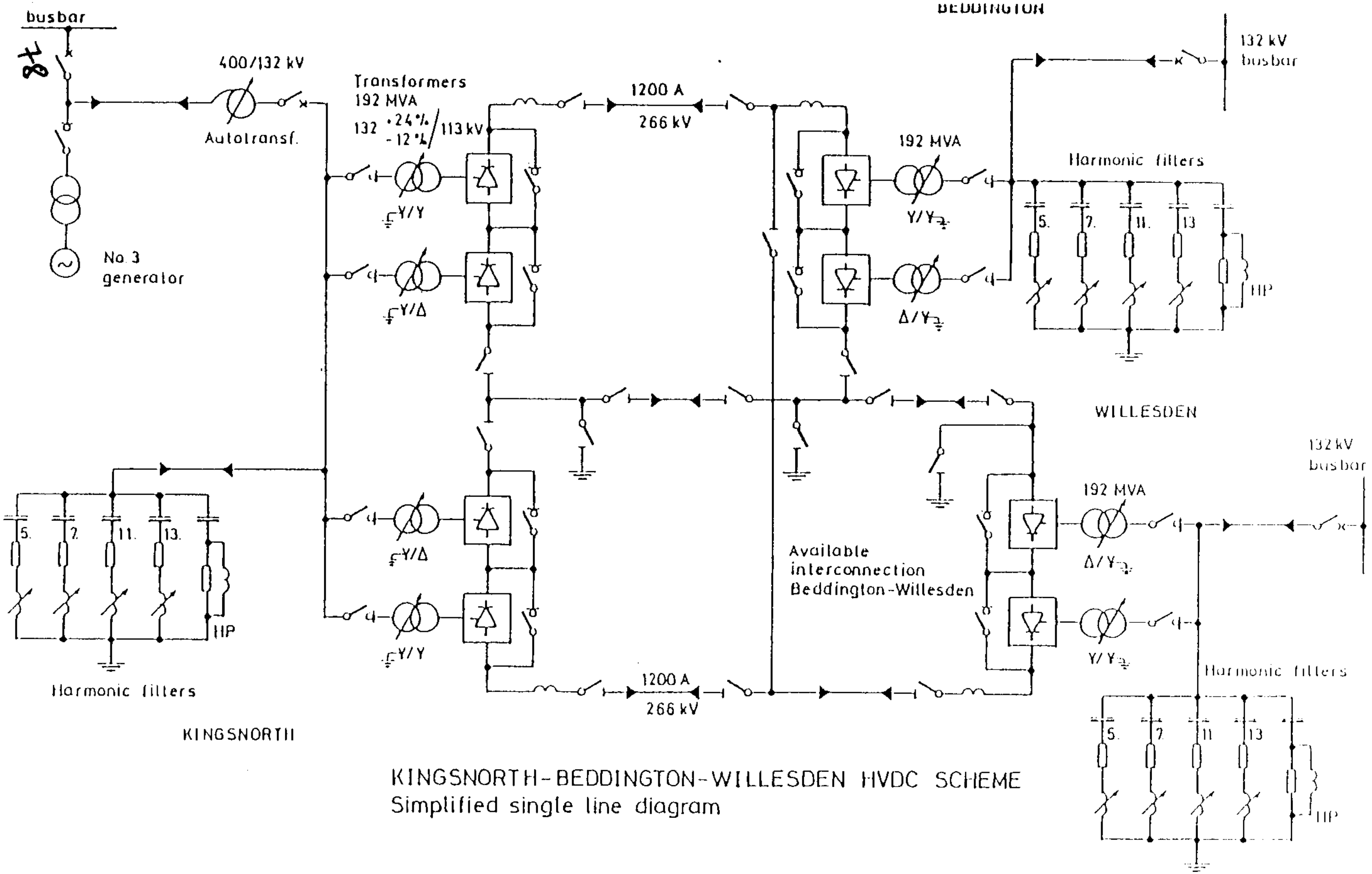


THE KINGSNORTH HVDC-SCHEME
Geographic map



KINGSNORTH-BEDDINGTON-WILLESDEN HVDC SCHEME
Simplified single line diagram

The Kingsnorth HVDC system.

Between: Kingsnorth and Beddington - Willesden, England.

Power Comp.: Central Electricity Generating Board, London.

Manufacturer: G.E.C, England

Commissioned: In June 1976.

Main purpose: Urban reinforcement within an a.c.interconnected system Normal transmission from Kingsnorth to Beddington and Willesden. Transmission between Beddington and Willesden is also possible (reversible) using an interconnection mode.

Main data: Bipole: 640 MW at ±266 kV and 1200 A/pole.

Monopole: (metallic return) 320 MW between Beddington and Willesden.

Overload capacity: no.

AC Networks: At the three terminals, one 3-phase convertor transformer/6-pulse convertor unit is used.

Kingsnorth: 192 MVA, 132 kV $^{+24}_{-12}$%/113 kV.
The 4 transformers are connected to the 132/400 kV a.c.system.
short circuit: min. 3500 MVA. (132kV leve

Beddington: 192 MVA, 132 kV $^{+24}_{-12}$%/113 kV.
The 2 transformers are connected to the 132/275 kV a.c.system.
short circuit: min. 1700 MVA(132 kV level

Willesden: 192 MVA, 132 kV $^{+24}_{-12}$%/113 kV
The 2 transformers are connected to the 132/275 kV a.c.system.
short circuit: min. 1700 MVA (132kV level

The a.c filters at each station consist of 5th, 7th, 11th and 13th arms which are self tuned by variable reactors in series with the capacitor banks and a damped high pass filter.

HVDC system: The three terminals are connected by underground cables.

1) *Kingsnorth - Beddington:*
Route length = 59 km.
2 main cables, oilfilled paper insulated with a single CU-conductor, 806 mm^2.
1 neutral cable, solid type paper insulated with a single Al-conductor, 1161 mm^2.

2) *Beddington - Willesden:*
Route length = 23 km.
1 main cable, oilfilled paper insulated with a single CU-conductor, 806 mm^2
1 neutral cable, extruded PVC insulated with a single Al-conductor, 1935. mm^2.

Electrodes: Metallic return is used and therefore, no earth return. In case of a fault on the neutral cable between Kingsnorth and Beddington, a balanced mode can be used in which the currents in the two poles from Kingsnorth are kept equal.

DC-filters: There are no filters on the d.c.sides of the terminals.

HVDC valves: Mercury arc valves are used. The valve has water cooled cathode and air cooled anodes. There are 4 anodes/valve and 6 main valves plus 1 bypass valve in each 6-pulse convertor unit.

The smoothing reactors are placed on the high voltage side and are designed for 266 kV d.c. and the rated inductance is 0.6 H at 1200 A.

A.C. Filters: Harmonic filters are provided at Kingsnorth as well as at Willesden and Beddington

Kingsnorth:

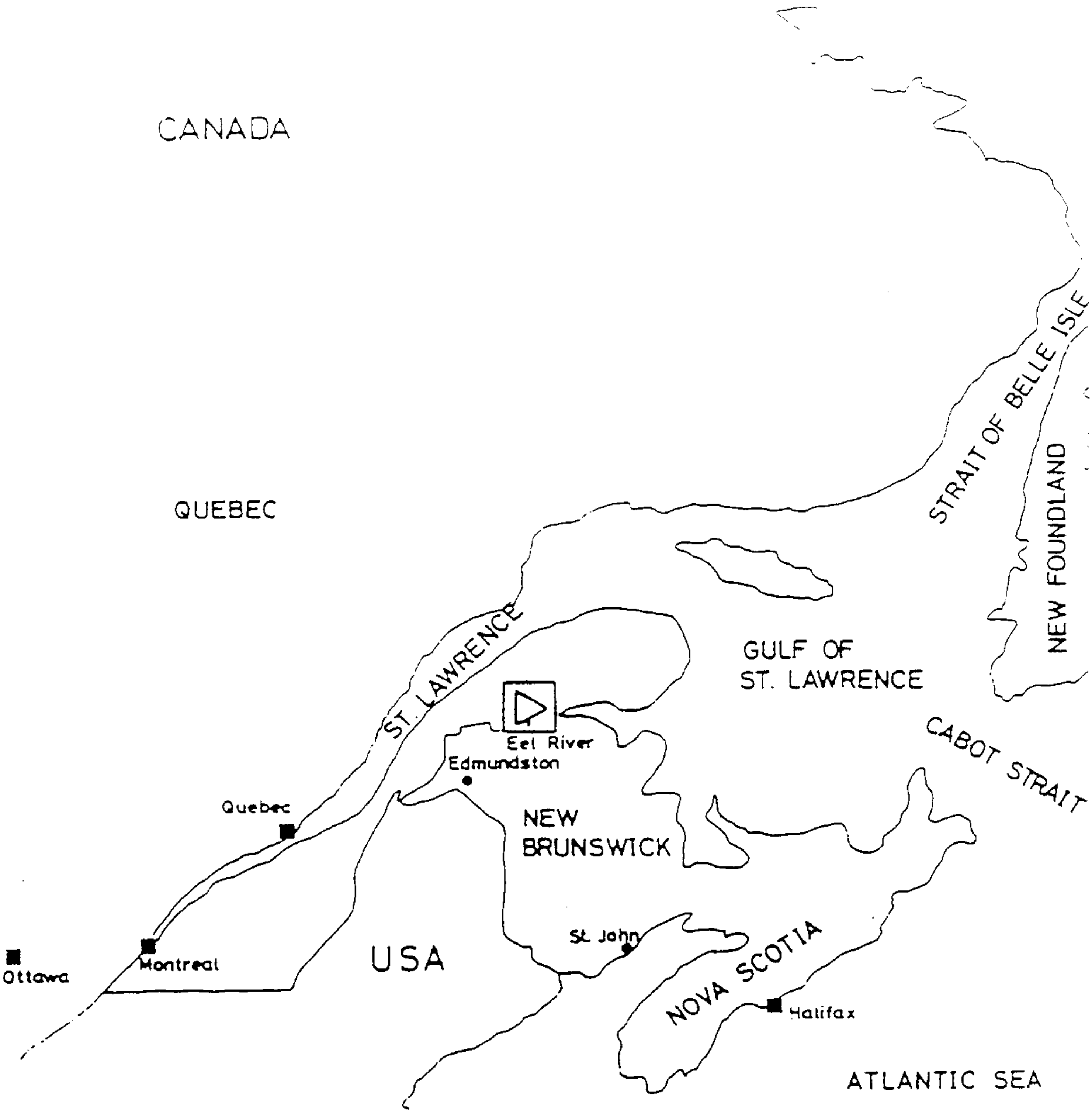
Harm.	MVAr	C=uF	L=mH	R=ohm
5	39	7.13	57	0.894
7.	18	3.28	63.3	1.39
11.	19	3.48	24.1	0.833
13.	22	4.0	15.3	0.625
HP	19	3.5	6.34	67

Beddington and Willedden: (at each terminal)

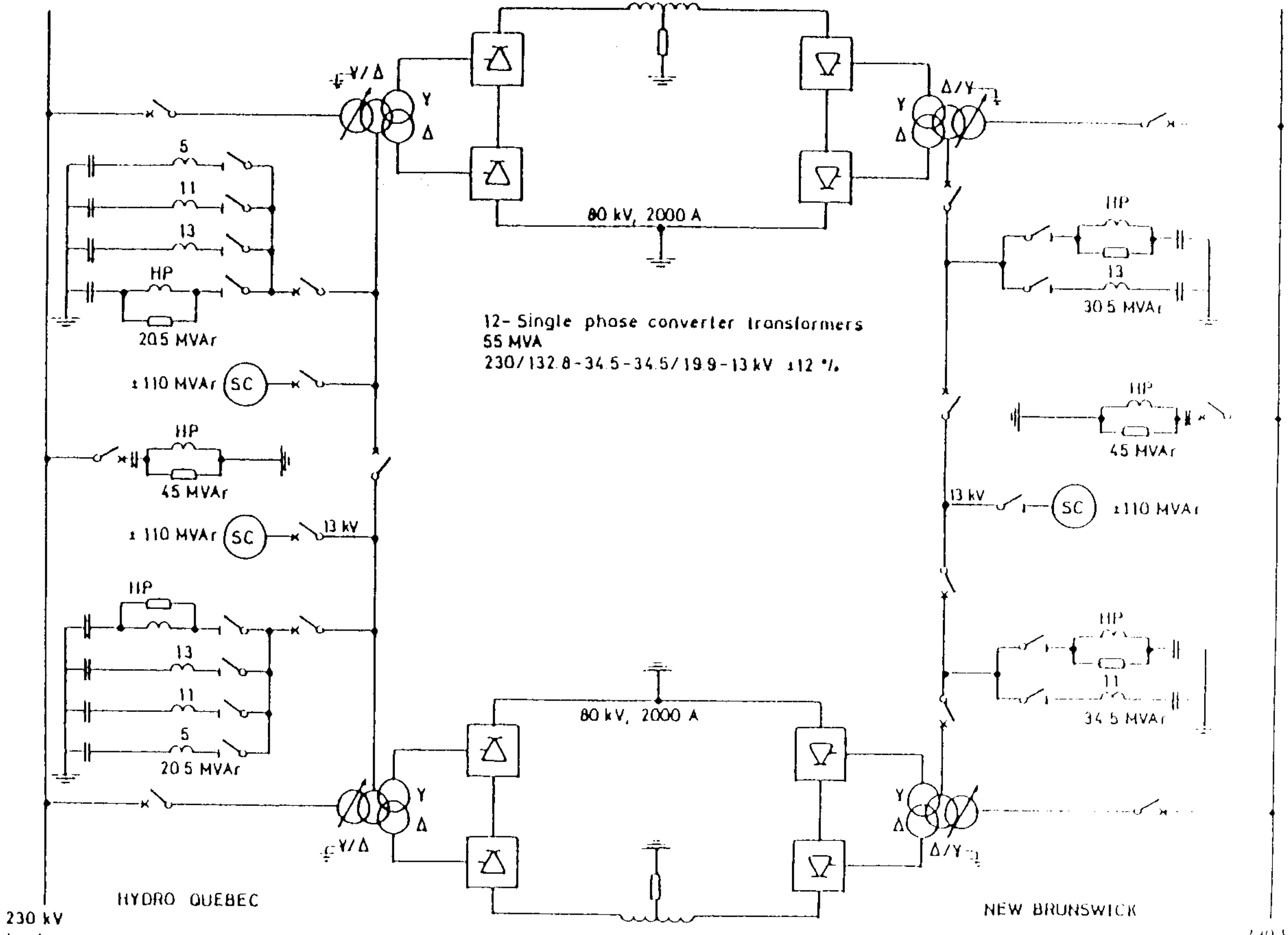
Harm.	MVAr	C=μF	L=mH	R=ohm
5.	13	2.5	162.5	2.55
7.	10.9	2.0	101.8	2.27
11.	10.4	1.9	44.1	1.53
13.1	6.0	1.47	40.8	1.67
HP	13.7	2.5	10.8	104

References:

Electra No 63 (1979)
"A.C. Harmonic filter and reactive compensation for HVDC"
A general survey by SC14-WG03



EEL RIVER HVDC-SYSTEM
Geographic map



EEL RIVER HVDC SYSTEM
Simplified single line diagram

Eel River HVDC system.

Between: Hydro Quebec and New Brunswick, Canada.

Power comp.: Hydro Quebec and N.B. Power, Fredericton.

Manufacturer: General Electric, USA.

Commissioned: July 1972.

Main purpose: The interconnection is designed as an asynchronous HVDC coupling system, predominantly for bulk power transmission to New Brunswick.
Power reversal is possible.
Energy supply during emergency situations to support either of the a.c. systems in case of frequency problems.

Main data: Bipole, 320 MW at + or - 80 kV d.c. and 2000 A.

Overload capacity: 10% continuously.

AC Networks: The four convertor transformers used are single phase units with dual converter windings and tertiary windings for supplying the a.c. filters and synchronous compensators.

data: 55 MVA, 230 ± 12%/34.5/13.0 kV

The transformers are connected to the 230 kV a.c. systems of Hydro Quebec and New Brunswick Power, respectively.

Short circuit capacity: Hydro Quebec: Min. 1716 MVA.
N.B. Power : Min. 1612 MVA.

HVDC system: Due to the station design (back to back) there are no d.c. transmission lines.

The BIL is 350 kV for all d.c. equipment.

d.c. filters: No special d.c. filters are installed.

HVDC valves: Thyristor valves are used. Each terminal has two 6 pulse convertor units in series connection. The six valves of one 6-pulse convertor unit is housed in one indoor valve structure.
Each valve section has 5 modules in series connection.
Each module has 10 thyristor levels in series and each

85

thyristor level has 4 thyristors in parallel connection.

This makes a total of 200 thyristors (50 thyristor levels) per valve arm or 1200 thyristors per 6 pulse converter unit for 40 kV d.c. and 2000 A.

One module has a weight of 200 kg.

The valves are air insulated and air cooled.

The smoothing reactor is designed for 140 kV and 0.14 H at 2000 A.

A.C. Filters: Harmonic filters are provided at each side.

Hydro Quebec:

At the 13 kV level: Two filters banks each with:

5. harm. = 2 MVAr; L = 8.35mH and C = 33.6uF
11. harm. = 7 MVAr; L = 0.532mH and C = 109uF
13. harm. = 5 MVAr; L = 0.532mH and C = 78.3uF
(Q=125 for the three filters above)
HP = 6.5 MVAr; L = 1.22mH; R = 3.2 ohm and C = 78,5uF

at the 230 kV level:

HP = 45 MVAr; C = 2.25uF; L = 10.8mH and R = 69 ohm

New Brunswick:

at the 13 kV level:

11.harm.= 14 MVAr; L= 0.265mH and C = 218 uF, Q = 125
HP = 20.5MVAr; L= 0.45 mH and C= 317 uF;

13.harm.= 10 MVAr; L= 0.265mH and C= 158 uF; Q = 125
HP = 20.5MVAr; L= 0.45 mH and C= 317 uF

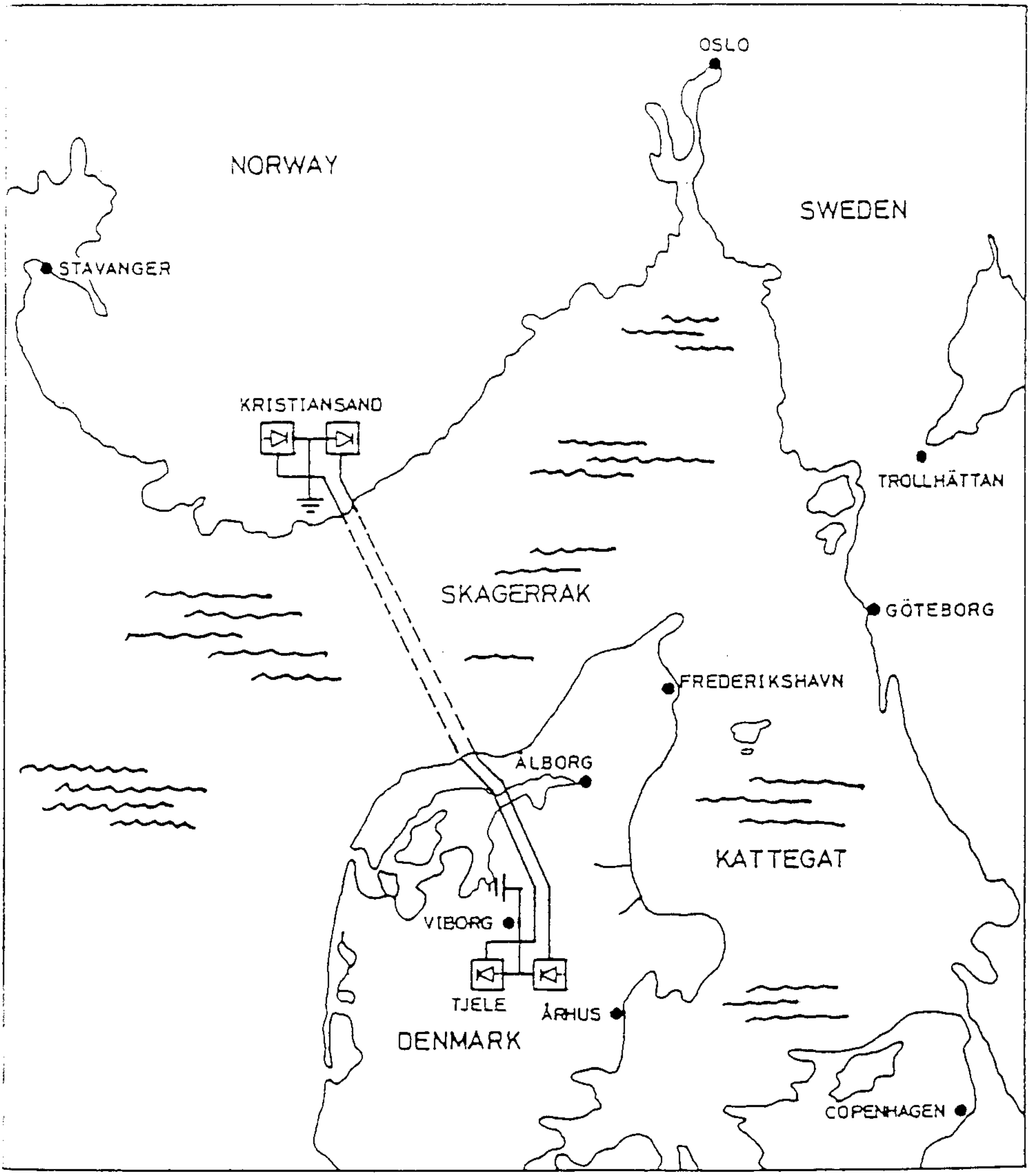
at the 230 kV level

HP = 45 MVAr; C= 2.25 uF; L= 10.8 mH and R= 69 ohm

References:

Electra no. 63 (1979)
"A.C. Harmonic filter and reactive compensation for HV
A general Survey by SC14-WG03

SKAGERRAK HVDC TRANSMISSION



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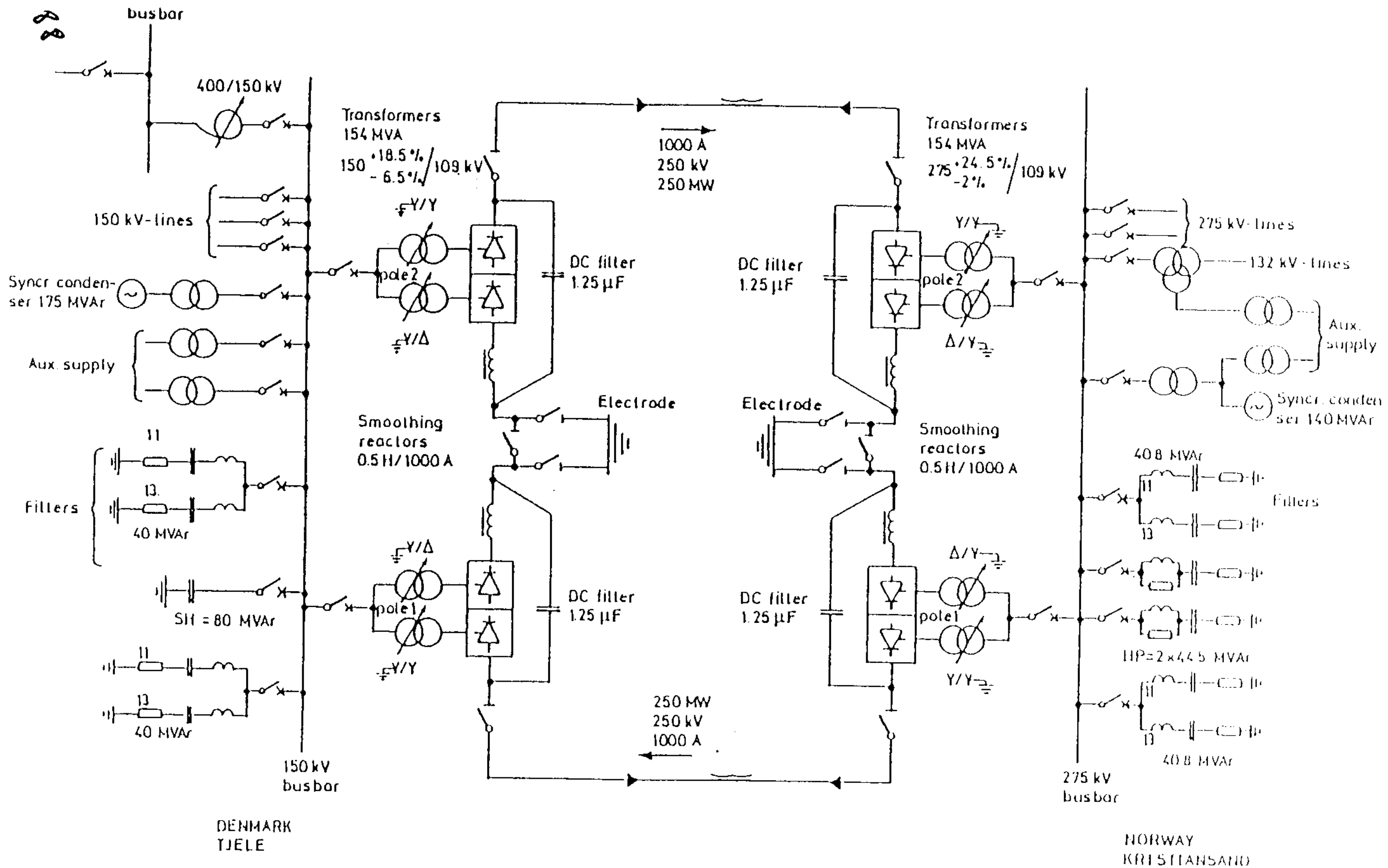


THE SKAGERRAK SCHEME
Simplified single line diagram

The Skagerrak HVDC scheme:

Between: Denmark (Tjele) and Norway (Kristiansand)

Power Comp: The Jutland-Funen Power Pool, Elsam, Fredericia and the Norwegian State Power Board, Statkraft, Oslo.

Manufacturer: ASEA, Sweden

Commissioned: Monopole (Pole 1) in October 1976
Bipole in September 1977

Main purpose: Peak power transmission to Denmark, with off peak return Energy supply to Norway in dry years
Excess energy supply to Denmark in years with ample precipitation.
Energy supply during emergency situations, to support the AC systems in both countries.
i.e. in case of AC network disturbances or loss of generation etc.

Main data: Bipole 500 MW at ± 250 kV DC and 1000 A/pole
Earth return is possible with only one pole in service. Overload capacity: Current limit = 1030 A

AC Networks: At both terminals two 3-phase convertor transformers are used per pole and 12-pulse convertor unit.

Tjele: 154 MVA 150 kV $^{+18.5\%}_{-6.5\%}$ / 109 kV

The four transformers are connected to the 150/400 kV AC system.
Short circuit capacity: min. 3000 MVA

Kristiansand: 154 MVA, 275 kV $^{+24.5\%}_{-2\%}$ / 109 kV

The four transformers are connected to the 300 kV AC system
Short circuit capacity: min. = 2500 MVA

HVDC system: Route length = 240 km
Overhead lines: are both in Denmark and Norway designed as double bipole lines. Each line has a single ACSR conductor of 772 mm^2 (Martin).

At the initial stage with only one bipole commissioned, two conductors are temporarily used in parallel.

Length of overhead lines: in Denmark = 85 km and in Norway = 28 km.

Line towers: are self supporting lattice steel structures.

Shieldings: The overhead lines are shielded in Denmark by a single steel wire, and in Norway by 2 steel wires (Portal towers).

Insulator leakage: 4.1 cm/kV (on 250 kV)

Submarine cables: There are two cables, each with a single Cu-conductor of 800 mm^2. The cables have oilimpregnated paper insulation (solid type).

Length = 127 km, weight = 48 kg/m in air

Armouring: a double contrahelically wrapped steel armouring of 5 and 7 mm respectively is used.

Electrodes:

The electrode stations are located on the shore in Denmark and Norway. The distance from the convertor stations is about 29-30 km.

In Denmark the electrode is designed as a number of parallel connected graphite electrodes, arranged in concrete rings, each with d = 2.5 m and at a depth of 2 m. Coke backfill is used R = 0.35 .

In Norway the electrode is designed in a similar way except that the graphite electrodes are placed in a wooden structure with coke backfill; R = 0.22 .

Electrode lines: In Denmark 2 x 454 mm^2 ACSR conductors in parallel are used for the first 18 km, and supported by the overhead line towers. For the remaining 11 km two parallel underground PEX-cables are used, each with a single Al-conductor of 300 mm^2, which means a current limited to 750 A in case of one faulty cable and monopolar operation.

In Norway the first 20 km of the electrode lines are likewise supported by the line towers whereas the remaining 10 km are designed as a separate overhead line. The conductors used are 2 x 198 mm^2 ACSR in parallel.

<u>DC filters:</u>

No special DC filters are used, but due to telephone interference along the DC line, a pure capacitor of 1.25 F/pole is installed both in Denmark and Norway.
Each capacitor is connected between the pole-and the electrode line, i.e. they are grounded at the electrode stations, and not to the convertor station grounding system.

<u>HDVC valves:</u>

The thyristor valves are housed indoor, and they are designed as "Quadruple" valves. Three quadruple valves form a 12-pulse convertor unit. Each quadruple valve has 4 valve sections in series connection. One valve section has 24 modules, each with 6 series connected thyristors, giving the total of 144 thyristors in series connection per valve arm. This makes 576 thyristors for one quadruple valve or 1728 thyristors in one 12-pulse convertor unit for 250 kV DC and 1000 A. Parallel connection of thyristors is not used.
The valve structure is air insulated and air cooled.

<u>The smoothing reactor</u> is placed on the neutral side and is designed for 0.5 H at 1000 A.

<u>A.C. Filters:</u>

Harmonic filters are provided at each terminal:
<u>Denmark:</u> Two 11. + 13. harm. filters each <u>40 MVar,</u> with:

Harm.	MVAr	C=μF	L=mH	R=ohm
11.	20	2.50	34	0.71
13.	20	2.50	24.3	0.48

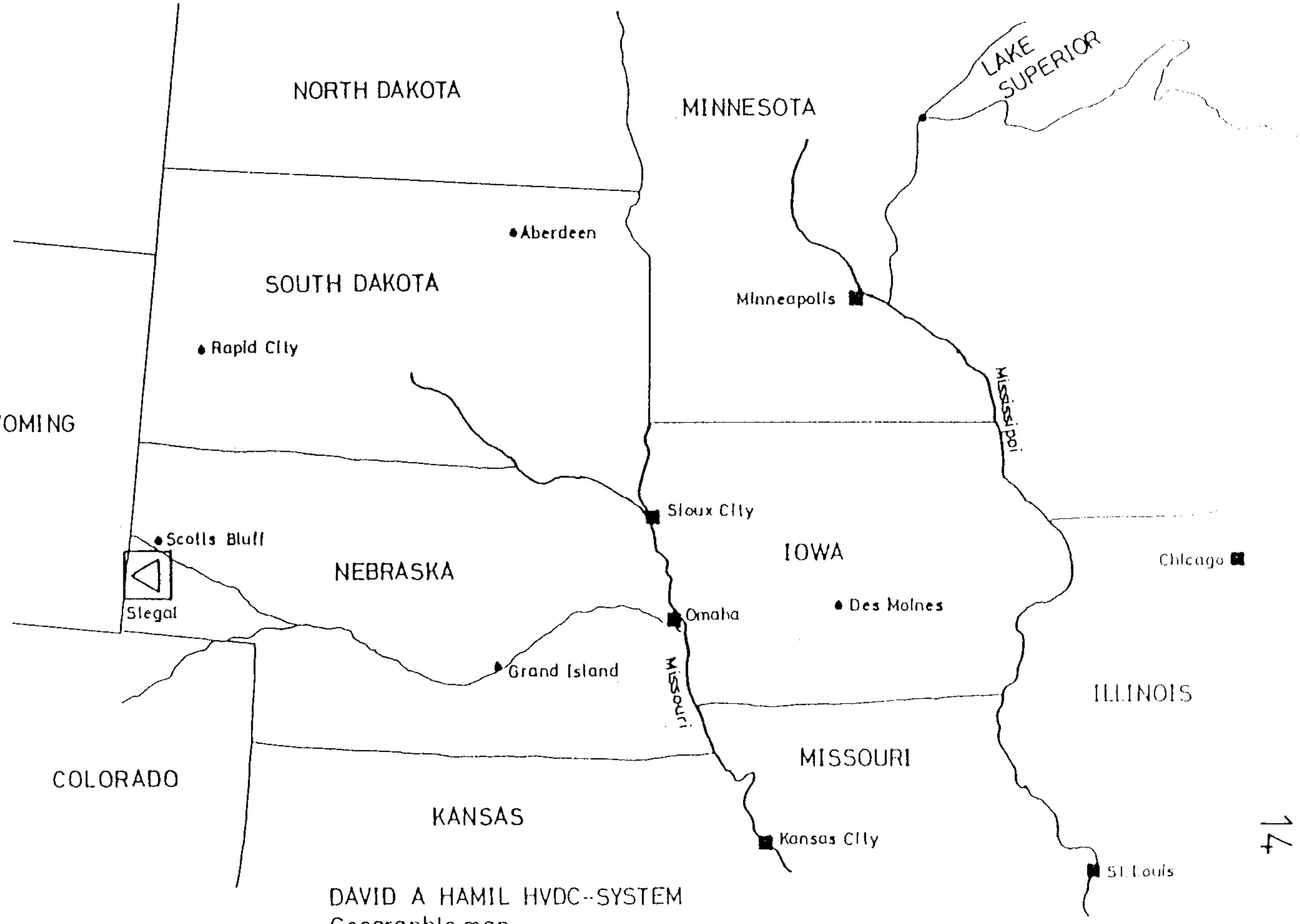
Furthermore one shunt capacitor bank=80 MVAr (changed from HP in Dec. 1980); C=9.95 F

Norway: Two 11. + 13. harmonic filters each 40.8 MVar, with and two HP filters, each 44.5 MWAr, with:

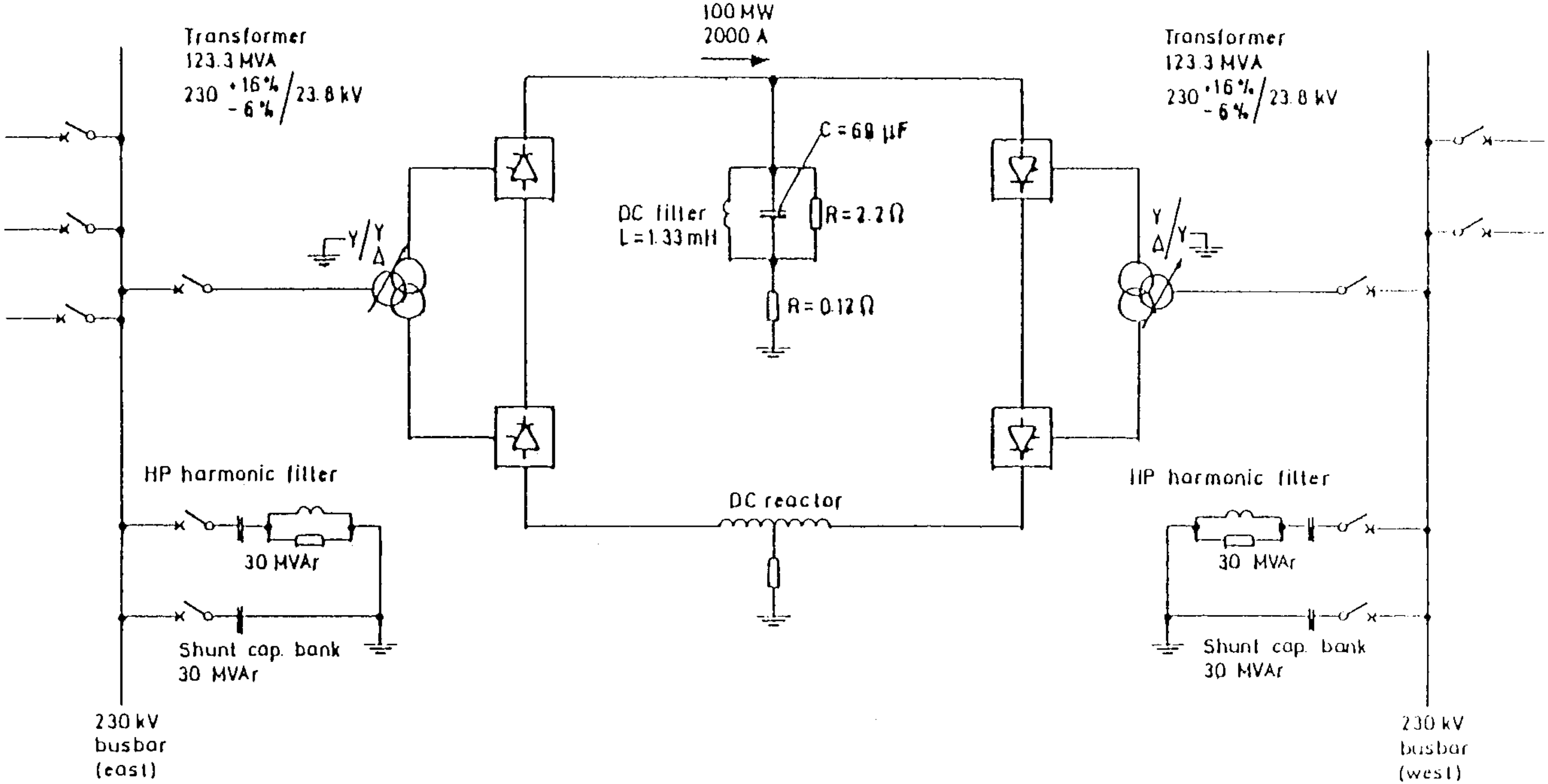
Harm.	MVAr	C=μF	L=mH	R=ohm
11.	20.4	0.821	102	3.9
13.	20.4	0.821	73	3.3
HP	44.5	1.81	9.7	294

References:

Cigre 1978, papers 14.04
The Skagerrak HVDC Transmission scheme, System design features and service experiment.
O. Hauge, S. Vikanes, E. Andersen and G. Styrbro
Electra no. 63 (1979)
"A.C. Harmonic filter and reactive compensation for HVDC"
A general survey by SC14-WG03.



DAVID A HAMIL HVDC--SYSTEM
Geographic map



DAVID A HAMIL HVCD SCHEME
Simplified single line diagram

The David A.Hamil HVDC scheme:

Between: The eastern and western interconnected 230 kV a.c. systems at Stegall, Nebraska USA.

Power comp.: Tri-State Generation and Transmission Ass.

Manufacturer: General Electric USA.

Commissioned: 1st January 1977.

Main purpose: Due to an inadequate a.c.transmission system in the Rocky Mointains area the interconnection is designed as an asynchronous HVDC coupling system to provide a stable power transfer path between the two a.c.systems.

Main data: Monopole 100 MW at + or - 50 kV d.c.and 2000 A. Overload capacity: 10% continuously.

AC Networks: The two convertor transformers used are 3-phase units with two secondary windings, one in star connection and the other in delta connection giving 12-pulse operation.
Both transformers are star connected on the primary sid
data: 123.3 MVA - 230$^{\pm\ 16}_{\ \ \ 6}$ %/23.8 kV

The transformers are connected to the eastern/western 230 kV a.c.systems respectively. (60 Hz).

Short circuit capacity: East: min. 540 MVA
West: min. 1240 MVA

HVDC system: Due to the station design (back to back) there are no d.c.transmission lines.
The BIL is 200 kV for all d.c.equipment.

DC filters: HP type, single tuned to the 11th harmonic.

HVDC valves: Thyristor valves are used. Each terminal has two 6-pulse convertor units in series connection and the 12 valves of one terminal are housed in one valve structure. Both terminals which consist of 2 valve structures are housed indoor in one valve hall.
Each valve has 3 modules in series connection. Each module has 10 thyristor levels in series and each thyristor level has 4 thyristors in parallel connection.

This makes a total of 120 thyristors per valve arm or 720 thyristors per 6-pulse convertor unit.

One module has a weight of approx. 300 kg.

The valves are air insulated and air cooled.

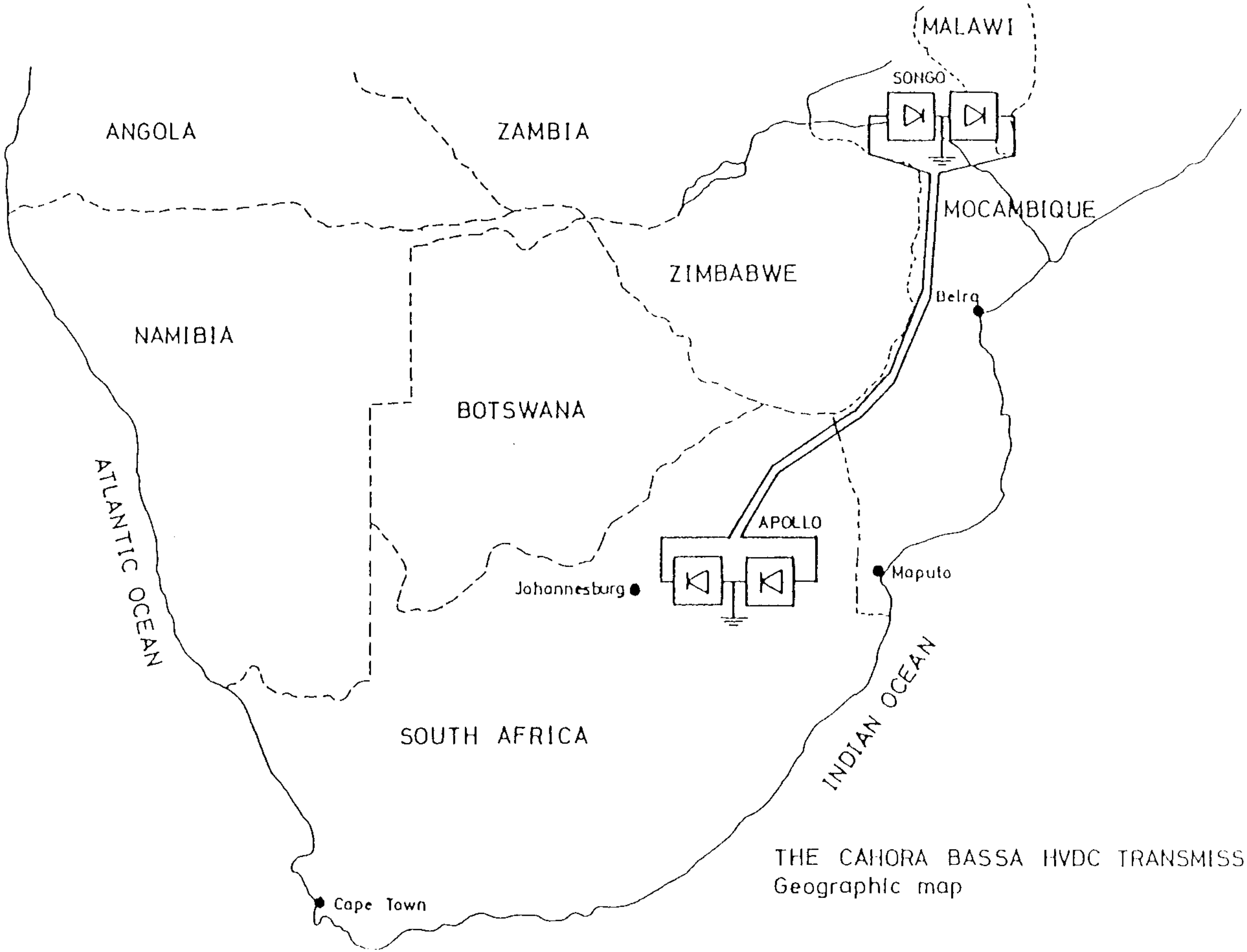
The d.c. reactor is designed for operation in 50 kV d.c. circuit and 0.06 H at 2000 A.

A.C. Filters: Harmonic filters are provided, equal designed at each side:

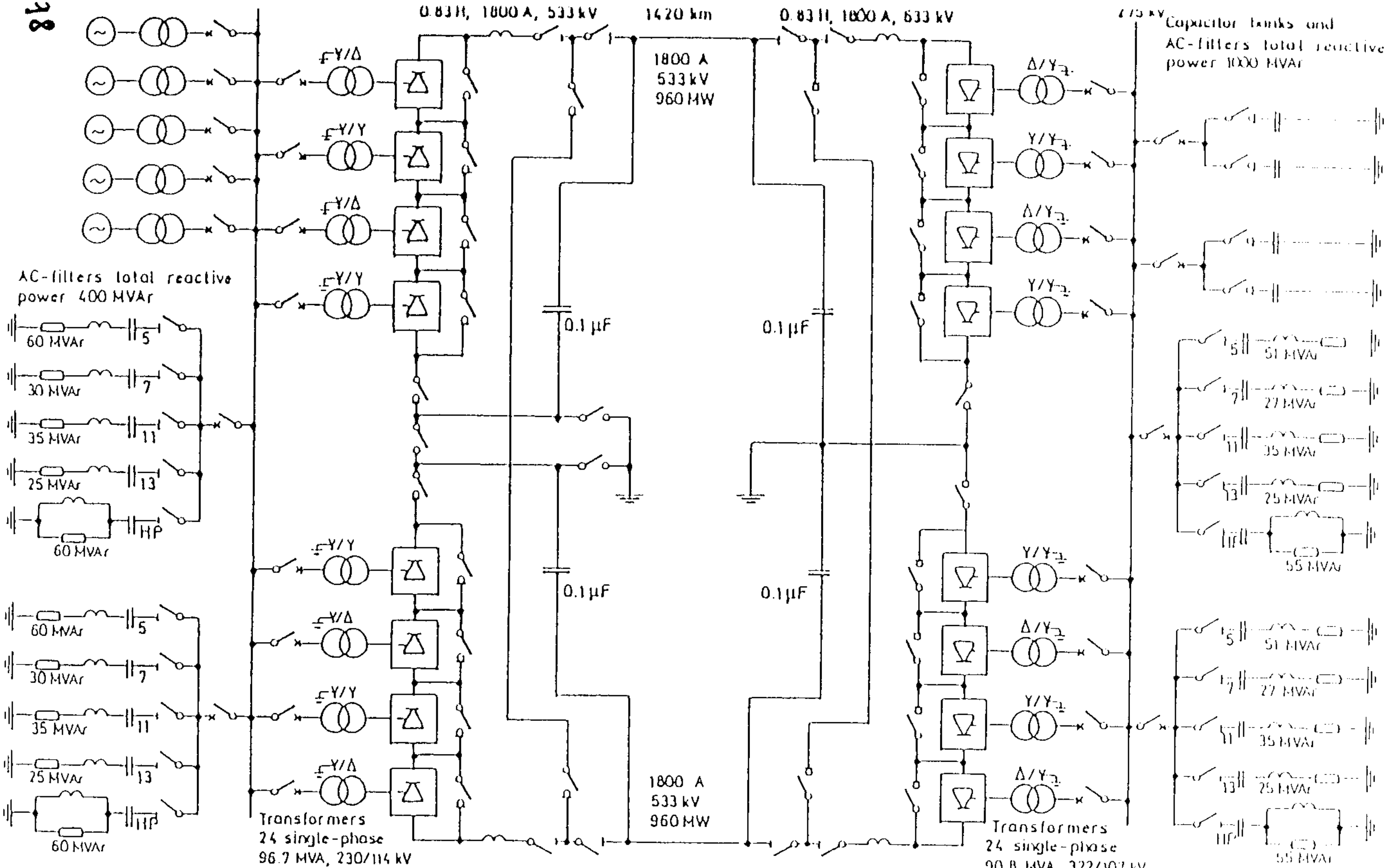
East = West; HP filter, 30 MVAr with C= 1.5 uF; L = 39 mH
R = 231ohm

further more a shunt batteri;
30 MVAr is installed at each of the 230 kV busbar

eferences: Electra No 63 (1979)
"Harmonic filter and reactive compensation for HVDC"
A General survey by SC14-WG03



THE CAHORA BASSA HVDC TRANSMISSION
Geographic map



APOLLO CAHORA BASSA HVDC SCHEME
Simplified single line diagram

The Cahora Bassa HVDC scheme.

Between: Songo in Mocambique and Apollo, near Johannesburg South Africa.

Power comp.: The Electricity Supply Commission, Escom, Johannesburg South Africa and
The Hidroelectrica de Cahora Bassa, Mocambique

Manufacturer: ZAMCO consortium; members responsible for the converter equipment: AEG-TELEFUNKEN, BBC and SIEMENS AG, Germany.

Commissioned:

Stage I:	March 1977	(4 bridges)
Stage II:	April 1978	(2 bridges)
Stage III:	June 1979	(2 bridges)

Main purpose: Bulk power transmission from Songo to Apollo.

Main data: Bipole, 1920 MW at $\pm$533 kV d.c. and 1800 A/pole.
Earth return is available with only one pole in service.

Overload capacity: none

a.c. networks: Single phase transformers are used at both terminals, e.i. 3 transformers per 6 pulse unit or 24 transformers as a total per terminal.

Apollo: 90.8 MVA, 322 ± 16%/107 kV
The transformers are connected to the 275 kV a.c.system.
Short circuit capacity: min. 8000 MVA

Songo: 96.7 MVA, 230 kV ± 16%/114 kV.
The transformers are connected to the 220 kV a.c.system.
Short circuit capacity: min. 2000 MVA

HVDC system: Route length = 1420 km.

Overhead lines: Two monopolar d.c. lines with isolated earth conductors.

Conductors: 4 x 565 mm^2 ACSR per pole (main)
1 x 117 mm^2 ACSR per pole (earthwire)

Line towers: Self supporting steel structures.

Insulator leakage: 2.3..2.7 cm/kV (on 533 kV).

ectrodes:

The electrode stations are located:
7 km from the Apollo terminal, and
15 km from the Songo terminal.

The electrode stations are at both ends designed as deep electrodes.

Apollo: 4 graphite electrodes with a diameter of 300 mm, arranged in vertical holes with a diameter of 750 mm. Graphite chips are used between rod and hole and as drain is used coarse-grained gravel filling. The electrodes are arranged in a 40 m conducting layer down to 130 m below ground level. These electrodes are going to be replaced by a different type using bitumen and graphite as back-fill.

Songo: 5 graphite electrodes with a diameter of 100 mm, and length of 60 m, arranged in boreholes and spaced by 10 m in a coal layer down to 30 m below ground level. Graphite powder emulsion is used between rod and hole (d > 300 mm) Total measure R≅ 0.03 ohm.

c. filters:

No special d.c. filters have been used initially, but in each of the terminals, a surge, capacitor of 0.1 μF was installed. Lateron the surge capacitors have been extended to d.c. filter circuits.

DC valves:

The thyristor valves used, are a double valve type, oil-insulated and oilcooled in a tank. With special consideration for the climatic conditions. This means that 3 double valves form a 6 pulse converter unit, supplied by 3 single phase converter transformers.
In each double valve unit is used:

Stage I: (4 bridges) 280 thyristor levels in series connection per valve arm and 2 thyristors in parallel. This makes for one double valve a total of 560 thyristor levels or 1120 thyristors.

For a 6 pulse converter unit this makes 3360 thyristors for 133 kV d.c. and 1800 A.

Stage II and III: (4 bridges) 192 thyristor levels in series connection per valvearm and 2 thyristors in parallel. This makes for one double valve a total of 384 thyristor levels or 768 thyristors.
For a 6 pulse converter unit this makes 2304 thyristors for 133 kV and 1800 A.
Each terminal has installed eight 6 pulse brudges, giving a total of 11328 thyristor levels or 22656 thyristors per station.

The smoothing reactors are placed on the high voltage side and designed for 533 kV d.c. and 0.83 H at 1800 A.

A.C. Filters: Harmonic filters are provided at each terminal, and they are designed as two identical filters each with:

Apollo: total installed 195 MVAr.

Harm.	MVAr	C=µF	L=mH	R=ohm
5.	51	1.79	226	
7.	27	0.96	216	
11.	35	1.26	66	
13.	25	0.89	67.9	
HP	55	1.99	8.8	94.2

101

Songo: total installed 210 MVAr.

Harm.	MVAr	C=uF	L=mH	R=ohm
5.	60	3.4	119	
7.	30	1.8	116	
11.	35	2.2	38	
13.	25	1.6	37	
HP	60	3.7	4.8	51.5

References:

1: Cigré 1974, paper 14-04:
Layouts of the HVDC terminal stations.
A. Heyner, E.F. Raynham, A. de Ornelas Mario, P. Sieber.

2: Cigré 1974, paper 14-07:
Design and testing of the Cabora Bassa thyristor valves.
I. Boban, Ö. Ergin, H.W. Gierlich, H. Rötting.

3: Cigré 1976, paper 14-06:
Control system.
W. Becker, S. Ranade, E. Rumpf, H. Wess

4: Cigré 1978, paper 14-13:
Commissioning of the Cabora Bassa HVDC system.
K.W. Kanngiesser, A. de Orelas Mario, H. Pesch, E.F. Raynham, W. Ziegler.

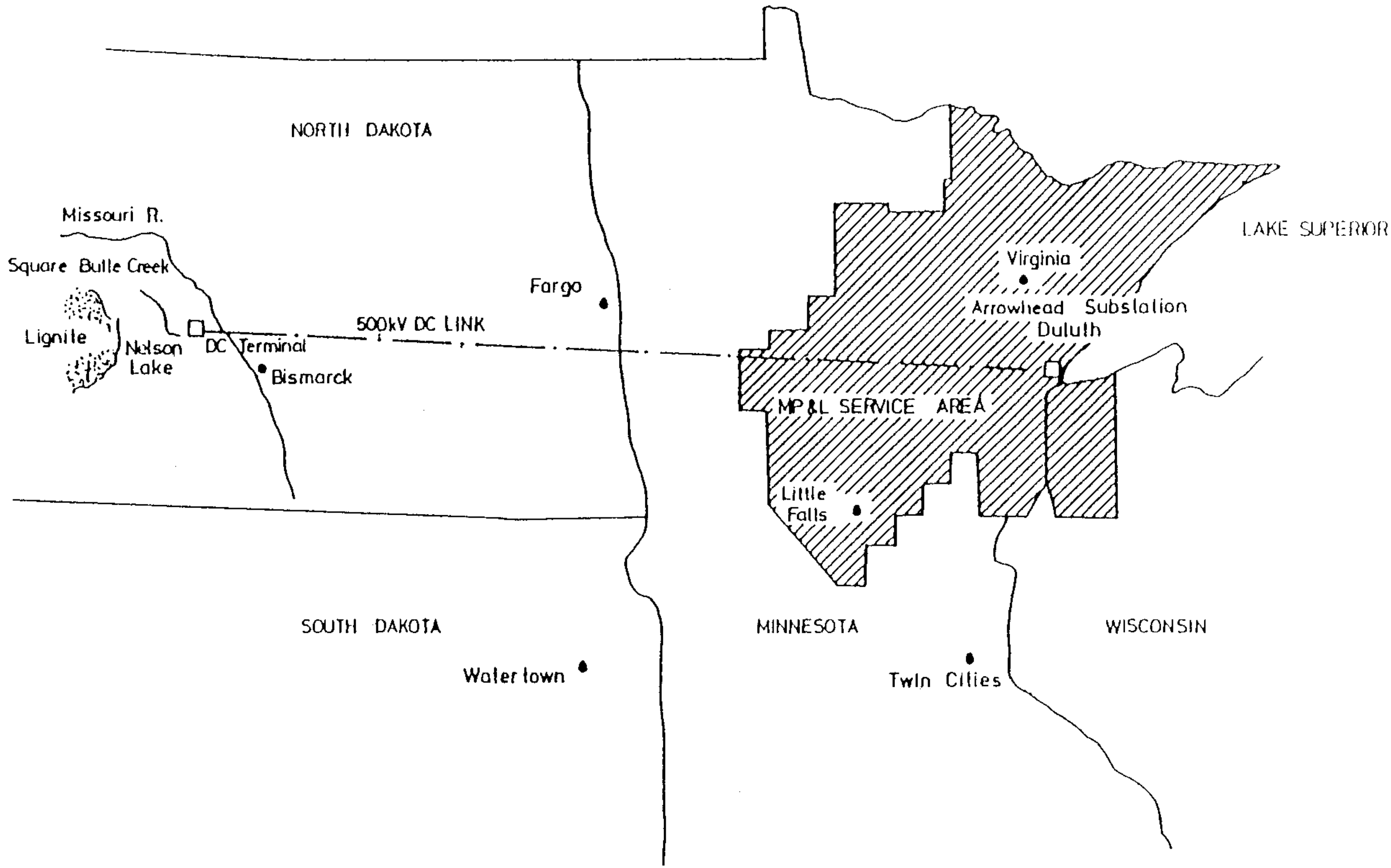
5: "Electra" No. 63 (1979)
"A.C. Harmonic filter and reactive kompensation for HVDC"
A General survey by SC14 WG03

6: Cigré 1982, paper 14-05:
Apollo Inverter Station HVDC operationel experience.
E.F. Raynham, P.W. Goosen.

V A N C O U V E R   I S L A N D

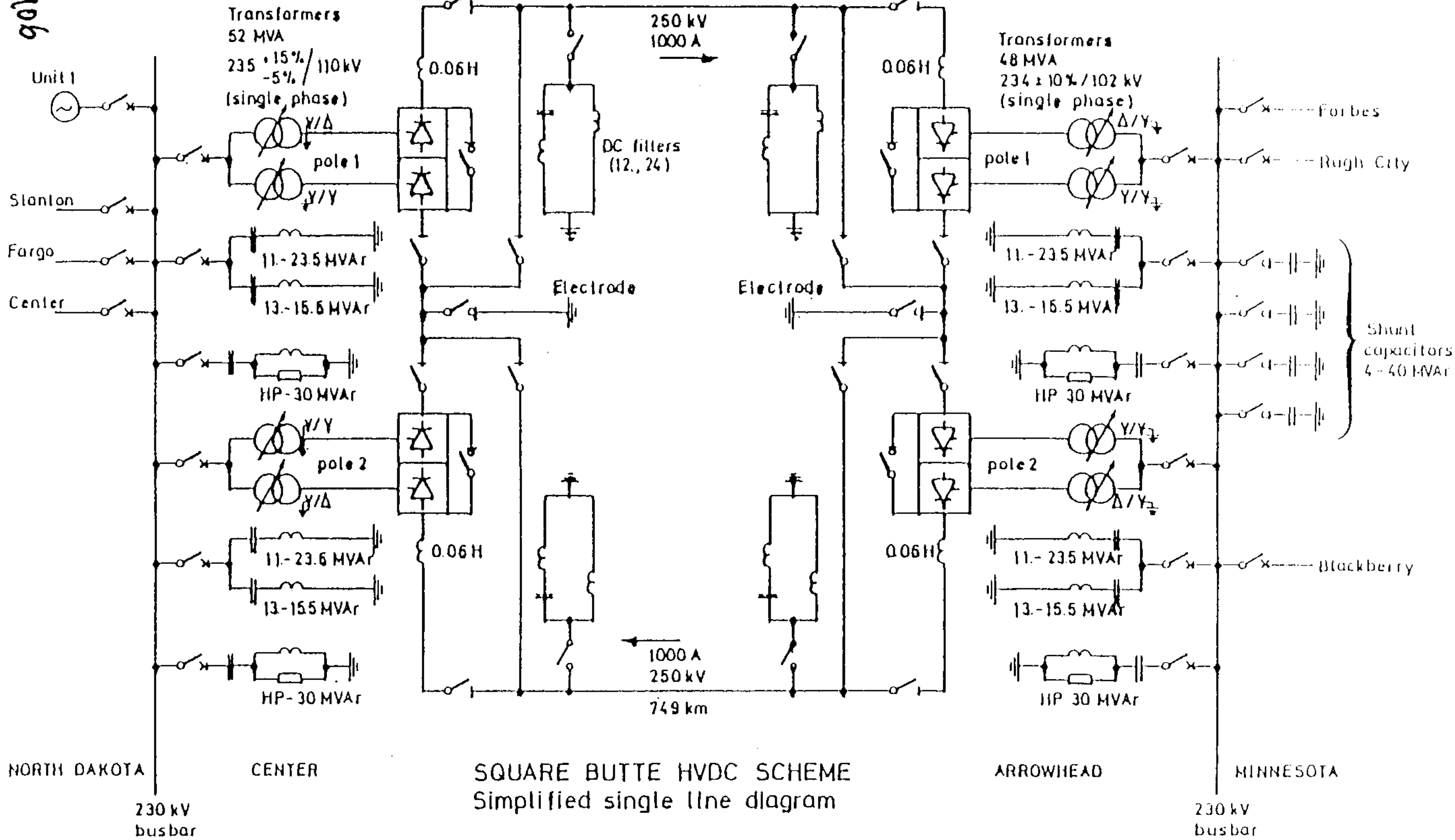
s e e

Nr. 8



GEOGRAPHIC MAP OF SQUARE BUTTE HVDC SCHEME.

105



SQUARE BUTTE HVDC SCHEME
Simplified single line diagram

The Square Butte HVDC scheme:

Between: Center, North Dakota and Arrowhead (Duluth), Minnesota.

Power Comp.: Minnesota Power & Light Co. (MP & L) Duluth - Minnesota
Minnkota Power Cooperative (MPC) Grand Forks - North Dakota.

Manufacturer: G.E., USA.

Commissioned: 4th of May 1977.

Main purpose: Base load, bulk power transmission from Center to Arrowhead; reversal transmission is possible.
Reinforcement of the AC system in North Dakota.

Main data: Bipole, 500 MW at ±250 kV DC and 1000A/pole.
Overload capacity: 1100 A continuously
1250 A for 100 sec.
1400 A for 10 sec.
1800 A for 1 sec.

AC Networks: At both terminals, single phase convertor transformer units are used.
Center: 52 MVA, 235 kV $^{+15}_{-5}$%/ 110 kV
Connection to the 230 kV AC system
short circuit: min. 3000 MVA.

Arrowhead: 48 MVA, 234 kV $^{+10}_{-10}$%/102 kV
Connection to the 230 kV AC system
short circuit: min. 2.500 MVA.

HVDC system: Overhead lines, 749 km
line towers: Self supporting lattice aluminium structures; guyed towers are used in bogs.
conductors: 1 x 1439 mm^2 ACRS/pole.
shieldings: 1 x 70 mm^2 steel wire.
insulator leakage: 2.72 cm/kV (of 250 kV).

Electrodes: At Center designed as circular trench, containing electrodes surrounded by coke; resistance = 0.03Ω.
Electrode lines: 2 x 380 mm^2 Al, 15 kV underground cable
length ≈ 10 km. R ≈ 0.3Ω.
At Arrowhead designed by using 800 prepackaged vertical anodes. R ≈ 0.3 Ω.

Electrode lines: 1 x 483 mm^2 ACSR, length ≈ 40 km.
R ≈ 2.5Ω.

On-line metallic return switching is possible.

DC filters: are double tuned to the 12th and 24th harmonic.

HVDC valves: The thyristor valves are housed indoor, and they are designed as "Quadruple" valves. Three quadruple valves form a 12-pulse convertor unit.

One valve has 12 modules, each with 12 thyristors in series connection, giving the total of 144 thyristors in series connection/valve arm and none in parallel. This makes 576 thyristors in one quadruple valve or 1728 thyristors in one 12-pulse convertor unit for 250 kV DC and 1000 A.
The valve structure is air insulated and air cooled.

The smoothing reactor is placed on the high voltage side and is designed for 250 kV DC, 1000 A and 0.06 henry.

A.C. Filters:

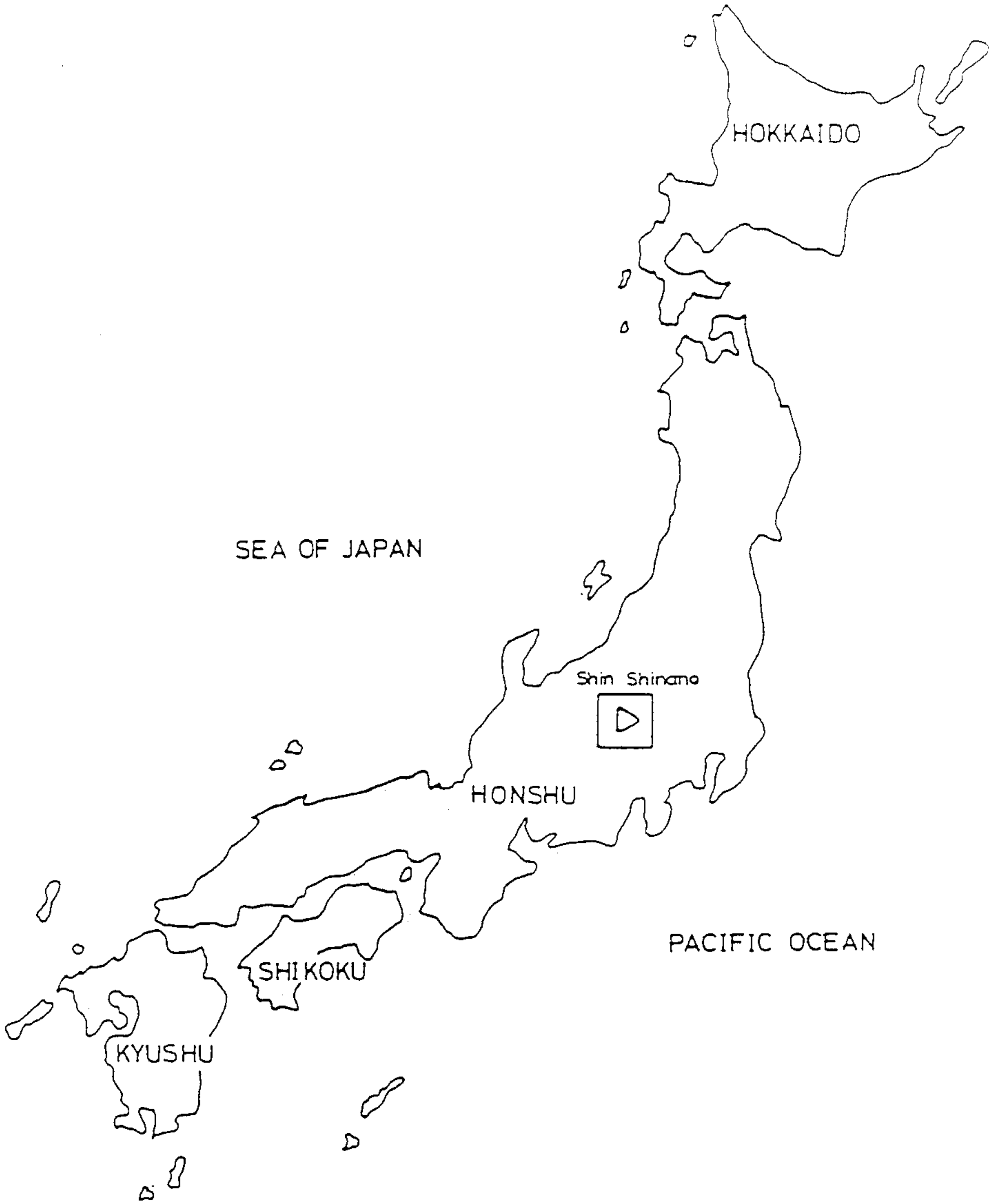
Harmonic filters are provided equal designed at each terminal.

Center=Arrowhead: Two 11.+13.harm. filters, each 39 MVAr with:

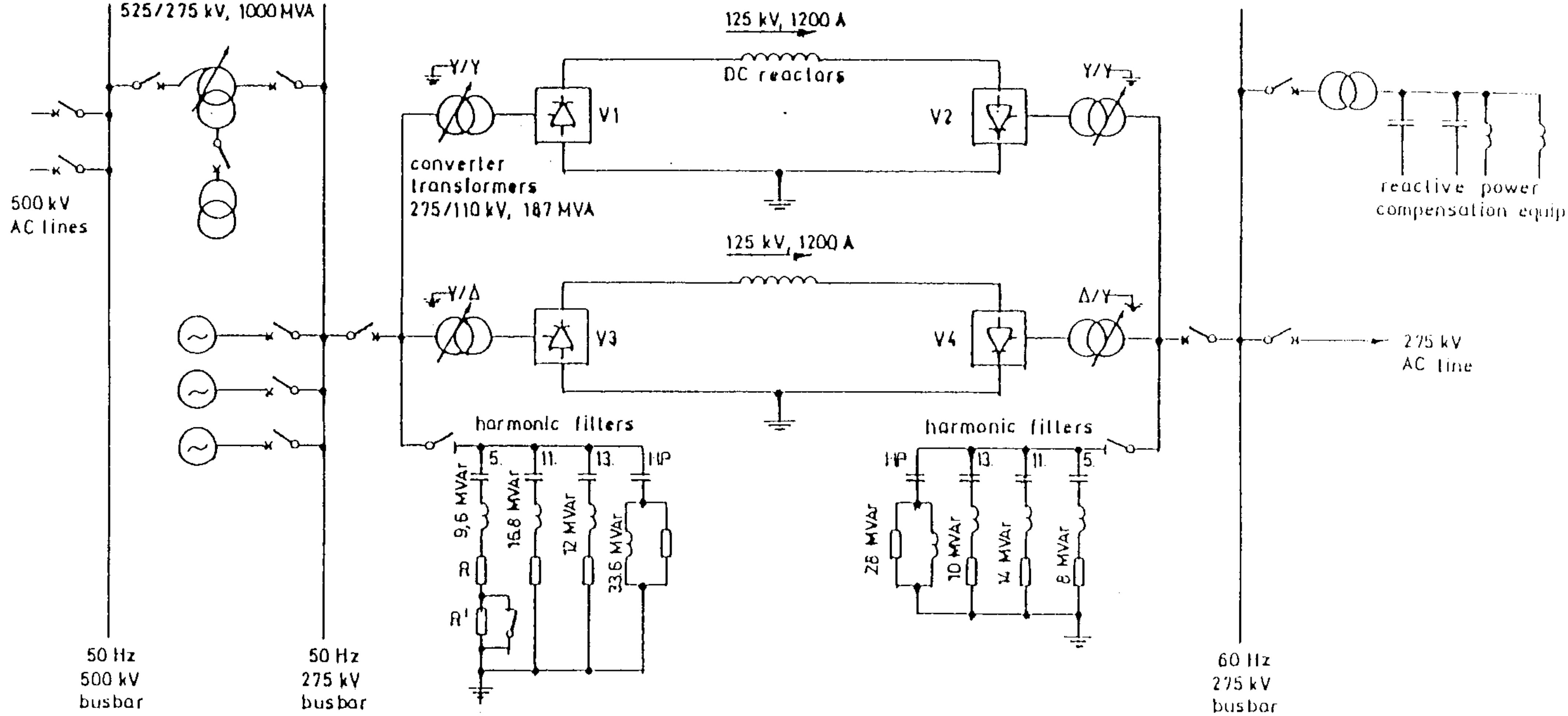
11.harm.= 23.5 MVAr; C= 1.16 μF; L= 50 mH
13.harm.= 15.5 MVAr; C= 0.77 μF; L= 53.5 mH } Q = 12.5

Two HP filters, each 30 MVAr with:
C= 1.5 μF; L= 9 mH and R= 166 ohm

References:
Electra no. 63 (1979)
" Harmonic filter and reactive compensation for HVDC"
A general survey by SC14-WG03.



SHIN SHINANO
Frequency converter station



THE SHIN SHINANO FREQUENCY CONVERTER STATION
Simplified single line diagram

The Shin-Shinano Frequency HVDC Convertor Station.

Between:	The 50 Hz 275 kV and the 60 Hz 275 kV a.c. system at Nagano Prefecture, Japan.
Power comp.:	The Tokyo Electric Power Co. Inc., Japan.
Manufacturer:	Toshiba Electric Co., Japan for 50 Hz side. Hitachi Co., Japan for 60 Hz side. Nisshin Electric Co., Japan for the a.c. harmonic filters.
Commissioned:	December 1977.
Main purpose:	The interconnection is designed as an asynchronous HVDC coupling system between the two electric power systems of the east (50Hz) and the west (60Hz) of Japan. The main purpose is peak power reserve for both electric power systems. Energy supply during emergency situations and economical exchange of excess energy in normal operation.
Main data:	Bipole, 300 MW at + or - 125 kV d.c. and 1200 A. Overload capacity: none
a.c. networks:	One 3-phase convertor transformer per 6-pulse convertor unit is used. The two transformers are connected to the 275 kV 50 Hz system and the other two are connected to the 275 kV 60 Hz system. Data: 187 MVA, 275 kV $\pm$ 11%/110 kV 20% impedance (187 MVA base) Short circuit capacity: 50 Hz side = min. 1400 MVA 60 Hz side = min. 1500 MVA
d.c. system:	Due to the station design (back to back) there are no HVDC transmission lines.

AM

d.c. filters: d.c. filters are not used.

HVDC valves: Thyristor valves are used. Each 50 Hz or 60 Hz terminal has two 6 pulse convertor units, operating in parallel to obtain 12 pulse operation.
Each 6 pulse unit is connected to one 3 phase convertor-transformer in Y/Y or Δ/Y connection respectively.
The thyristor valves are designed as an outdoor type, which is oilinsulated, oilcooled and housed in a tank containing one valve section.

For the 50 Hz side: Each valve section has 192 thyristors in series connection and none in parallel. This makes a total of 1152 thyristors per 6 pulse unit.

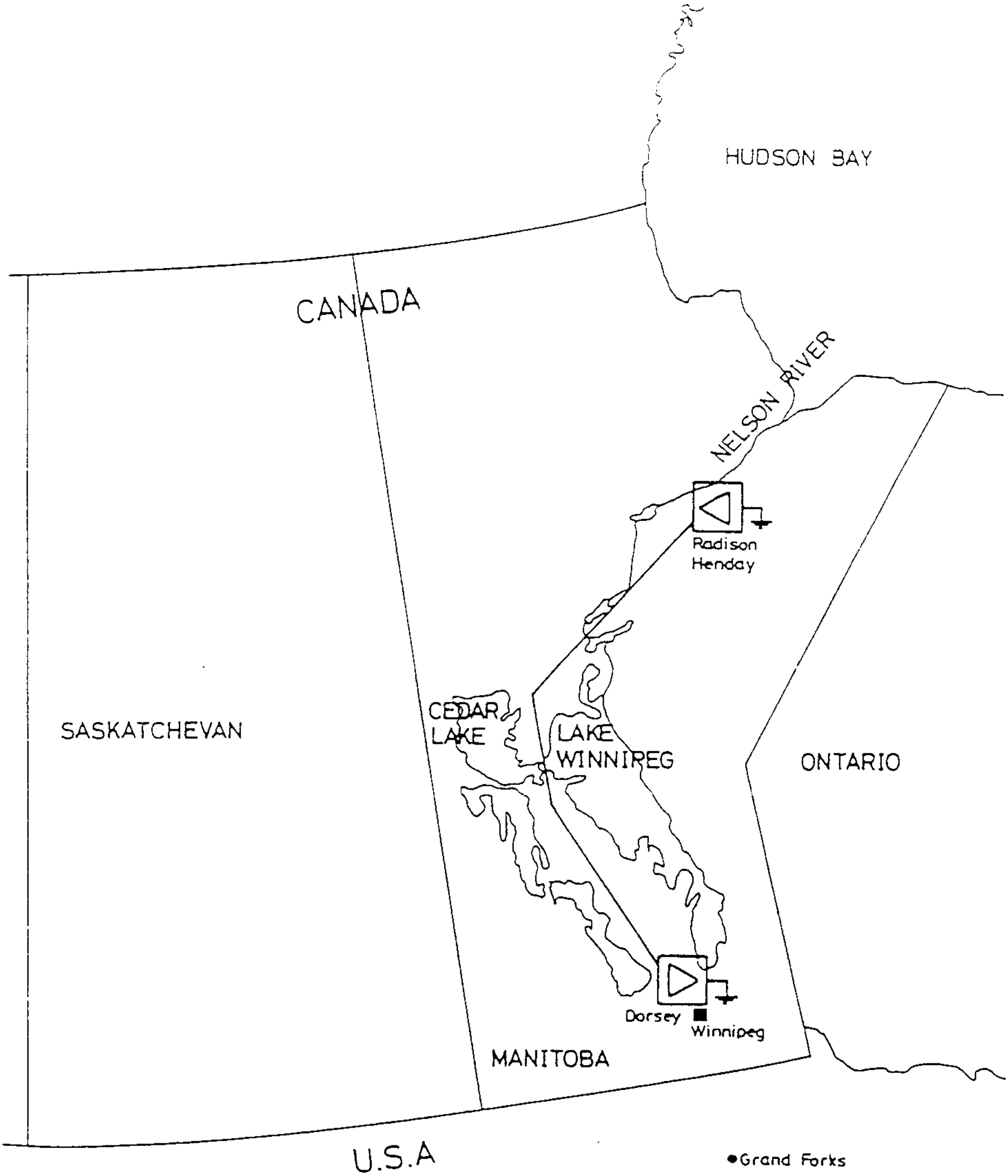
For the 60 Hz side: Each valve section has 120 thyristors in series connection and 2 in parallel, giving a total number of 2880 thyristors or 1440 thyristor levels per 6 pulse unit.
Each 6 pulse unit is for 125 kV d.c. and 1200 A.
The smoothing reactors are designed for 125 kV d.c. and 1.0 H at 1200 A.

AC. Filtre

	50 Hz - side				60 Hz - side		
harm	R=ohm	R´=ohm	L=mH	C=μF	R=ohm	L=mH	C=μF
5.	23.4	300.-	1045.-	387.9	28.1	1045.-	269.4
7.							
11.	5.9		119.4	701.4	7.1	119.4	486.9
13.	7.0		119.4	502.3	8.4	119.4	348.7
HP	340.-		12.45	1415.4	340.-	12.47	979.2

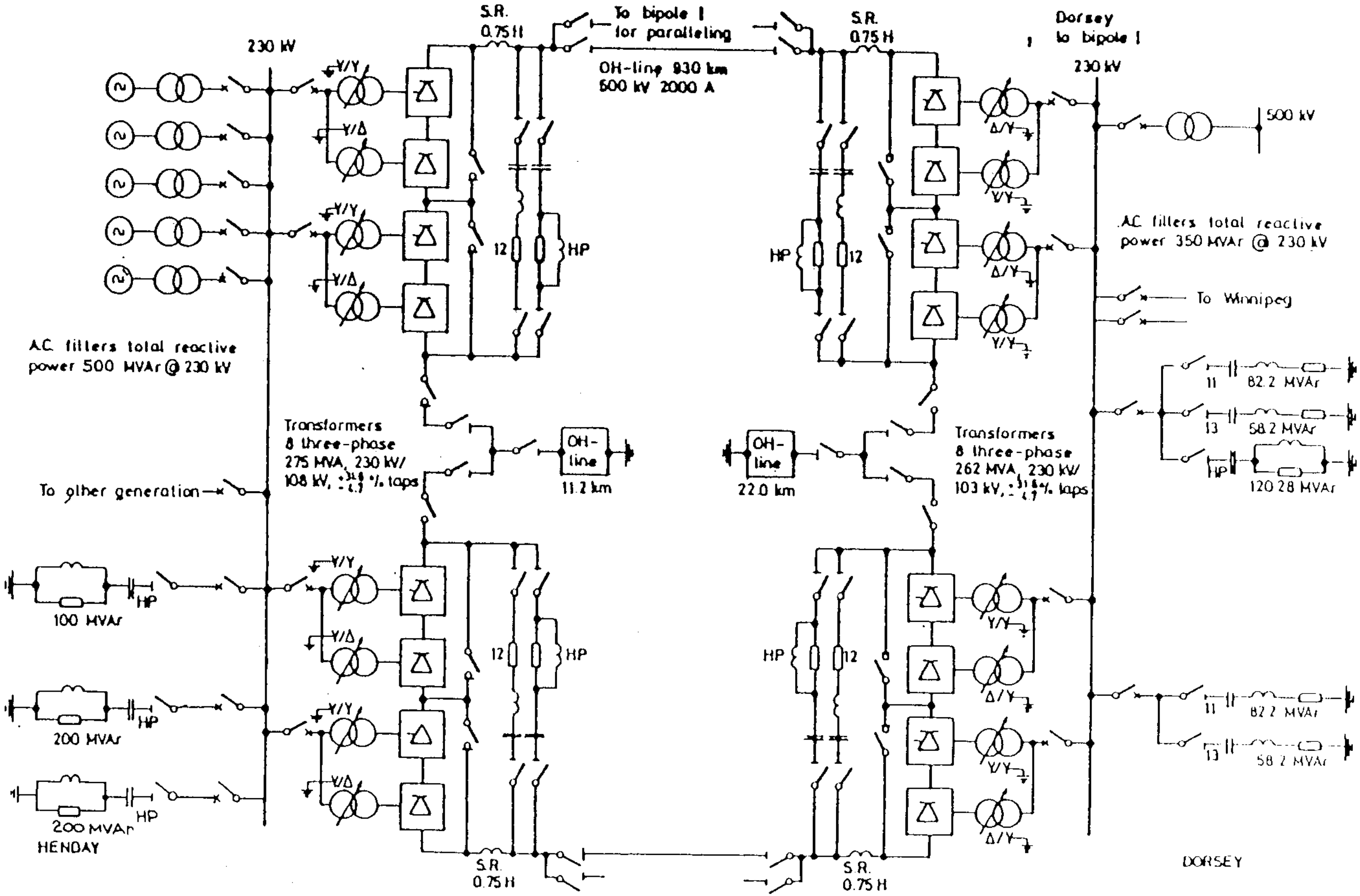
References:

Cigré 1978, paper 14-02
"Shin Shinano Frequency Converter Station"
by M. Yasuda, K. Mizushima, Y. Kato and A. Seki



NELSON RIVER HVDC SYSTEM
Geographic map

113



NELSON RIVER BIPOLE II HVDC SCHEME
Simplified single line diagram

The River Bipole 2 HVDC scheme.

Between: Henday near Gillam and Dorsey near Winnipeg, Manitoba.

Power Co: Manitoba Hydro-Electric Board, Manitoba, Canada.

Manufacturer: The German Working Group consisting of:

a) Brown Boveri
b) Siemens AG
c) AEG Telefunken

Commissioned:

Stage 1 October 3, 1978 (1000 MW)
Stage 2 October 1, 1984 (500 MW)
Nov. 27, 1984 (500 MW)
Stage 3 May 1, 1985 (500 MW)
June 17, 1985 (500 MW)

Main data: Bipole: 2000 MW at the rectifier at ± 500 kV d.c. and 2000 A
This reduces to 1800 A at high ambient temperatures.

A.C. networks: At both terminals two three-phase converter transformers (one wye and one delta) are used for each of the two 12-pulse converter units per pole.

Henday

Transformers: 275 MVA, 230 kV $\begin{smallmatrix}+ 31.6\% \\ - 4.7\%\end{smallmatrix}$ /108kV

Short circuit capacity: Min. 1800 MVA (7 generators)

A.C.Filters: 3xHP (all tuned to 12th harmonic)

Dorsey

Transformers: 262 MVA, 230 kV $\begin{matrix} + 31.6\% \\ - 4.7\% \end{matrix}$ /103kV

Short circuit capacity: Min. 5000 MVA (4 sync. condensers, no 500 kV tie)

A.C.Filters: 2 x (11,13) and one HP.

This a.c. network is common with the Bipole 1 at Dorsey.

HVDC System: Route length - 930 km

Overhead lines: The lines are identical to those of Melson River Bipole 1, HVDC scheme, therefore refer to it for details; except d.c. resistance per pole is 14.53 ohms at 20°C.

Henday: Three HP filters are installed:

Harm.	MVAr	C=uF	L=mH	R=ohm
HP	100	5.0	4.88	134
HP	200	10	4.88	134
HP	200	10	4.88	134

Electrodes: Henday: It is located 11.2 km from the station and is of the ring type 548 meters in diameter. It is comprised of a steel rod and is installed in a low sulphur coke bed.

Resistance: 0,4 ohms.

Dorsey: Please refer to Nelson River Bipole 1 HVDC scheme as the electrode is common to both bipoles, however a separate electrode line has been constructed.

D.C. Filters: Each pole has one twelfth and one High Pass (tuned to the 24th harmonic) harmonic filter. The filters are connected between the pole and the electrode line.

HVDC Valves: Thyristor valves are used. The valve group consists of three quadrivalve structures. Each valve arm contains 16 thyristor modules and 8 valve reactor modules.

Each thyristor module has six thyristor levels in series and two in parallel connection.

Each valve arm contains 96 thyristor pairs in series of which 91 are required for safe operation.

The thyristor modules are air insulated and water-cooled. Each thyristor module weighs 120 kg. The bypass path of each bridge is accomplished with a bypass thyristor pair of valves. Each pole containes one smoothing reactor on the high side rated at 0.75 henry.

A.C. Filters: Both terminals for bipole II are provided with harmonic filters.

Dorsey: One filter for 11. + 13. harm. + HP filter with:

Harm.	MVAr	C=μF	L=mH	R=ohm
11.	82.2	4.1	14.3	1.08
13.	58.2	2.9	14.3	1.27
HP	120.28	6	2.2	158
one filter for 11.+13.harm. with:				
11.	82.2	4.1	14.3	1.08
13.	58.2	2.9	14.3	1.27

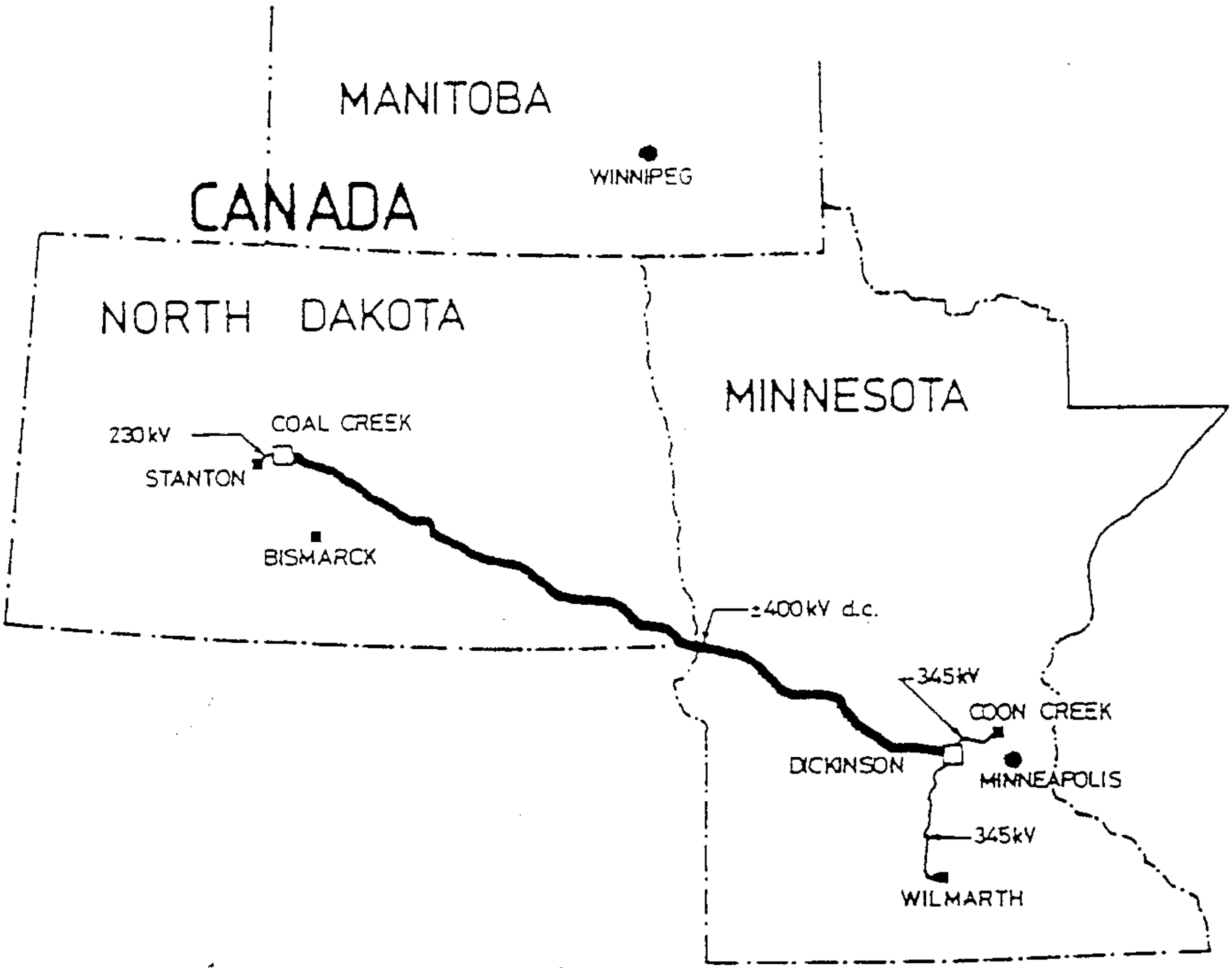
<u>References:</u>

1. Haywood R.W., Patterson W.A. - Application of control on the Eel River and Nelson River HDVD System to enhance operation of interconnected systems (CIGRE 1976 session paper 14-04).

2. Beriger C., Etter P., Hengsberger J., Thiele G. - Design of water cooled thyristor valve groups for extension of Manitoba Hydro HVDC system (CIGRE 1976 session, paper 14-05).

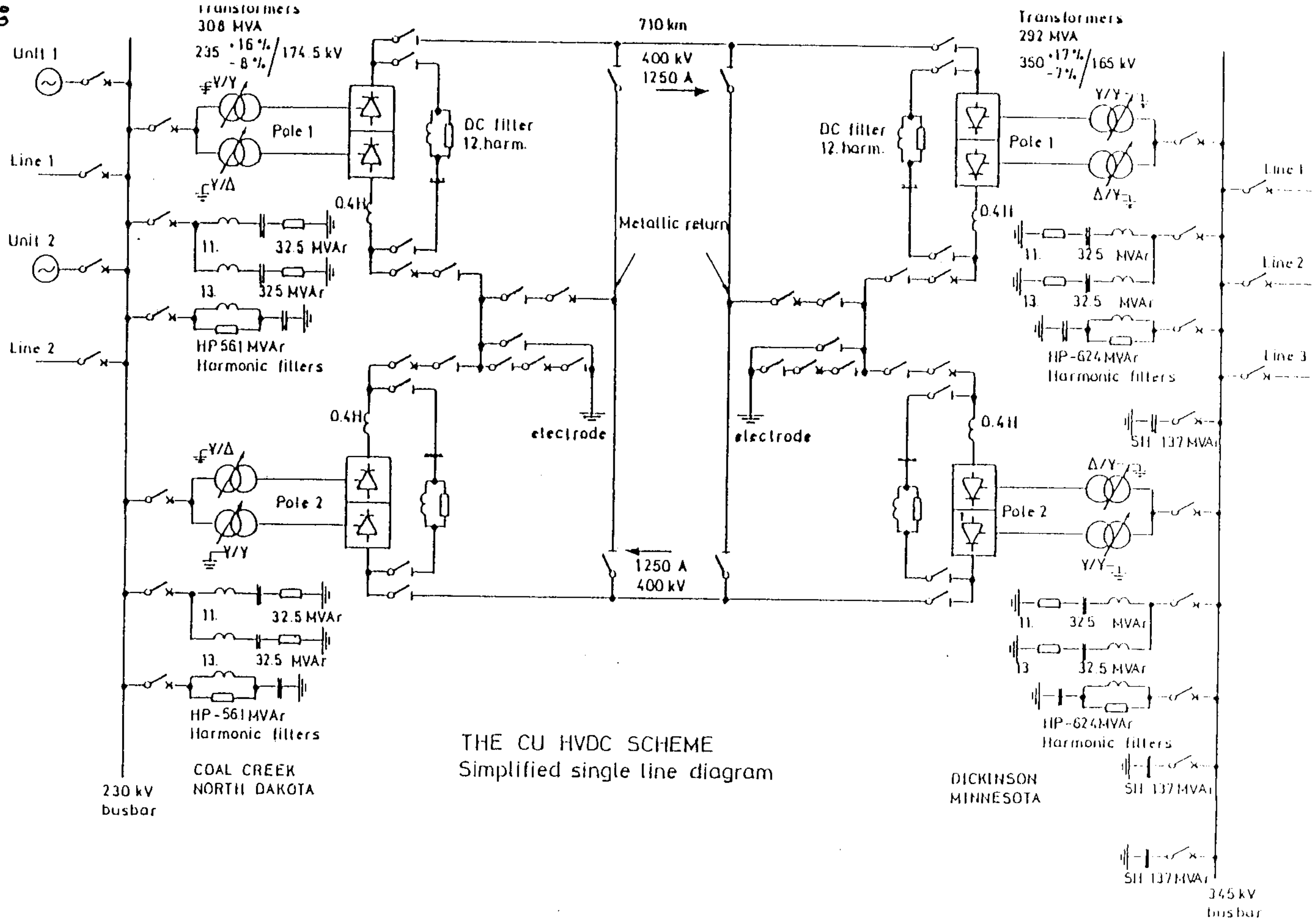
3. Hengsberger J., Roth K., Thiele G. - Testing of thyristor valves for bipole 2 of the Manitoba Hydro HVDC system (CIGRE 1978 session paper 14-03).

4. Kaeuferle J., Linhofer G., Thio C.V., Wistow E., Hamlin R.J. - system tests for HVDC (CIGRE 1980 session, paper 14-06).



THE CU HVDC SCHEME
Location map showing station sites, the ± 400 kV d.c. line and connecting 230 kV and 345 kV a.c. lines

.19



THE CU HVDC SCHEME
Simplified single line diagram

The CU HVDC Scheme

Between: Coal Creek, North Dakota and Dickinson, Minnesota

Power Company: Cooperative Power, CP, Minneapolis, MN
United Power Association, UPA, Elk River, MN

Manufacturer: ASEA, Sweden

Commissioned: August, 1979

Main Purpose: Base load, bulk power transmission between Coal Creek lignite mine-mouth generation plant to Dickinson; reversal transmission is possible.

Main Data: Bipole 1000 MW at ± 400 kV and 1250 A/pole
Overload capacity: 1375 A continuously
1500 A for 1 hour or continuously if the temperature is below 8°C
max. 1820 A during damping control sequence

AC Networks: At both terminals, two 3-phase converter transformers (Wye-Delta and Wye-Wye) per pole, 1 for each 6-pulse group at each terminal

Coal Creek: 4 @ 308/339 MVA; 235 kV +20 %/174.5 kV
-10 %/174.5 kV
(+16 and -8 taps @ 1.25 %/tap)
connection to the 230 kV AC system

Dickinson: 4 @ 292/321 MVA; 350 kV +21.25 %/165 kV
- 8.75 %/165 kV
(+17 and -7 taps @ 1.25 %/tap)
connection to the 345 kV AC system
Minimum short circuit ratio of 3.5

<u>HVDC System:</u>

<u>Overhead lines</u>, 701 km (435.5 miles)

Line towers: self supporting lattice steel structures
Conductors: 2 x 1150 mm^2 ACSR/pole (d=1.504 in)
Shieldings: 2 x 130 mm^2 steel wire (d=0.5 in)
Insulator leakage: 25 mm/kV

<u>Electrodes:</u>

At both terminals the electrodes are designed as 18 vertical electrodes, each with d = 300 mm and approx. 60 mm deep; coke backfill is used.

Resistance/electrode: total less than 0.1

<u>Electrode lines:</u> 2 x 620 mm^2 ACSR (d=1.108 in)

Coal Creek: length = 10 km (6.5 miles); R = 0.38Ω

Dickinson: length = 22 km (14 miles); R = 0.88Ω

On-line metallic return switching is available.

<u>DC Filters:</u>

Dickinson - Double tuned to the 12th HP 24th harmonic
Coal Creek - High pass type, tuned to the 12th harmonic

<u>HVDC Valves:</u>

The thyristor valves are housed indoors, and they are designed as "Quadruple" valves. Three quadruple valves form a 12-pulse converter unit.

Each quadruple valve has 4 valve sections in series connection. One valve section has 30 modules, each with 6 thyristors in series connection, giving the total of 180 thyristors in series connection/valve arm and none in parallel. This makes 720 thyristors in one quadruple valve or 2160 thyristors in one 12-pulse converter unit for 400 kV DC and 1250 A. The valve structure is air insulated and air cooled.

The <u>smoothing reactor</u> is placed on the neutral side and is designed for 0.4 henry.

AC Filters and Shunt Banks: Both terminals are provided with harmonic filters:

Coal Creek: 2 filters each for 11th and 13th harmonic and 2 high pass filters each

Quan.	Harm.	MVAR*	C= μF	L=mH	R=ohm
2	11th	32.3	1.55	37.3	1.6
2	13th	33.9	1.63	25.6	1.5
2	HP	56.5	2.72	4.3	78
Shunt Banks					
1	SH	102.8	4.94	--	--

* MVAR @ 235 kV

Dickinson: 2 filters each for 11th and 13th harmonic and high pass filters

Quan.	Harm.	MVAR*	C= μF	L=mH	R=ohm
2	11th	31.4	.678	85.5	4.8
2	13th	33.4	.72	57.7	4.4
2	HP	71.7	1.55	7.9	143
Shunt Banks					
3	SH	114.7	2.48	--	--

* MVAR @ 350 kV

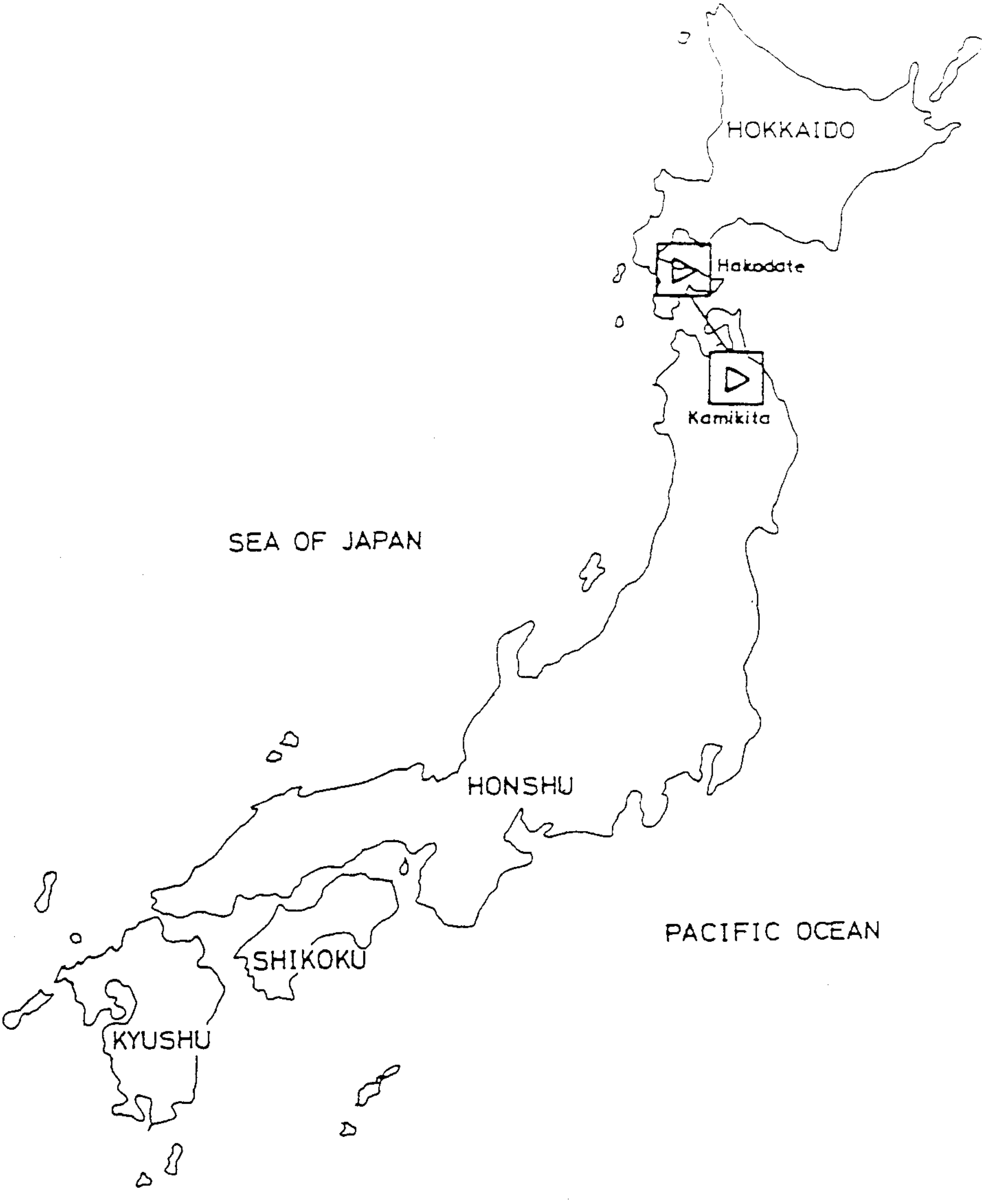
References:

"Electra" No. 63 (1979)

"A.C. Harmonic filter and reactive compensation for HVDC"
A General survey by SC14-WG03

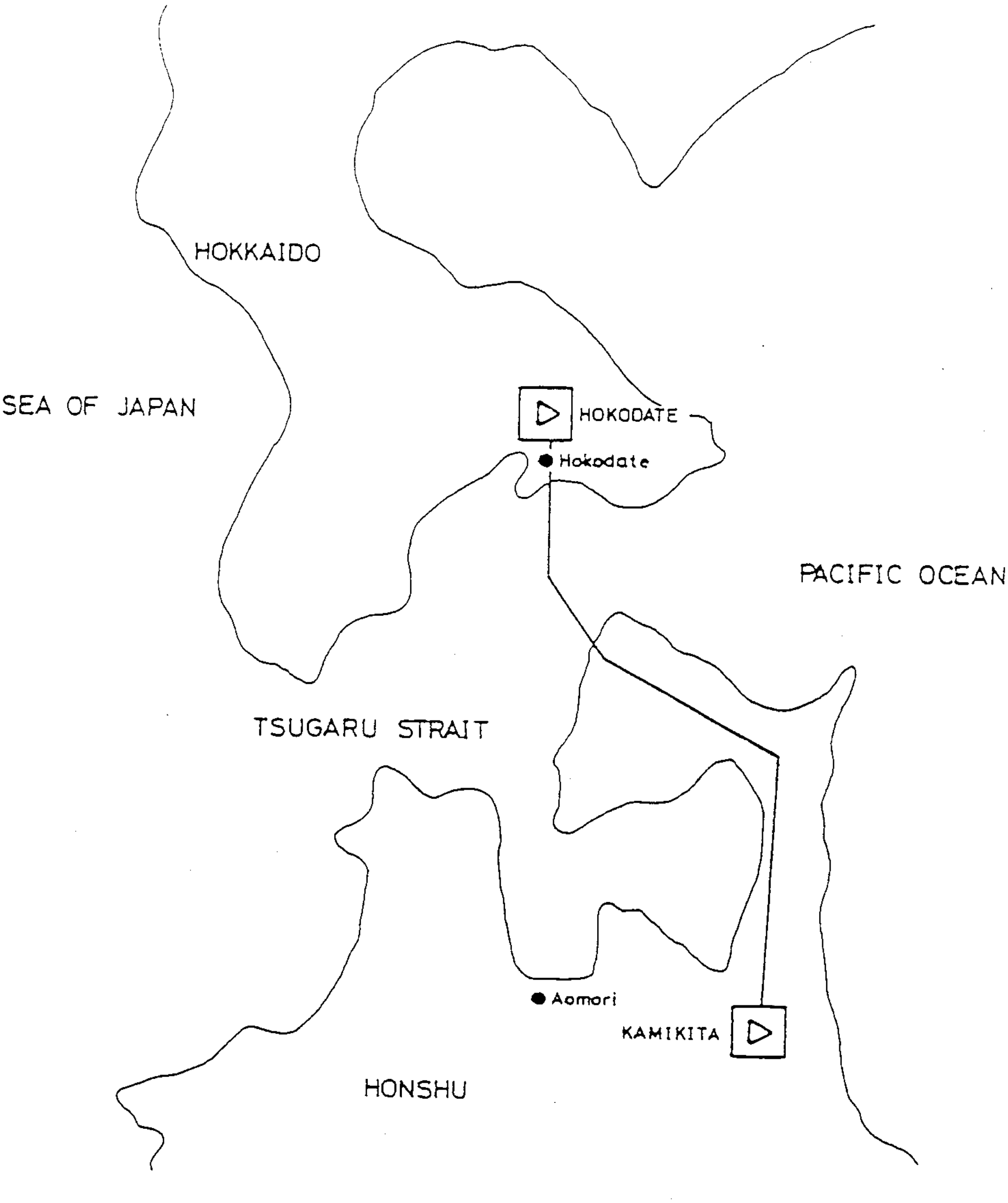
"The CPA/UPA ± 400 kV HVDC Project", Arnold E. Poppens, Robert J. Heiser, and John M. Nelson Proceedings of the American Power Conference, 1976

"CU ± 400 kV HVDC Project, Converter Station Layout", D. J. Christofersen and J. C. Goerss Panel Session, IEEE Power Engineering Society Tenth Conference and Expostion on Overhead and Underground Transmission and Distribution, September 14-19, 1986



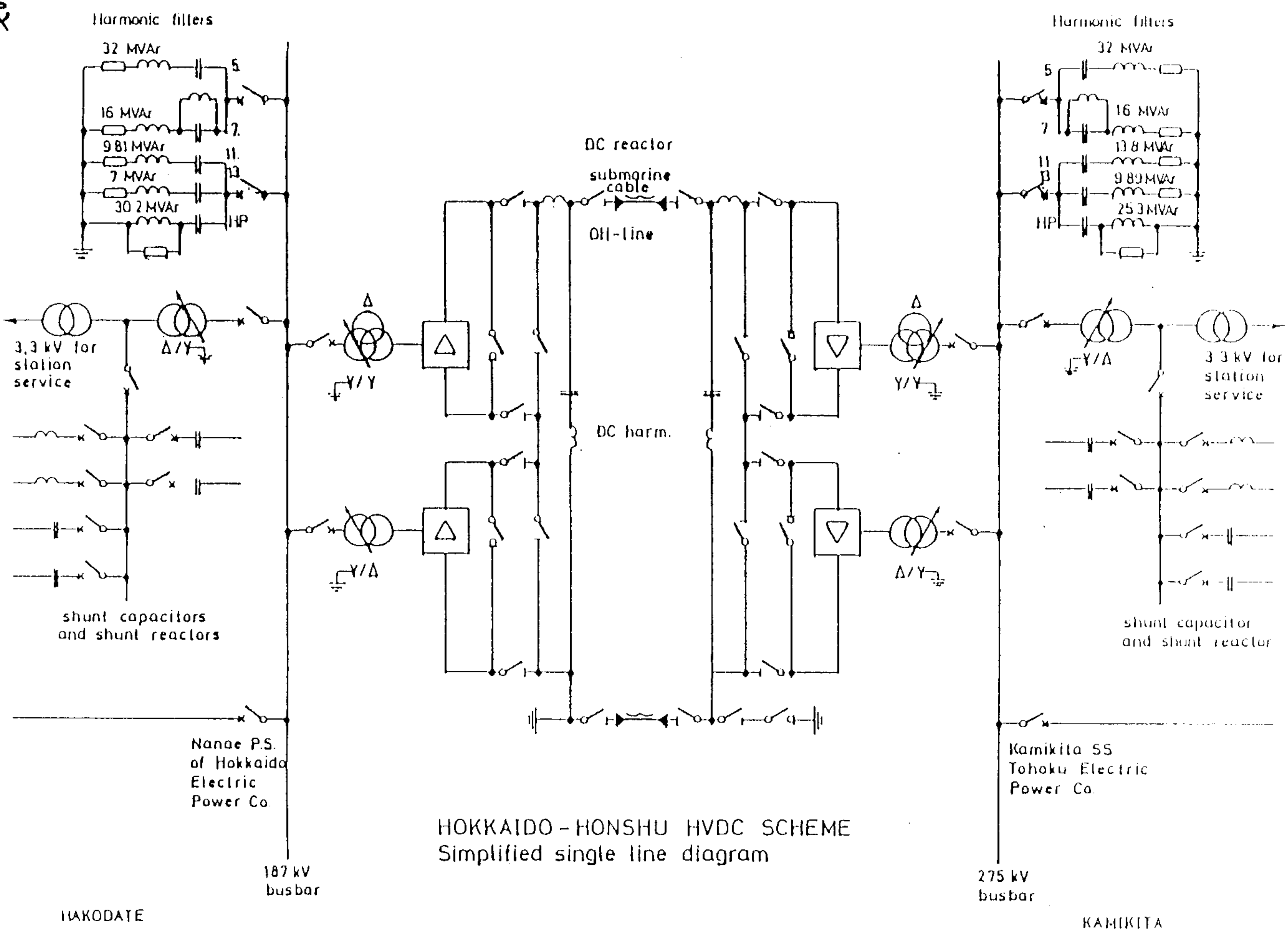
HOKKAIDO - HONSHU HVDC SCHEME
Geographic map

125



HOKKAIDO - HONSHU HVDC SCHEME
Geographic map

126



HOKKAIDO - HONSHU HVDC SCHEME
Simplified single line diagram

The Hokkaido - Honshu HVDC link Scheme.

Between:	Hakodate, Hokkaido (north island) and Kamikita, Honshu (main island).
Power comp.:	Electric Power Development Co., Tokyo, Japan.
Manufacturer:	HITACHI CO. (Hakodate), and TOSHIBA CO.(Kamikita), Japan for the valves, transformers and d.c. equipments. Nisshin Electric Co., Japan for the a.c. filters and d.c. filters.
Commissioned:	First stage 150 MW: December 1979 Second stage 300 MW: June 1980 Final stage 600 MW: Undecided
Main purpose:	The HVDC link interconnects the power systems of Hokkaido and Honshu with the aim of improving reliability and economy through wide-area power system operation. The purpose of this link is a saving of reserve power, effective control of frequency variations, mutual emergency power assistance in fault occurrences and wide-area power system operation.
Main data:	300 MW, monopole metallic return, 250 kV, 1200 A. (Final 600 MW, bipole, ± 250 kV, 1200 A) Overload capacity: none
a.c. networks:	At both terminals one 3-phase convertor transformer/ 6-pulse convertor unit is used.

Hakodate:	187 MVA, 187 kV + 19,5%/- 7.5%/110kV The two transformers are connected to the 50 Hz 187 kV a.c. network. Short circuit capacity: min. 900 MVA
Kamikita	187 MVA, 275 kV + 18.3%/-8.6%/110 kV The two transformers are connected to the 50 Hz 275 kV a.c. network. Short circuit capacity: min. 1500 MVA

29

HVDC systems: Route length = 167 km.

Overhead lines: length in Hokkaido = 27 km.
length in Honshu = 97 km.

Line towers: Self supporting steel structures.

Conductors:
main circuit = 810 mm^2, ACSR, 810 mm^2 ACSR/EAS
return circuit = 240 mm^2, EACSR, 240 mm^2 AS (double)

Insulator leakage: 3.8 - 6.9 cm/kV (on 250 kV).

d.c. filters: Hakodate: 6th and HP filters
Kamikita: 6th and surge capacitor.

Submarine cables: Length = 43 km.

The cables used for the Tsugaru Strait crossing are:

Main circuit: An oilfilled cable (OF) with a Cu-conductor = 600 mm^2 and designed with an oil channel, d = 25 mm in the center
Normal oil pressure = 2.31 MPa
Transient max. = 3.61 MPa
Total diameter of the cable = 125 mm

Return circuit: A polyethylene cable (XLPE) with a CU-conductor = 500 mm^2.
Total diameter of the cable = 75 mm

Both cables have a single layer of galvanized steel armouring (8 mm for main circuit cable, 6 mm for return circuit cable).

HVDC valves: Thyristor valves are used. Each terminal has two 6 pulse converter units in series connection, and 6- or 12 pulse operation is possible.

The six valves of one 6 pulse converter unit is designed as three indoor double valves with 2 valve sections per valve structure.
Each valve section has:

A: For the Hokkaido side (Hakodate)
19 modules in series connection, and each module has 6 thyristors in series and none in parallel. This makes a total of 114 thyristors per valve section or 684 thyristors per 6 pulse converter unit.

B: For the Honshu side (Kamikita)
28 modules in series connection and each module has 4 thyristors in series and none in parallel. This makes a total of 112 thyristors per valve section or 672 thyristors per 6 pulse converter unit.

The double valves are airinsulated and aircooled.
Each 6 pulse unit is for 125 kV d.c. and 1200 A.
The smoothing reactors are placed on the high voltage side and are designed for 250 kV d.c. and 1.0 H at 1200 A.

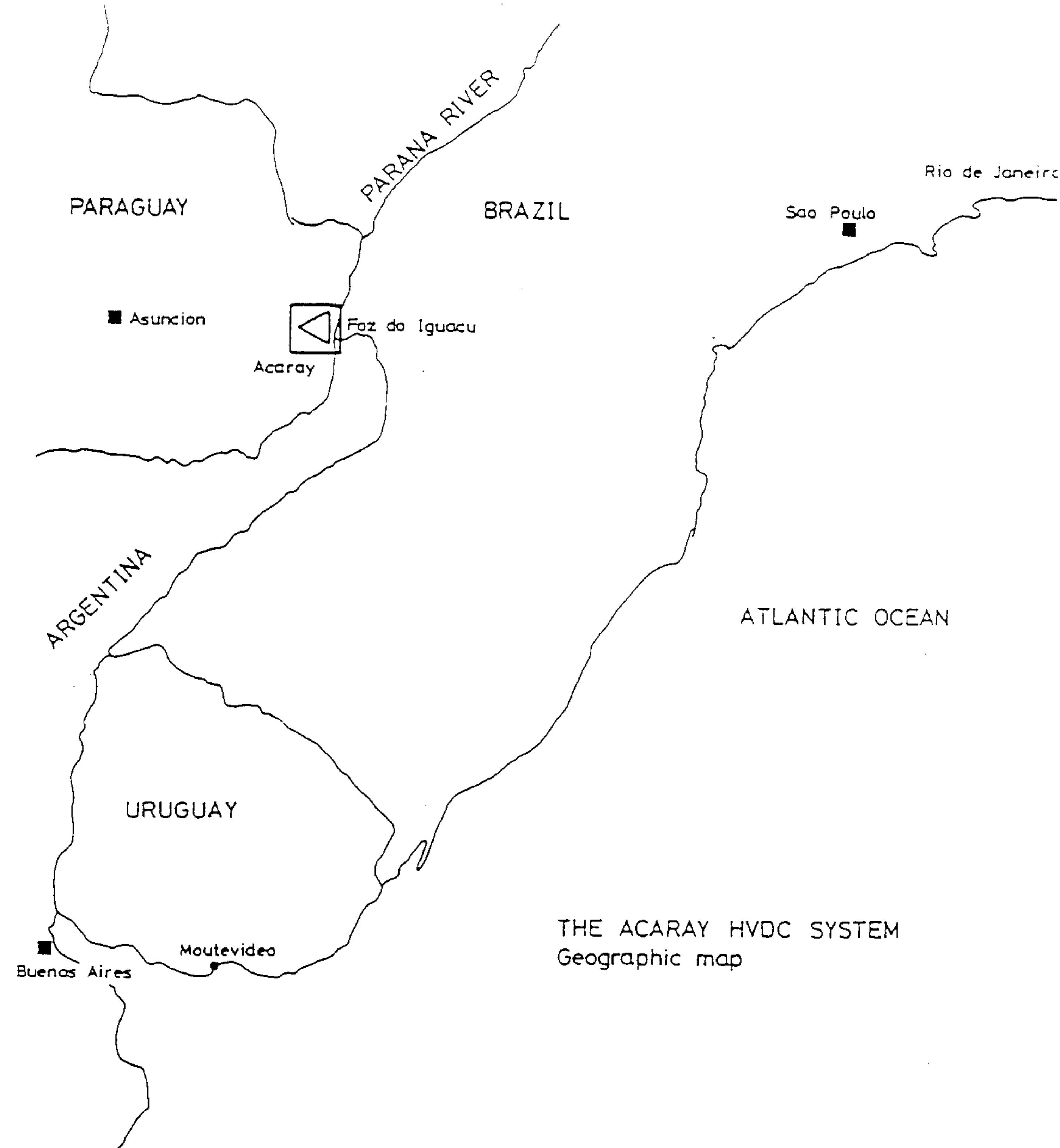
AC. Filtre

	Hokodate				Kamikita		
harm	R=ohm	L=mH	C=uF		R=ohm	L=mH	C=uF
5.	4.55	144.9	2.79		9.85	313.7	1.29
7.	6.37	144.9	1.43		13.8	313.7	0.661
11.	6.54	94.6	0.884		10.-	144.9	0.578
13.	7.73	94.6	0.634		11.8	144.9	0.414
HP	166.-	8.38	2.75		428.-	21.7	1.06

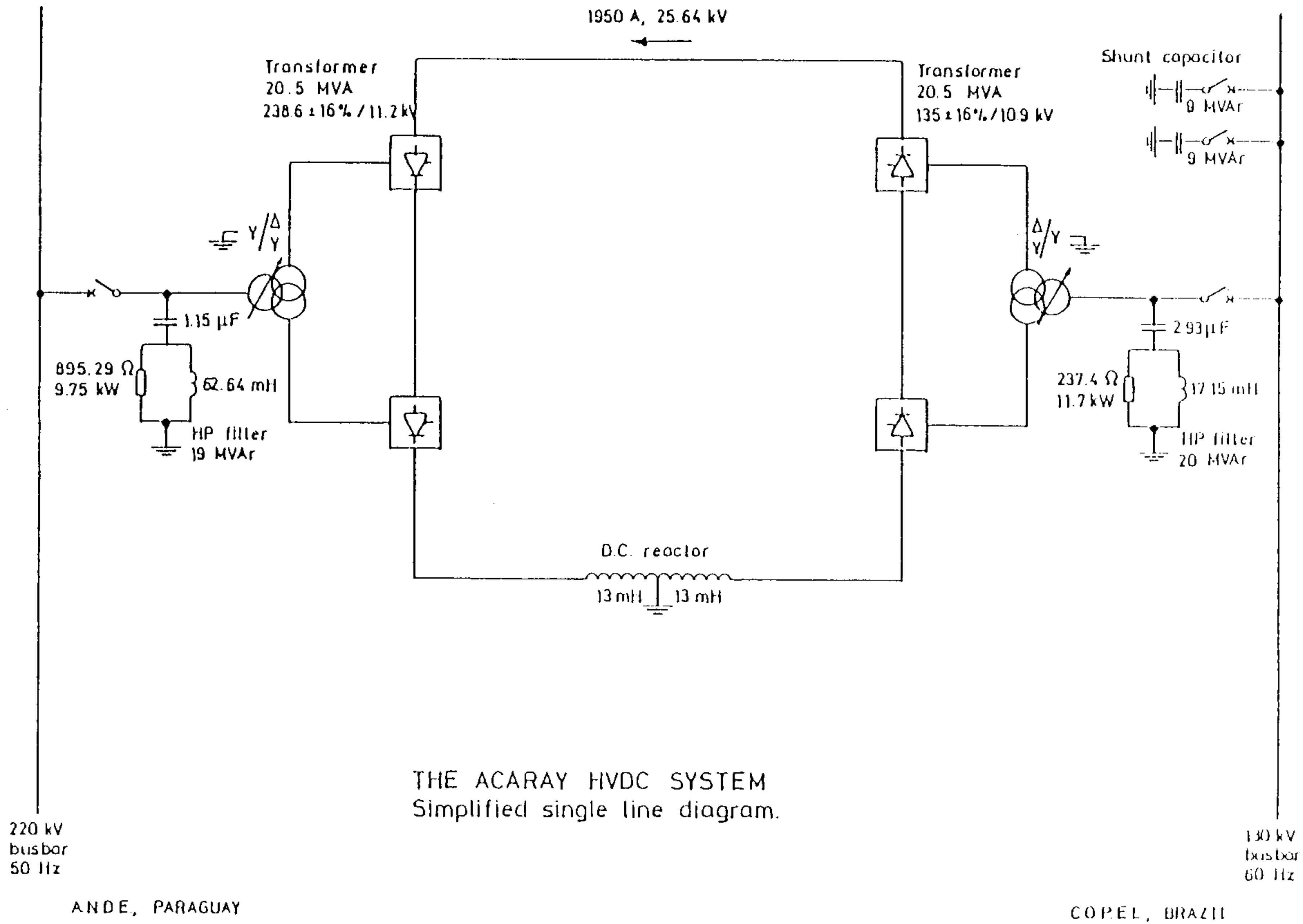
References:

Cigré 1980 - paper 14-03
"Hokkaido - Honshu" HVDC Link
by T. Takemuchi, K. Muzushima, Y. Kato and K. Muratani

131



THE ACARAY HVDC SYSTEM
Geographic map



THE ACARAY HVDC SYSTEM
Simplified single line diagram.

The ACARAY HVDC system.

Between:	The 50 Hz, 220 kV a.c. system at Acaray, Paraguay and the 60 Hz, 130 kV a.c. system in Brazil.
Power Comp.:	A.N.D.E., the Paraguayan Power Utility and C.O.P.E.L., the Brazilian Power Utility.
Manufacturer:	Siemens A.G., Germany.
Commissioned:	March 1981. (final acceptance March 1982).
Main purpose:	Energy supply to Paraguay during periods with shortage of water in the hydro electric power systems, and export to Brazil when there is a surplus of water in Paraguay. Stabilizing the 50 Hz system frequency in Paraguay by HVDC power - or frequency control.
Main data:	Monopole 50 MW at + or - 25.6 kV d.c. and 1950 A. Overload capacity: 10% continously.
a.c. Networks:	Six single phase three winding converter transformers are used. The lower valve windings are star connected and the upper valve windings are delta connected to obtain 12-pulse operation. data: 50 Hz side: 20.5 MVA, 238.6 $\pm$ 16%/11.2 kV short circuit range: min. 800 MVA 60 Hz side: 20.5 MVA, 135 $\pm$ 16%/10.9 kV short circuit range: min. 410 MVA.
HVDC system:	Due to the station design (back to back) there are no d.c. transmission lines.
d.c. filters:	No d.c. filters are used.
HVDC valves:	Water cooled thyristor valves are used. Each terminal has two 6-pulse converter units in series

connection and the 12 valves of one terminal are housed in one horizontal valve structure, consisting of four units each housing three insulated frames for the thyristor modules.

For each valve arm only one module, consisting of 8 thyristor levels (one redundant) has been used. No thyristors in parallel.

For a 12 pulse converter unit this makes at total of 12 modules or 96 thyristors.

Both terminals which consist of two valve structures are housed indoor in one valve hall of 180 m^3. (h=8m)

d.c. reactor: The d.c. reactor is placed on the earth side with earthed centre tap. It is designed as an air insulated, coreless type for 25.6 kV and 2 x 13 mH at 1950 A.

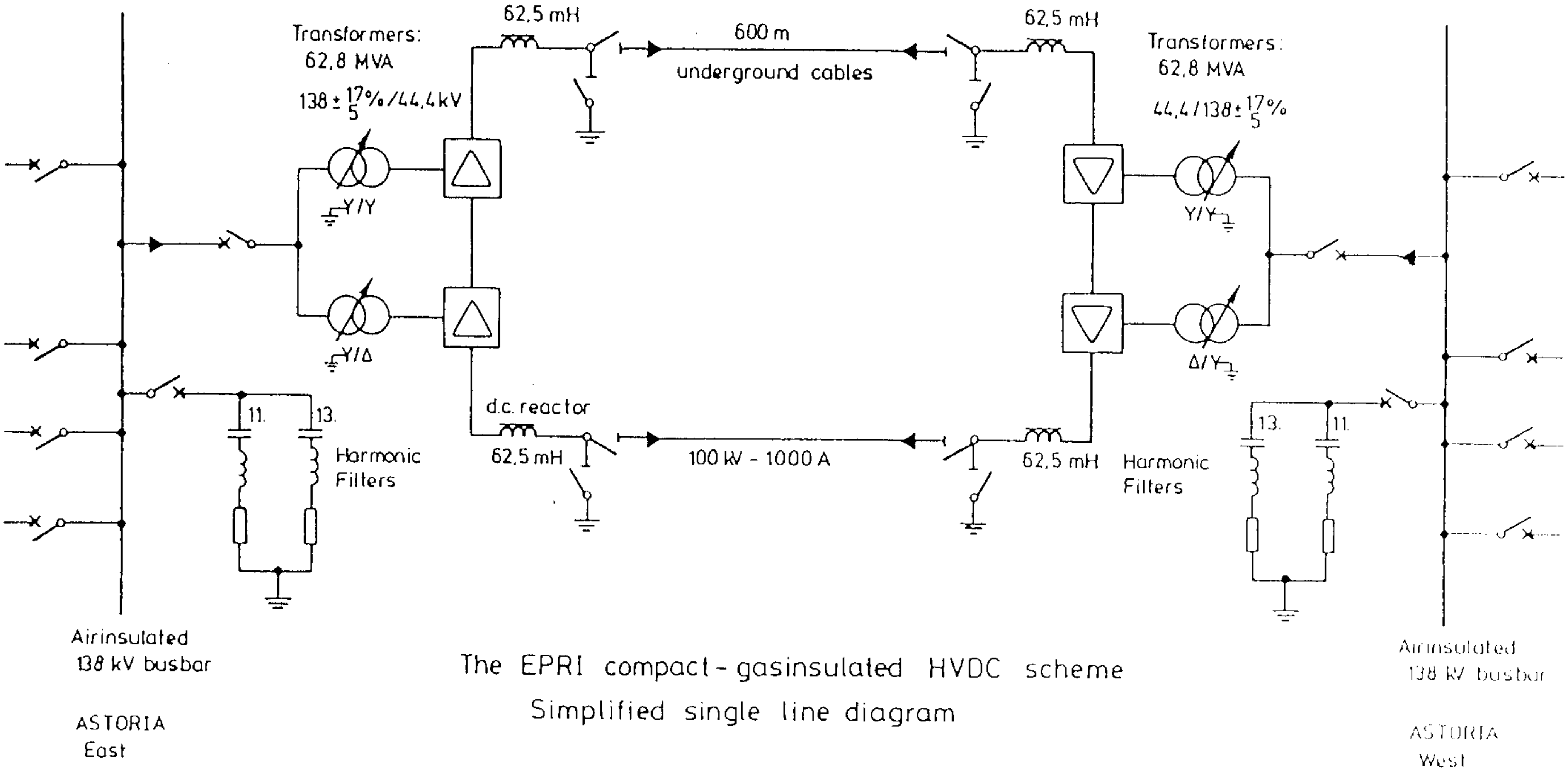
References:

Cigré 1982, paper 14-02
"Acaray HVDC back-to-back station"
by O. Ruiz Diaz, D. Povh, W. Feldmann and D. Tröller

The

EPRI

HVDC System



The EPRI compact - gasinsulated HVDC scheme

Simplified single line diagram

The E.P.R.I compact, gasinsulated HVDC system.

Between: Two large 138 kV a.c. stations, Astoria East and Astoria West in Con Ed's system in New York City.

Power Co.: Consolidated Edison Co., New York City, USA.

Manufacturer: General Electric Co. in cooperation with EPRI.

Commissioned: Dec. 1978.

Main purpose: The Electric Power Research Institute has sponsored this prototype HVDC project for investigation, research and development on gasinsulated outdoor d.c. bussystems, d.c. valvesystems and cables in order to meet the future requirements of electricity supply to urban and city areas.
The facility will be used by EPRI to obtain performance, reliability, operation and maintenance data.

Due to heavy short circuit duty at each of the stations a solution by using a.c. was not technical possible in this case.

Main data: Monopole: 100 MW at + or - 100 kV d.c. and 1000A.

A.C. Networks: At each terminal one 3-phase, FOA cooled transformers is used per 6 pulse converter unit. The four transformers are identical with following data.

62.5 MVA, 138 kV $^{+17}_{-5}\%$ / 44.4 kV

Short circuit capacity: min. 10.000 MVA.

A.C. Filters: Each terminal is provided with harmonic filters for the 11. and 13. harmonic.
They are designed as compact gas insulated filters developed by EPRI and taken into service late 1979.

Data	MVAr	C µF	L mH	R ohm
11. harm.				
13. harm.				

HVDC System: Each terminal consist of two series connected 6 pulse converter units for obtaining 12 pulse operation.

Each 6 pulse converter unit comprises two series connected valve arms, housed in a dead-tank, gas insulated with liquid cooled thyristors.

Each valve arm consist of 5 series connected modules, each with 12 thyristor levels giving the total of 60 thyristor levels per valve or 120 thyristor levels per tank. For a complete 12 pulse unit this makes 720 thyristor levels, each with thyristors in parallel.

The two terminals are connected by two d.c. underground cables, each consisting of two types, spilced at the middle with special cable joints.

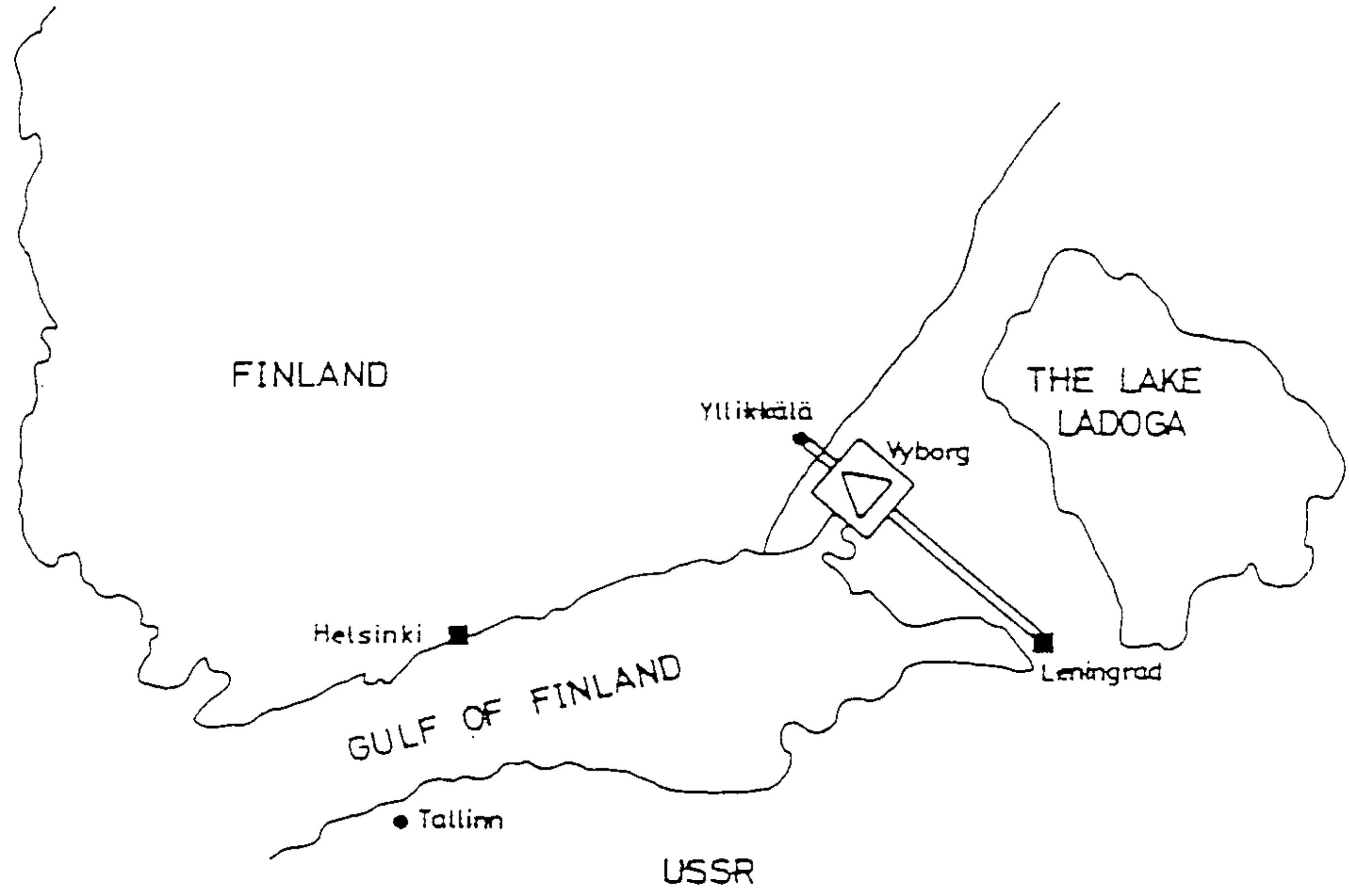
One type is a medium pressure oil filled d.c. cable (MPOF) and the other is a high pressure oil filled d.c. cable (HPOF) both for 400 kV d.c.

The length betw. terminals are 600 m.

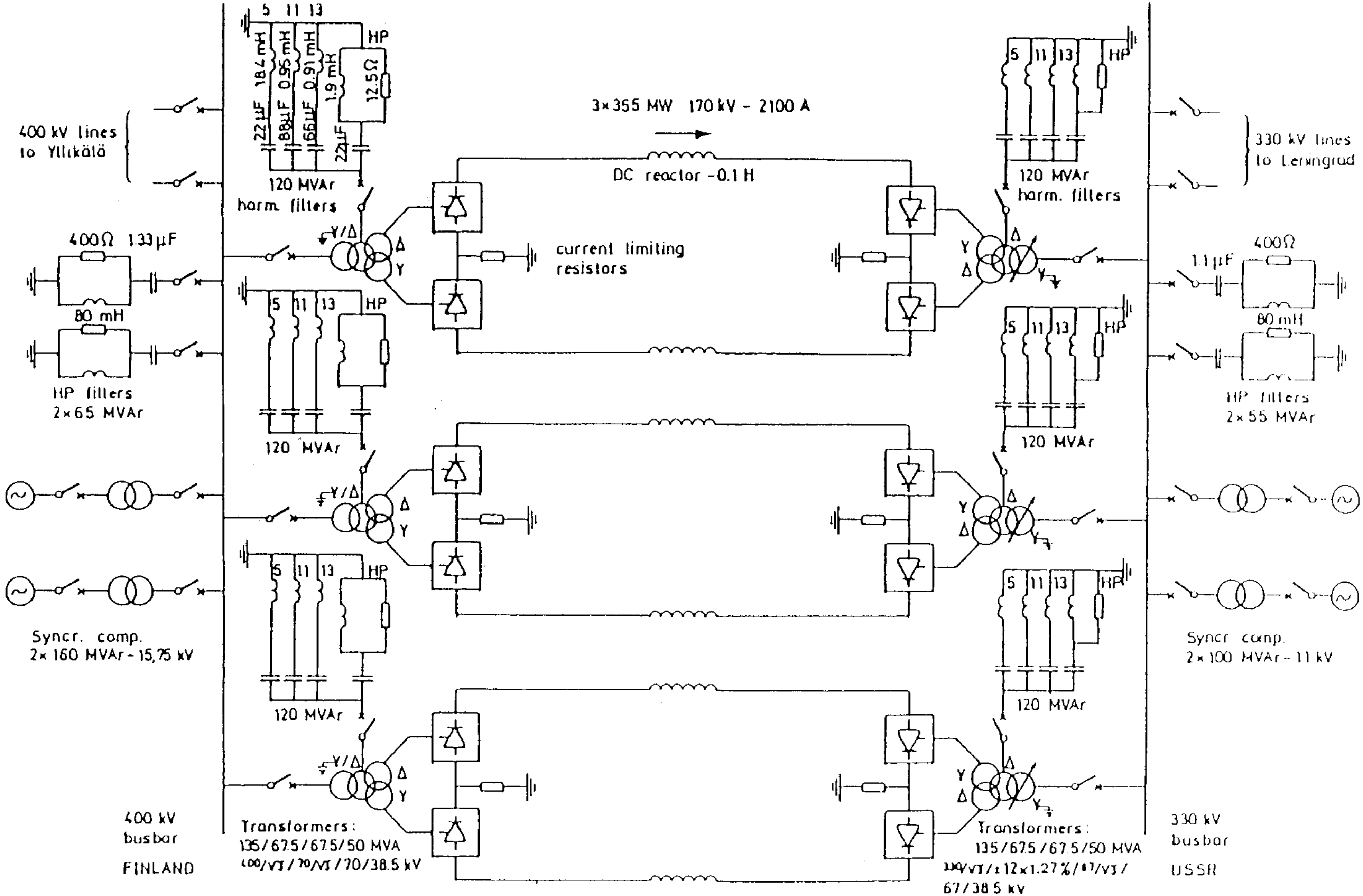
D.C. reactors: Each terminal is equiped with one reactor on each side of the converter. They are FOA cooled and designed for 62.5 mH at 1000A d.c.

References: Cigre 1978, paper 14-06:
Compact Gas Insulated HVDC Terminals

by: N.G. Hingorani, M.A. Dranchak, C. Flairty, A. Glassanos, R. Nakata, F.E. Fischer and N. Tai.



THE VYBORG HVDC SYSTEM
Geographic map



THE VYBORG HVDC SYSTEM
Simplified single line diagram

The USSR - Finland HVDC scheme.

Between:	The USSR and Finnish a.c. power systems at Vyborg.
Power Co.:	Lenenergo, Leningrad and Imatran Voima Oy, Helsinki.
Manufacturer:	Ministry for Electrotechnical Industry of the USSR.
Commissioned:	The first unit in December 1981. The second unit in the autumn 1982. The third unit in the summer 1984.
Main purpose:	Contracted energy supply (4 TWh/year) from USSR to Finland up to 1989.
Main data:	Totally commissioned the USSR - Finland interconnection will consist of three independent, parallel back-to-back units, each rated 355 MW, ± 85 kV d.c. and 2100 A, i.e. totally 1065 MW.
A.C. networks:	The converter station is situated near to the town Vyborg in the USSR. The station is connected with 2 x 330 kV a.c. lines to the united power system of the USSR, at the 330/220/110 kV substation "Vostochnaya", and with 2 x 400 kV a.c. lines

to the Finnish power system at the "Yllikkälä" 400/110 kV substation in Finland.

Transformer data:

18 single phase transformers are used. The line windings are star connected with earthed neutral.

The tertiary windings, rated at $67\sqrt{3}$ and 67 kV are star/delta connected respectively for obtaining 12-pulse operation.

USSR:

135/67.5/50MVA, $330/\sqrt{3} \pm 12 \times 1.27\%/67/\sqrt{3}/67/38.5$kV

Finland:

135/67.5/50 MVA, $400/\sqrt{3}/70/\sqrt{3}/70/38.5$ kV

The reactive power is supplied to the station by the a.c. filters connected to the tertiary windings of each of the converter transformers. The 2 x two HP filters (55 and 65 MVar) on the 330 and 400 kV a.c. busbar respectively and also the 2 x two synchronous condensers on each a.c. side are used for control of the a.c. voltage and the reactive power flow.

USSR: 2 x 100 MVAr at 11 kV, connected to the 330 kV a.c. busbar by two transformers, each 125 MVA, and 347/10.5 kV.

Finland: 2 x 160 MVAr at 15.75 kV, connected to the 400 kV busbar by two transformers, each 250 MVA, and 420/15.75 kV.

Short circuit range: USSR (330kV) min. 2900 MVA
Finland (400kV)min.3200MVA

HVDC System: Due to the station design there are no d.c. lines.

D.C. Filters: No d.c. filters are used.

HVDC valves: Water cooled thyristor valves are used. Each terminal has two 6-pulse converter units in series connection for obtaining 12-pulse operation.
One valve arm has 3 modules, each with 32 thyristor levels in series.
Each level has 3 thyristors in parallel giving the total of 288 thyristors per valve arm.

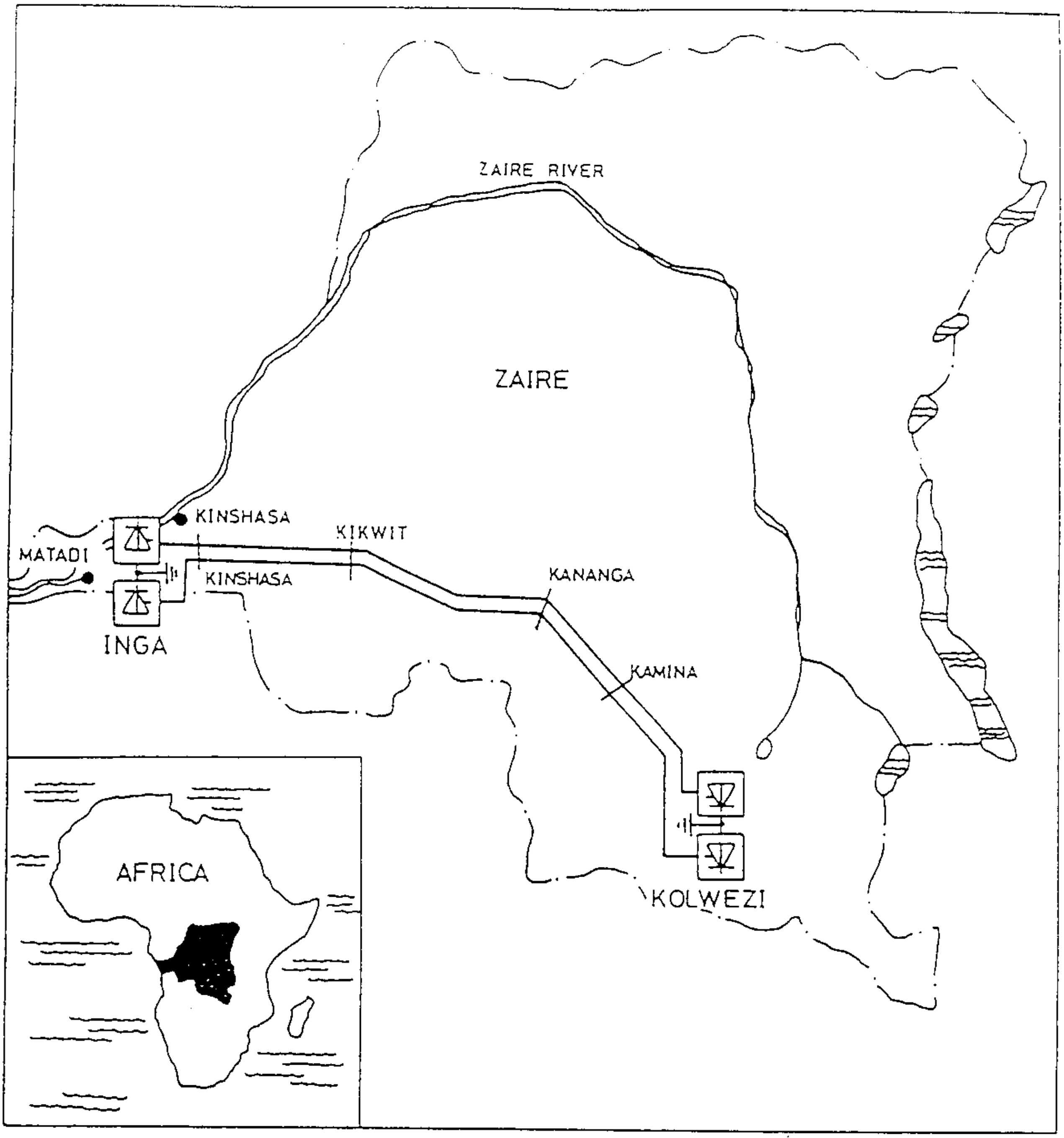
This makes 1152 thyristor levels and 3456 thyristors for one 12-pulse converter unit for 85 kV d.c. and 2100 A.

Each of the three back-to-back units is installed indoor in separate valve halls.

Smoothing reactors: These are placed in the connections between the two 12-pulse units of one back-to-back unit. They are designed for 0.1 H at 2100 A.

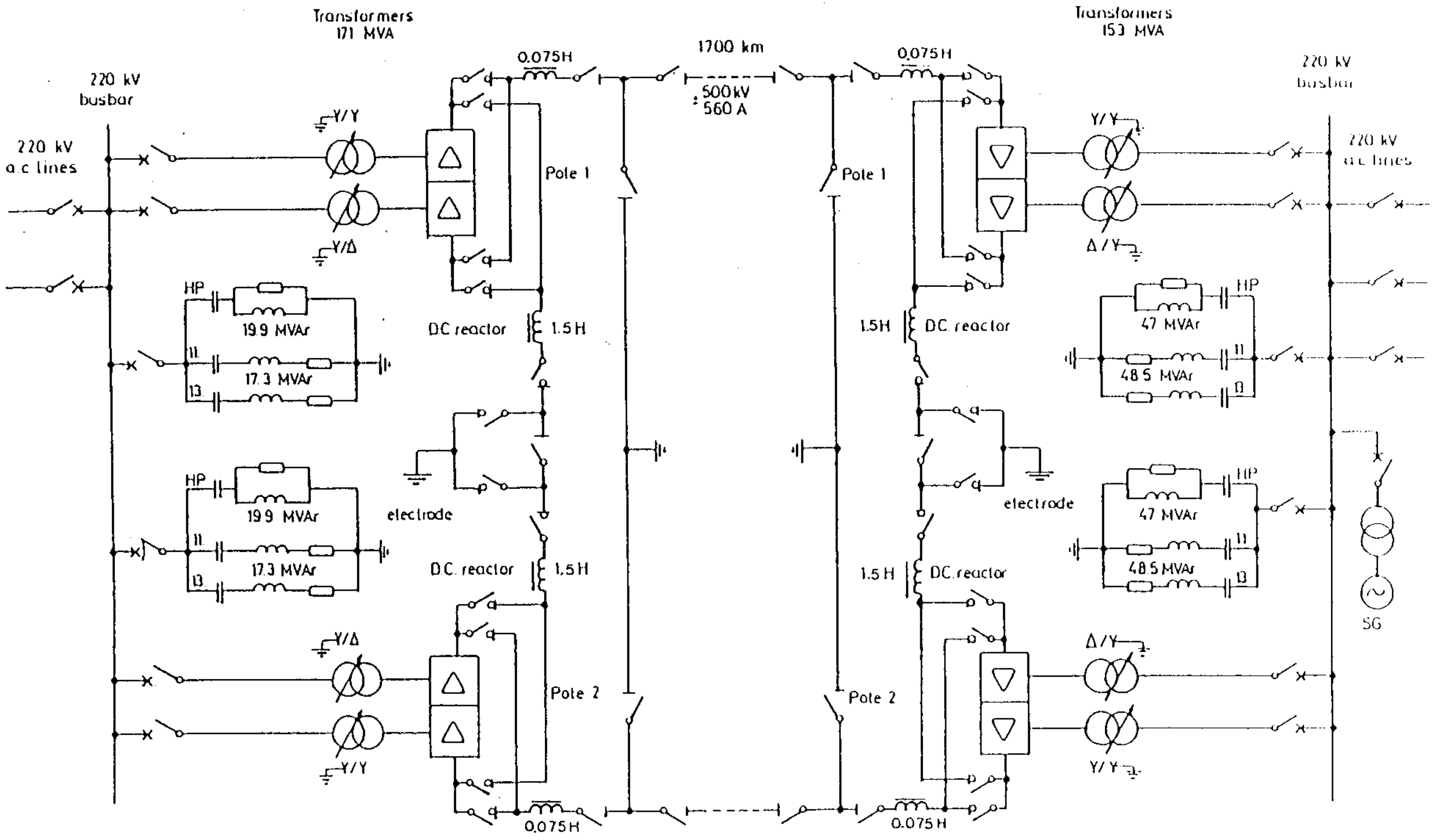
A.C. Filters: At each terminal three identical harmonic filters are provided. They are designed as combined filters for the 5., 11., and 13. harmonic and HP.
Totally installed 360 MVAr per terminal.

References: Cigré 1978 paper 14-11
"USSR - Finland HVDC Intertie"
V. Emeluanov, H. Heikkilä, L. Mäkelä
Cigré 1984, paper 14-11
Equipment for the USSR-Finland HVDC back-to-back link and its operational experience.
by: V.P. Kulakov, A.K. Mazurenko, I.P. Taratuta and G.M. Tshasman



THE INGA SHABA HVDC SCHEME
Geographic map

147



INGA SHABA HVDC SHEME
Simplified single line diagram

The Inga Shaba HVDC scheme.

Between:	The provinces of Inga and Shaba in the republic of ZAIRE.
Power Co.:	Societé Nationale d'Electricité Kinshasa, ZAIRE
Manufacturer:	Morrison-Knudson Co, USA, as main contractor with ASEA, Sweden and G.E., USA as subcontractors for the two converter stations.
Commissioned:	1982/1983
Main purpose:	Bulk power transmission for electricity supply to KOLWEZI in region of Shaba, the mining district of south east Zaire.
Main data:	First stage: 560 MW at $\pm$ 500 kV d.c. and 560 A/pole Overload capacity: 35% for 30 min.
A.C. networks:	At both terminals 6 single phase converter transformers are used per 12 pulse converter unit. Inga: 57 MVA, 220 kV +15/-10 kV/215 kV, 50 Hz The transformers are connected to the 220 kV a.c. busbar.

Short circuit capacity = min. 2930 MVA

KOLWEZI: 51 MVA; 220 kV +24.5/-21.0 kV/192 kV, 50 Hz

The transformers are connected to the 220 kV a.c. busbar.

Further more three 70 MVA synchronous condensers are connected to the busbar.

Short circuit capacity = min. 1690 MVA.

HVDC System: Route length = 1700 km.

Overhead lines: Designed as two separate lines with conductors = 3 x 524 mm^2 ACSR (1033 MCM)

The lines are separated 40 m from each other.

Line towers: These are self supporting lattice steel structures.

Shieldings: The overhead lines are shielded by a 520 mm^2 ACSR (1018 MCM).

Insulator leakage: 2.67 cm/kV at 500 kV d.c.

Electrodes: The electrode stations as well at Inga as at Kolwezi are located in a distance of 39 km and 11 km respectively from the converter stations, and both are designed as land electrodes.

Resistance - Inga: 0,240 ohms
Kolwezi: 0,14 ohms

The Inga electrode is designed as a linear ground electrode and the Kolwezi electrode is a three-legged ground star electrode

<u>D.C. Filters:</u> No d.c. filters are used.

<u>HVDC valves:</u> Air cooled thyristor valves are used. They are designed as double valves, fully insulated to ground in order to obtain the possibility of changing the polarity. Six double valves/pol form a 12 pulse converter unit.

One valve arm has 43 active modules, each with 6 series connected thyristors giving the total of 258 thyristors in series connection per valve arm. This makes 516 thyristors per valve structure or 3096 thyristors per 12 pulse converter unit for 500 kV d.c. and 560 A.

The valve structure is air insulated.

<u>The d.c. reactors</u> are placed on the neutral side and they are designed for 1.5 H at 560 A. As protection against incoming lightning surges reactors are placed on the high voltage side.
These are designed for 0.075 H at 560 A.

<u>A.C. Filters:</u> Harmonic filters are provided at each terminal and designed as two combined 11. - 13. harm. and HP filters each with:

151

Inga: total installed 37.2 x 2 MVAr.

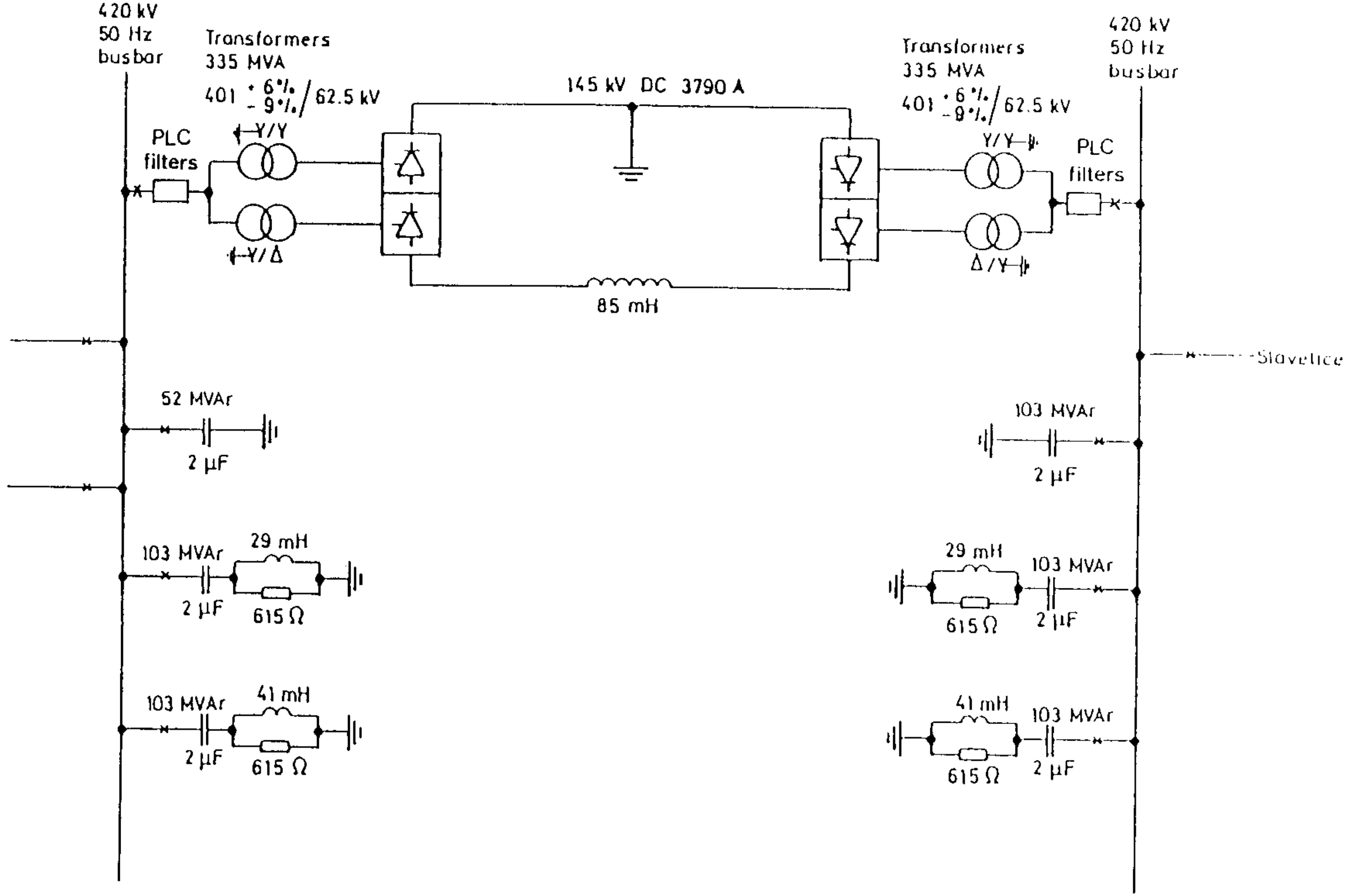
Harm.	MVAr	C=uF	L=mH	R=ohm
11.	10.1	0.664	126	3.0
13.	7.2	0.474	126	3.6
HP	19.9	1.31	13.4	283

Kolwezi: total installed 95.2 x 2

Harm.	MVAr	C=uF	L=mH	R=ohm
11.	28.1	1.85	45.3	1.1
13.	20.4	1.32	45.3	1.3
HP	47	3.09	5.7	164

References: Electra no. 63 (1979)
"A.C. Harmonic filter and reactive compensation for HVDC"
A general Survey by SC14 - WG03.

THE DUERNROHR HVDC SYSTEM
Geographic map



THE DUERNROHR HVDC SYSTEM
Simplified single line diagram

The Duernrohr HVDC scheme

Between: The 400 kV, 50 Hz CMEA network (East Europe) and the 420 kV, 50 Hz UCPTE network (West Europe at Duernrohr Austria. The interconnection is designed as an asynchronous HVDC coupling system.

Power Co.: Österreichische Elektrizitätswirtschafts AG. (The Austrian Electricity Supply board)

Manufacturer: The Austria - German - Swiss Consortium AEG - BBC - ELIN - SIEMENS.

Commissioned: 1st of September 1983

Main purpose: Exchange of energy between East- and West Europe.

Main data: 550 MW at 145 kV d.c. and 3790 A

Overload capacity: 15% at ambient temperatures below 10°C.

A.C. networks: The converter station DUERNROHR is situated 40 km from Vienna. This station is integrated in the Austrian 420 kV network, and is also connected to the Czechoslovakian transformer Station SLAVETICE by a 400 kV a.c. line, with the length of approximately 100 km.

Converter transformers: Two three phase transformers are used for each 12 pulse converter unit. They are identically on both Austrian and Czechoslovakian side:
335 MVA, 401 +6%/-9%/62.5 kV, 50 Hz
Short circuit capacity: min. 3000 MVA

On the Austrian side the SCR level will increase by the end of 1984.
The highest a.c. voltage allowed is 420 kV

A.C. filters: On each a.c. side of the converter two filters of HP-type are installed and each with the capacity of 103 MVAr (11. and 13. harm.) Furthermore to meet the demand of reactive power shunt capacitor banks are installed. One 103 MVAr (Czechoslovakia) and one 52 MVAr (Austria).

Between the transformers and the a.c. bus bar high frequency (PLC) filters are installed.

55

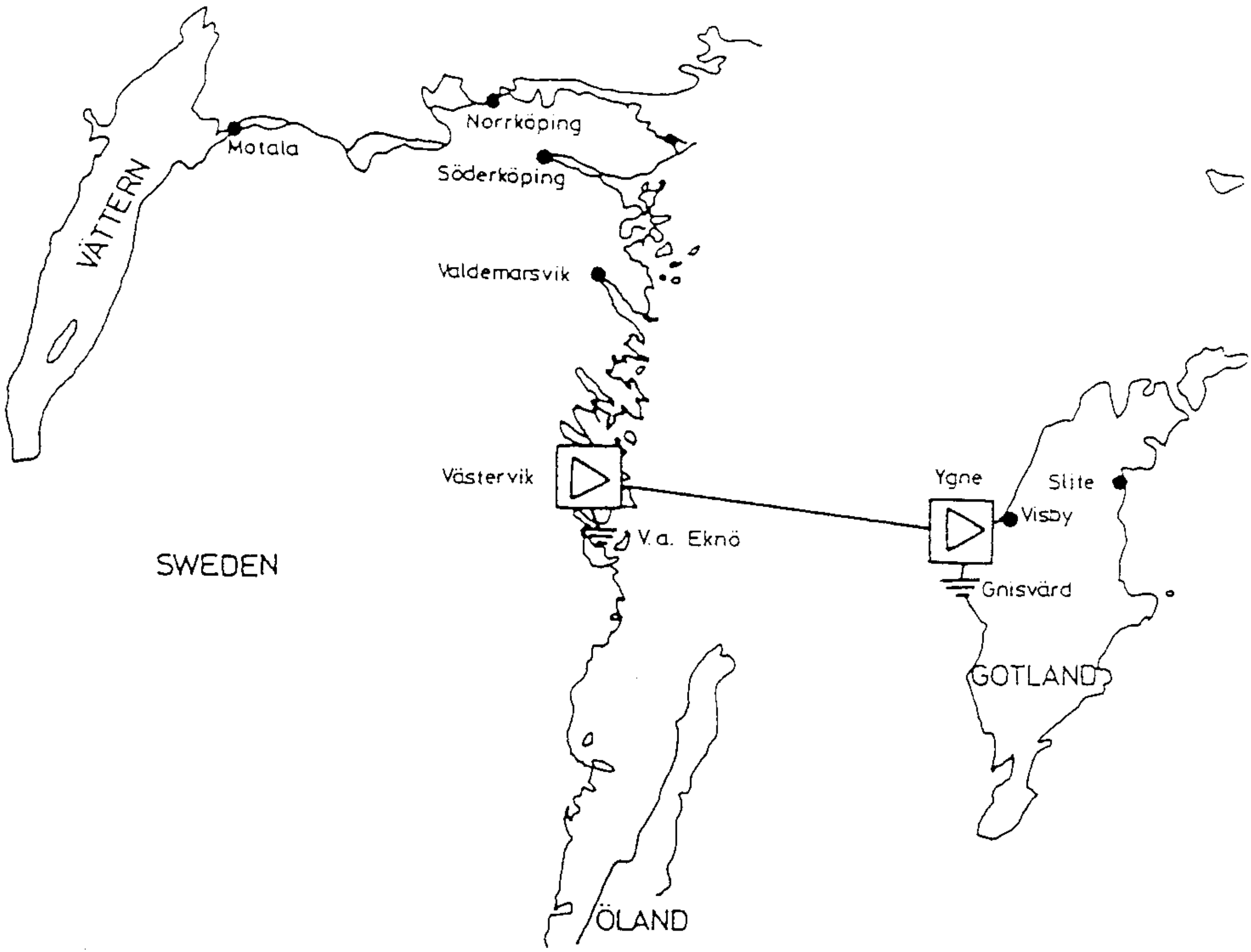
HVDC valves:

The thyristor valves are housed indoor and they are designed as quadruple valves, i.e. three quadrouple valves form a 12 pulse converter unit. The valves are water cooled and air insulated. Each quadruple valve has 4 valve sections in series connection. One valve section has 4 modules, each with 11 series connected thyristors giving the total of 44 thyristors in series connection per valve arm and none in parallel. This makes 176 thyristors in one quadruple valve or 528 thyristors in one 12 pulse converter unit for 145 kV d.c. and 3790 A.

The d.c. reactor is designed for 85 mH at 3790 A and placed between the two 12 pulse converter units.

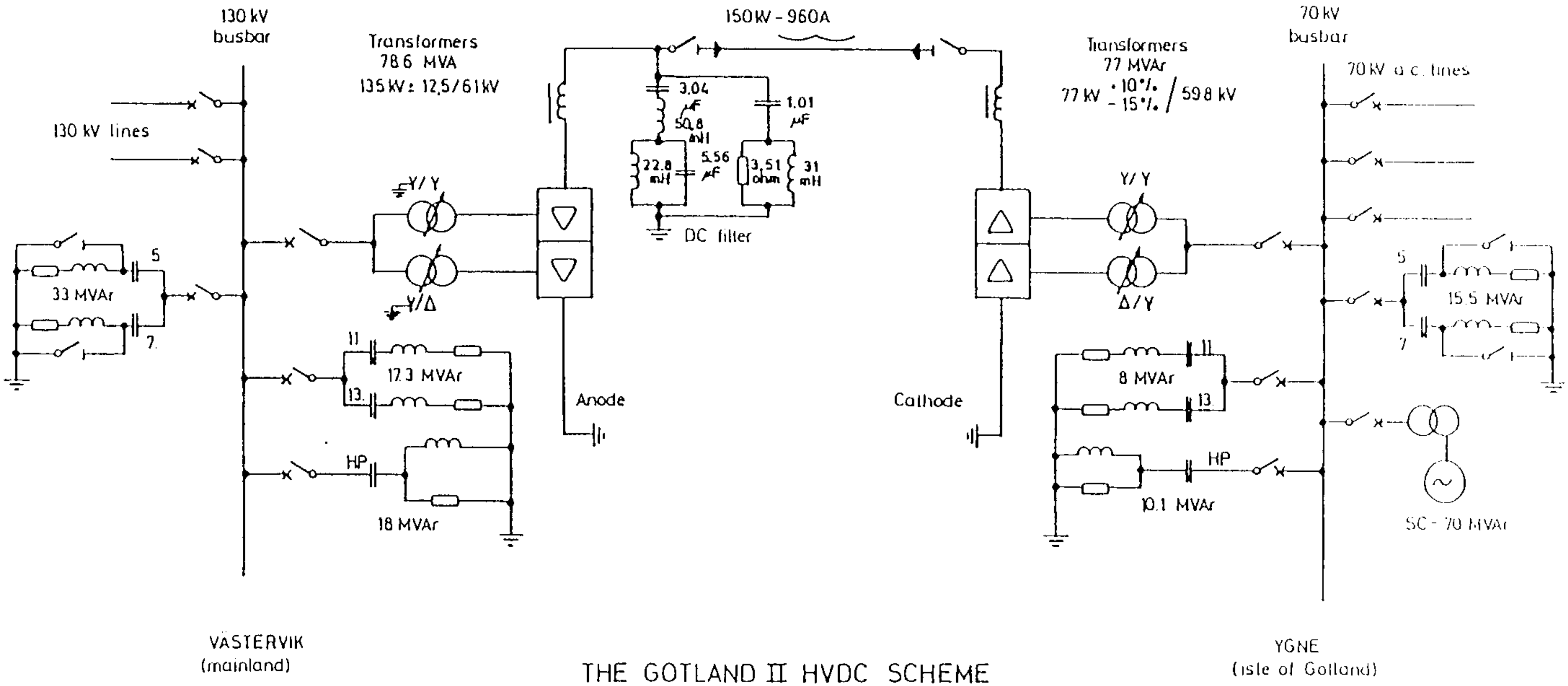
References:

Cigré 1982, paper 14-03:
Design and testing of thyristor valves and their components for the HVDC back-to-back link Duernrohr in Austria.
G. Thiele, H. Rötting, K.H. Weck.
Cigré 1984, paper 14-01:
Commissioning and system tests for the HVDC back-to-back tie Duernrohr/Austria
by: K.W. Kanngiesser, G. Moraw and D. Pouh.
Cigré 1984, paper 14-07:
Type testing of thyristor modules for Duern-rohr HVDC back-to-back link in Austria
by: G. Thiele and L. Vukasovic



THE GOTLAND II HVDC SCHEME
Geographic map

157



THE GOTLAND II HVDC SCHEME
Simplified single line diagram.

The Gotland II HVDC scheme.

Between: The Swedish mainland and the isle of Gotland

Power Co.: The Swedish State Power Board, Stockholm

Manufacturer: ASEA, Sweden

Commissioned: November 1983

Main purpose: Electricity supply to the island for compensating the local, oilfired electricity production on the island. In the future the local eletricity production and the old HVDC scheme, "Gotland I" (1954) will serve only as spare capacity.

Main data: Monopole: 130 MW at 150 kV d.c. and 910 A. Earth return with the anode station situated on the mainland side.

Overload Capacity: 160 MW at temperatures below 0°C.

A.C. networks: At both terminals, two 3-phase converter transformers are used per 12 pulse converter unit.
Six pulse operation is possible if one of the transformers is out of service. For this purpose 5.- and 7. harm. filters are installed, but during normal 12 pulse operation they can be connected as shunt capacitor banks.

Transformer data:

Mainland: 78.6 MVA, 135 kV ± 12.5/61 kV

The two transformers are con nected to the 130 kV a.c. system

Short circuit capacity: min.1650 MVA

Island: 77 MVA, 77 kV +15%/-10%/59.8 kV

The two transformers are connected to the 70 kV a.c. system

To improve the short circuit capacity a 70 MVAr synchronous condenser is installed and connected to the 70 kV busbar.

Short circuit capacity: min.550 MVA

The connections between the converter transformers and valve buildings, are both terminals designed as SF_6 insulated busbars.

HVDC System: Route length: 103 km.

On the mainland side an overhead line of 7 km is used.

The submarine cable ist the solid type with oilimpregnated paper insulation.

160

Conductor: 800 mm^2 Cu.

Length: 96 km incl. 1 km land cable on the island.

The cable has a single layer of steel armouring of 42 x 5 mm.

Electrodes: The electrode stations, are situated at the shores on both sides. They are designed as sea electrodes, and at the mainland side they are placed behind a breakweater.

D.C. filters: are provided at the mainland for eliminating telephone interference. They are tuned for the 6. - 12. - and 18. harmonics.

HVDC valves: The valves installed are water cooled thyristor valves designed in a suspended valve structure with quadruple valves.
Each valve arm consists of 36 series connected thyristors with 75 mm active silicone part, and arranged in 3 modules each with 12 thyristors. This makes a total of 144 thyristors per quadruple valve or 432 per 12 pulse converter unit for 150 kV d.c. and 910 A.

The d.c. reactors are equal at each terminal, and they are placed on the high voltage side, designed for 0.615 H at 910 A.

A.C. Filters: Harmonic filters are provided at each terminal

Västervik:

Harm.	MVAr	C=uF	L=mH	R=ohm
5.	15.6	2.617	158.4	2.36
7.	17.5	2.99	69.2	1.33
When connected as a shunt capacitor				
the total = 32.1 MVAr				
11.	8.7	1.495	56.0	1.07
13.	8.6	1.495	40.1	0.91
HP	18	3.14	5.6	196

Ygne:

Harm.	MVAr	C=uF	L=mH	R=ohm
5.	6.8	3.694	109.7	1.87
7.	8.7	4.831	42.8	0.92
When connected as a shunt capacitor				
the total = 15 MVAr				
11.	4	2.243	37.3	0.89
13.	4	2.243	26.7	0.75
HP	10.1	5.709	3.1	93

References:

Cigré 1984 - paper 14-05:
Development and testing of new generation of HVDC control system
by: A. Kroon and B. Normark.

E D D Y   C O U N T Y

163

Eddy County

Between:	This back-to-back tie connects the eastern and western electric grids in Eddy County in south-eastern New Mexico. The location is 9 1/2 miles east from Artesia.
Owners:	The Eddy County tie is a joint venture of El Paso Electric Co (EPE), Texas-New Mexico Power Co. (TNP) and Southwestern Public Service Co (SPS).
Manufacturer:	General Electric Co.: major portions SPS: overall project management, substadion switchgard design, civil and mechanical design
Commission date:	December 1983
Main purpose:	Energy transport from SPS coal fired energy to EPE and TNP
Main data:	200 MW 82 kV back to back system
AC networks:	Voltage: east side 230 kV west side 345 kV

Converter transformer:

east bus: 273 MVA rating
voltage: 230/35,4 kV
west bus: 273 MVA rating
voltage: 345/35,4 kV

A spare transformer for each side is available.

AC filters and capacitor banks:

east bus: 2 x 30 MVAr high pass filters
2 x 30 MVAr capacitors
west bus: 2 high pass filters

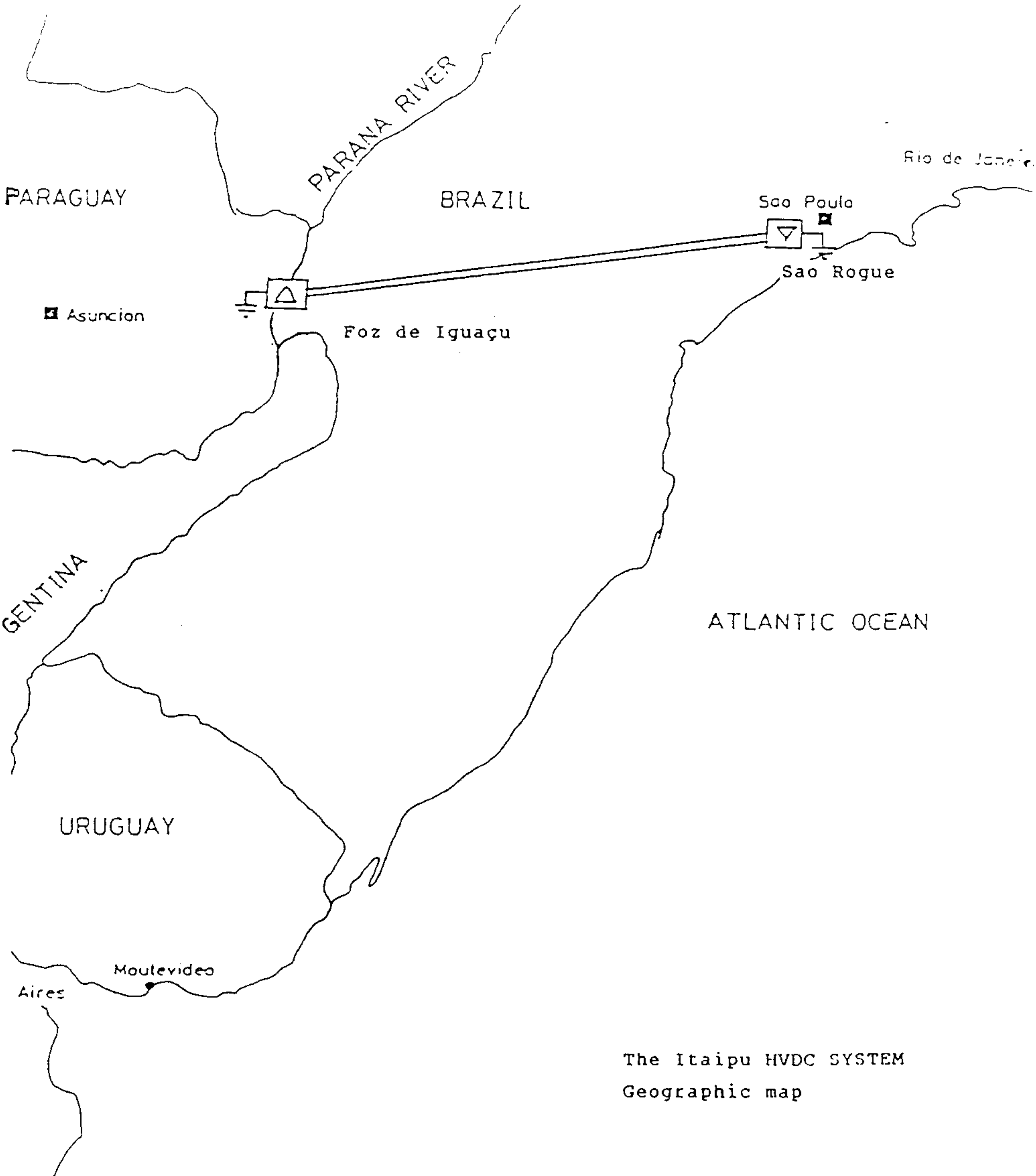
HVDC plant:

2 sixpulse converter bridges produce 12 pulse DC
Number of thyristors: 576
Valve: consisting of 24 groups
Group: two parallel thyristors (24 voltage level at each valve)
Nominal current/thyristor: 1600 A

,5

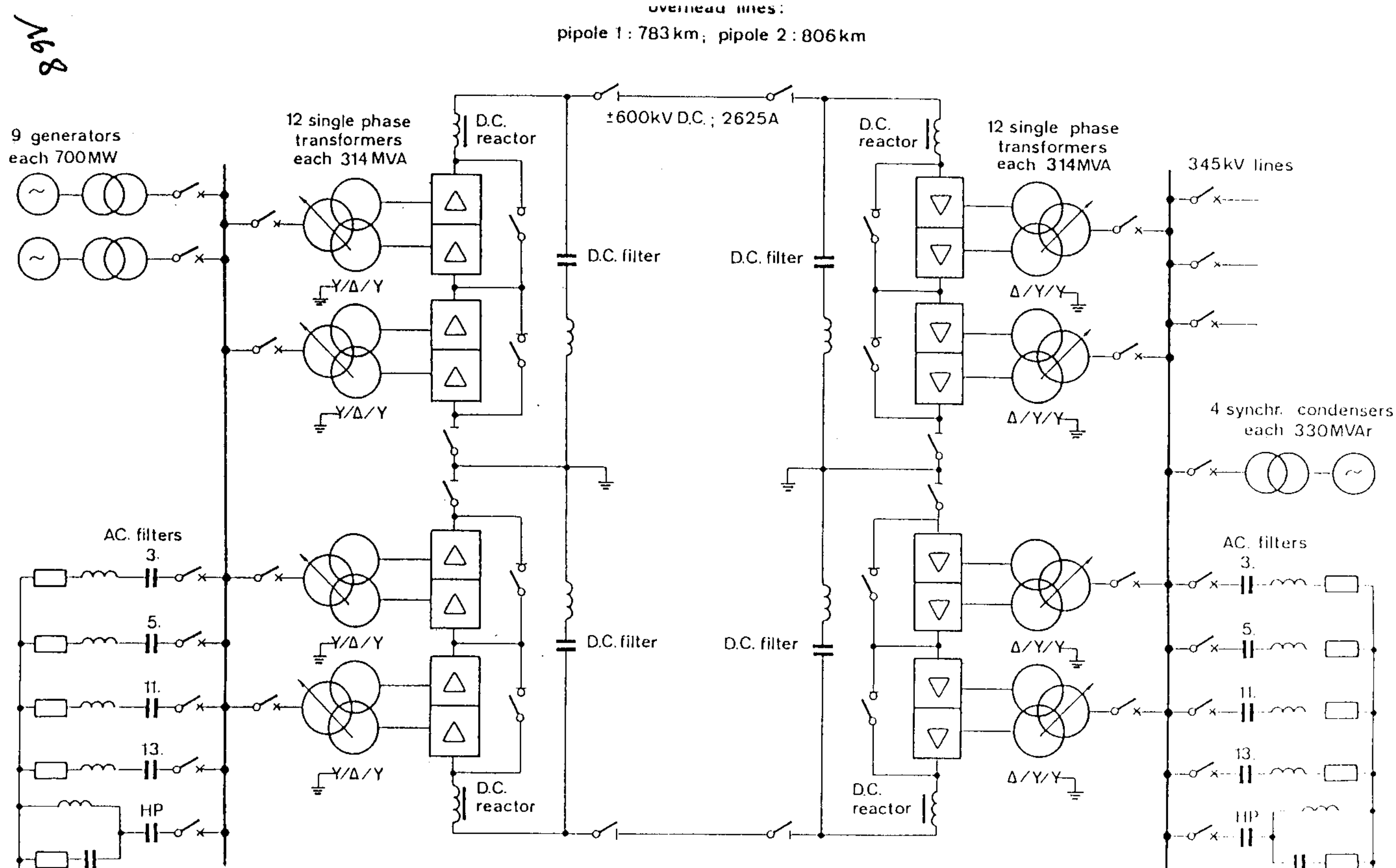
Valve cooling: The valve cooling system consists of two closed loops and an evaporative-assisted outdoor cooler. The heat from the air is moved from the lower plenum heat exchangers by means of a pumped water-glycol loop to the heat-exchanger in the outdoor evaporative cooler.
A special valve cooling control (VCC) is erected.

References: Electrical World, 1984 May:
HVDC ties East and West networks
by Billie L. Mellendon, P.F., Transmission and Distribution Design Dept. Southwestern Public Service Co.



The Itaipu HVDC SYSTEM
Geographic map

168



Itaipu HVDC scheme
(one of two pipoles; each of 3150MW: 600kV d.c.)
simplified single line diagram

The ITAIPU HVDC scheme.

Between:	Foz do Iguaçu at the border of Brazil and Paraguay to Sao Paulo, Brazil
Power Co.:	Furnas Centrais Elétricas S.A. Brazil
Manufacturer:	ASEA Promon HVDC consortium, formed by ASEA Sweden, ASEA Elétricas Ltda, Brazil and Promon Engenharia S.A. Brazil
Commissioned:	1.stage: ± 300 kV, 1575 MW at July of 1984
	2.stage: + 300 kV 2362,5 MW at April of 1985
Bipole 1.	− 600 kV
	3.stage: ± 600 kV, 3150 MW at May of 1986
Bipole 2.	4.stage: ± 300 kV, 1575 MW 5.stage: + 300 kV, 2362,5 MW − 600 kV 6.stage: ± 600 kV, 3150 MW } to be commissioned at the same time by February, 1987
Main purpose:	Bulk power supply from the great Hydro Power station (12600 MW) at Foz do Iguaço to the São Paulo industrial area. The power is generated by 18 hydro generators, nine of them are designed for 60 Hz with a capacity of 765 MVA, P.F. = 0,95 and the other nine are designed for 50 Hz with a capacity of 823 MVA, P.F. = 0,85 supplying the HVDC system.
Main data:	The HVDC system consists of two bipolar transmission systems, each one designed for 3150 MW at ± 600 kV d.c. and 2625 A.

overload capacity: 5 seg. ---------- 3260 Amp.
20 seg. ---------- 3000 Amp.

A.C. networks: 24 single phase - three winding converter transformers are used at each terminals which means three transformers/12 pulse unit, forming four converter per Bipole.

Foz do Iguaçu: 50 Hz, 314 MVA
$500/\sqrt{3}$ kV+20 x 1,25 % kV
-6

min. short circuit capacity: 16373 MVA

Sao Roque: 60 Hz, 300 MVA
$345/\sqrt{3}$ kV+20 x 1,25 % kV
-6

min. short circuit capacity: 7800 MVA (light road)

Synchronous Compensator: Sao Roque - 4 x 330 MVAr

AC filters: Harmonic filters are provided at 50 Hz and 60 Hz side. Shunt capacitor bank only at 60 Hz side

50 Hz Side - FOZ DO IGUACU

AC FILTERS

TYPE	HARMONIC	MVAr	UNITS	TOTAL
1	3º/5º,11º/13º,HP1A,HP1B	349.0	2	698.0
2	11º/13º, HP2	280.3	3	840.0

170

COMPON.	TYPE 1 3°/5°	11°/13°	HP1A	HP1B	TYPE 2 11°/13°	HP 2
C1(μF)	0.814	1.691	0.916	0.929	1.691	1.858
L1(mH)	830.0	41.95	19.86	7.715	41.95	9.41
C2(μF)	2.986	49.15	-	-	49.15	-
L2(mH)	226.6	1.44	-	-	1.44	-
R(ohms)	2930.0	0.444	1060.0	305.0	0.444	170.0
MVAR	70	134.3	72	72.7	134.3	146.0

60 Hz Side - SAO ROQUE

AC FILTERS

HARMONIC	MVAR	UNITS	TOTAL
11.°, 13.°	220.8	3	662.4
11.°, 13.°, 3.°/5.°	279.8	1	279.8
3.°/5.°, HP2	296.0	1	296.0
HP1	237.0	4	948.0
HP2	296.3	1	296.3

COMPON.	3.°/5.°	11.°	13.°	HP1	HP2
C1(μF)	1.160	2.417	2.468	5.273	6.591
L1(mH)	405.0	24.06	16.87	2.318	2.318
R(ohms)	2500	3990	3300	46.76	46.76
C2(μF)	4.281	-	-	-	-
L2(mH)	110.1	-	-	-	-
MVAR	59.0	109.4	111.4	237.0	296.3

Shunt capacitor bank: 2 x 294,0 MVAR, 6,45μF

HVDC System: Route length: Bipole 1 (South Line): 796,5 km
Bipole 2 (North Line): 816 km

Overhead lines: Conductors: 4 x 689 mm^2 ACSR (1272 MCM)
Shielding: 7 strand, galvanized steel wire (9.5mm)
Line towers: 23 % are selfsupported and 77 % are guyed lattice steel structures

The two bipolar line systems are separated 10 km from each other as a minimum.

Electrodes: The electrode switching houses are situated far from the stations:

Foz do Iguacu: Bipole 1: 15,5 km
Bipole 2: 16 km
San Roque: Bipole 1: 67,2 km
Bipole 2: 66 km

conductors type: 2 x 689 mm^2, 1272 MCM

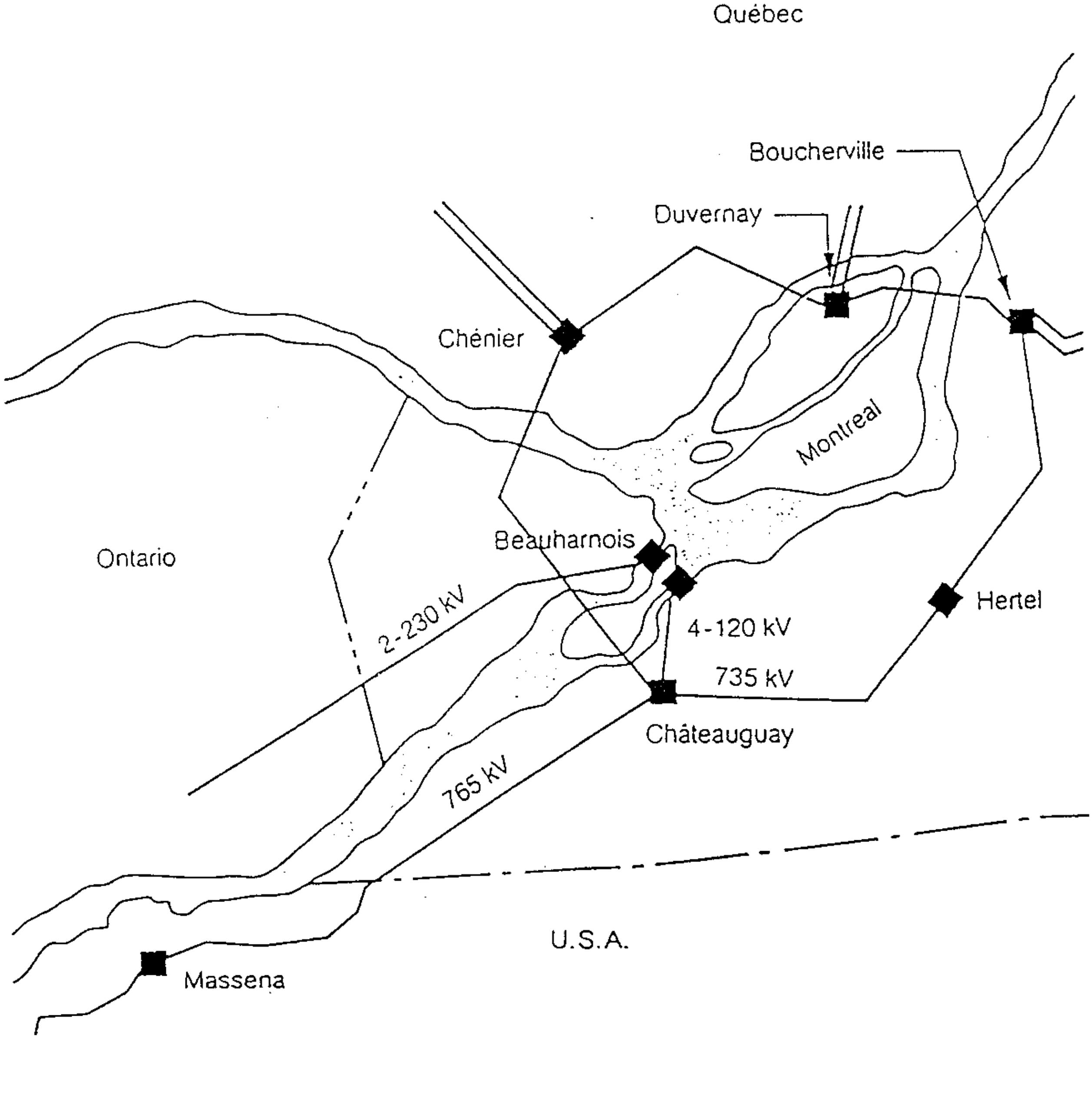
D.C. Filters:

STATION	BRANCH	BANK CAPA-CITANCE (μF)	TUNING FREQUENCY (HZ)	CH (μF)	L1 (mH)	R1 (ohms)	C1 (μF)	LH (mH)
Foz do Iguacu	2°/6°	0.533	100/300	0.5	2111.0	23.0	0.533	1267.0
	12°	0.715	600	1.285	-	1.32	0.715	35.04
	HP	1.570	1200	1.010	-	660.0	-	17.42
S.Roque	2°/6°	0.558	120/360	0.523	1401.0	18.0	0.5579	841.0
	12°	0.878	720	0.828	-	1.29	0.8753	28.42
	HP	1.570	1440	1.570	-	210.0	-	7.78

<u>HVDC Valves:</u> The Itaipu HVDC System uses thyristor valves, indoor type, water cooled and isolated by air. Mechanically, the valves are built up as quadruple - valves forming a convertor. One single valve is made up of 8 thyristor modules series connected, containing 12 thyristors with voltage dividers and control circuits.

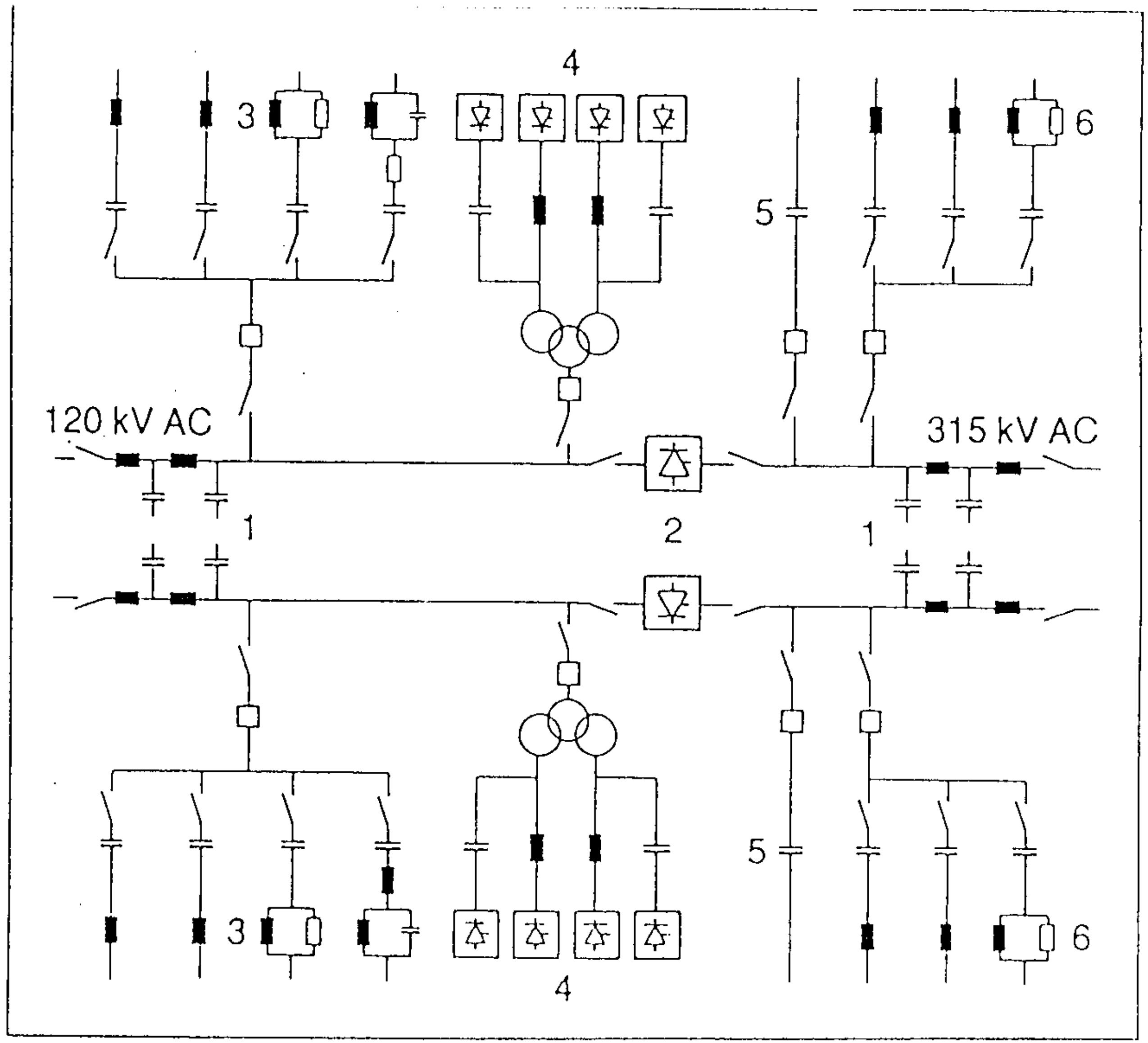
The Châteauguay scheme

back to back tie



Geographic map

175



1 PLC filters
2 Converter blocks 2 × 500 MW
3 AC filters 120 kV
4 Static compensators
5 Capacitors
6 AC filters 315 kV

The Châteauguay scheme

Simplified single line diagram

The Chateauguay scheme

(back-to-back tie)

Between:	Canada and USA. Network of Hydro Quebec Canada und the neighbouring network of the Power Authority of New York (NYPA).
Power comp.:	Hydro Quebec Canada Power Authority of New York.
Manufacturer:	BBC (prime contractor) BBC, Siemens (major supplier)
Commissioned:	start: October 1983 commercial operation: June 1984
Main purpose:	To transmit surplus power generated in the large hydro-power plants in northern Quebec (James Bay)
Main data:	Rated power: 2 x 500 MW units at 40° C Overload : 600 MW at 0° C V_{DC}: 140,6 kV I_{DC}: 3600 A
AC Network:	Transformers: Rating: 6 x 203 MVA, single phase 3 windings Connections: wye/wye - delta Voltage: 120/60/60 kV U.S. side 315/60/60 kV H.Q. side Tape-changer: ± 12 % + 6 %/- 5 % one spare transformer

AC filters:

	Harm.	MVAr	C = μF	L = mH	R= Ohm
315 kV side	11	51	1.35	43	-
	13	36,5	0.96	43	-
	26	75,5	2.01	6,05	500

177

	Harm.	MVAr	C = µF	L = mH	R= Ohm
	3/5	20	3,37/12,63	37,1/134,3	4,25
	11	34,5	6,3	4,5	-
120 kV side	13	24,7	9,2	9,2	-
	26	8,88	16,36	0,637	45

High frequency (20 kHz) PLC filters:

Voltage:	120 kV	315 kV
Inductance:	1,0 mH	3,0 mH
Capacitance:	0,6 F	0,2 F
Number of steps:	2	2

Capacitor banks: Rating: 1 x 150 Mvar
Voltage: 315 kV

Static compensators: Number: 2
Tye: thyristor-controlled reactore (TCR) and thyristor-switched capacitor (TSC)

Individual rating: 60 Mvar ind.
75 Mvar cap.

Transformers: 3 phase, 3 winding; 201 MVA
Voltage: 120 kV primary
12,45 secondary

HVDC system:

HVDC valves:

No. of vales: 6 quadruple
No. of modules/valve: 4
rated current: 5000 A
Blocking voltage: 4,5 kV
Diameter: 100 mm
Each of the valve halls contains 2 12-pulse converter groups separated by a service aisle

The 12-pulse converter groups are interconnected by a d.c. link on the low voltage side via air-cooled, air-insulated smoothing reactors located outside the building. The 315 kV sides are directly connected in the valves hall.

The valves are of fully modular structure of a design similar to that used in the Nelson River Bipole 2 transmission system and the Austrian back-to-back tie. The valve structures are elevated by approximately 2 meters above the valve hall floor, thus making it possible to place the cabinets of the valve base electronics directly underneath the valve towers.

Handling of the current without parallel connection of units.

<u>Cooling system:</u> The valves are water-cooled. A two circuit system is used:

a) deionisized water for the primary valve cooling.

b) glycol-water mixture for the secondary circuit.

<u>Smoothing reactor:</u> outdoor, dry type
4 x 9 mH in series
BIL: 150 kV

<u>References:</u>

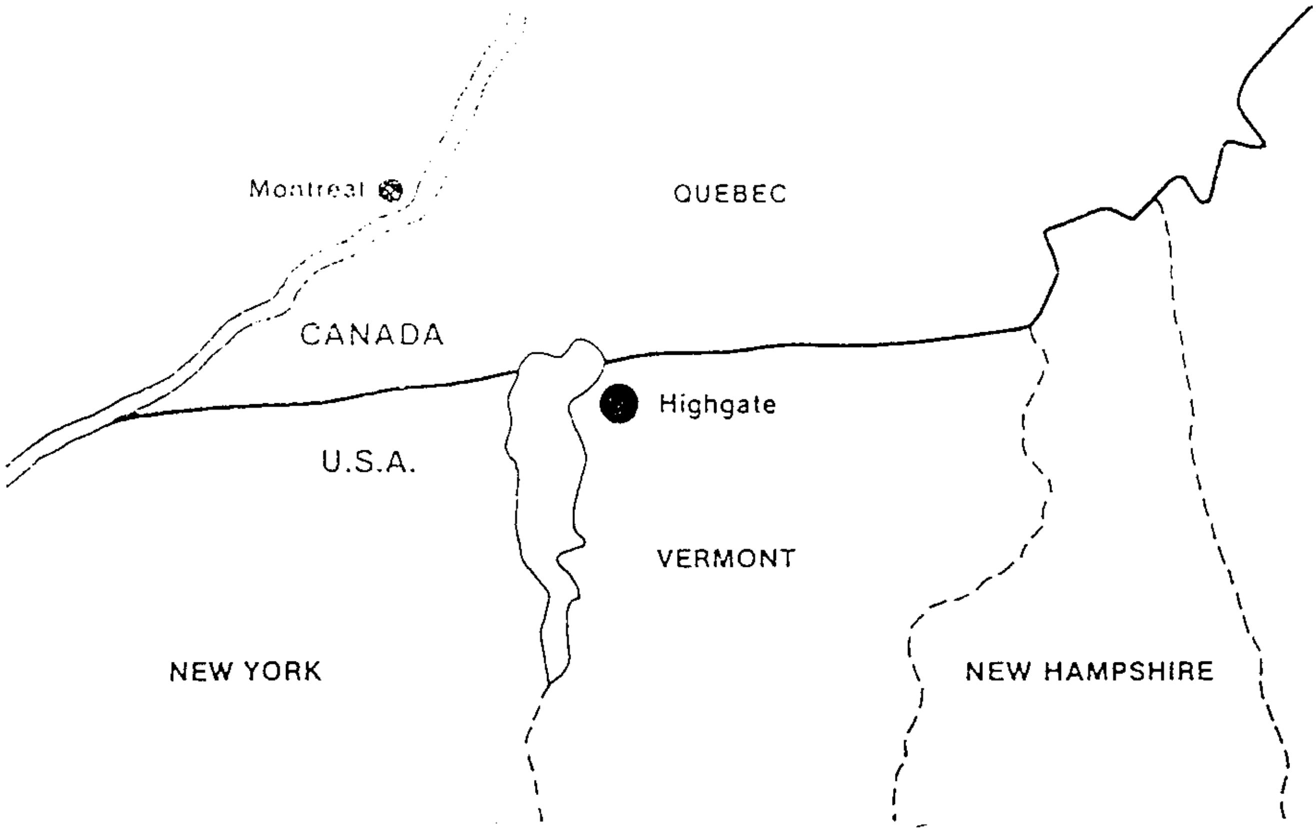
BBC publication No.: CH-N 22.003.2 E
CH-N 026 881 E

Aspects regarding the layout of Chateauguay, Madawaska and Des Cantons HVDC converter stations by Claude Durand, Jacques F. Allaire

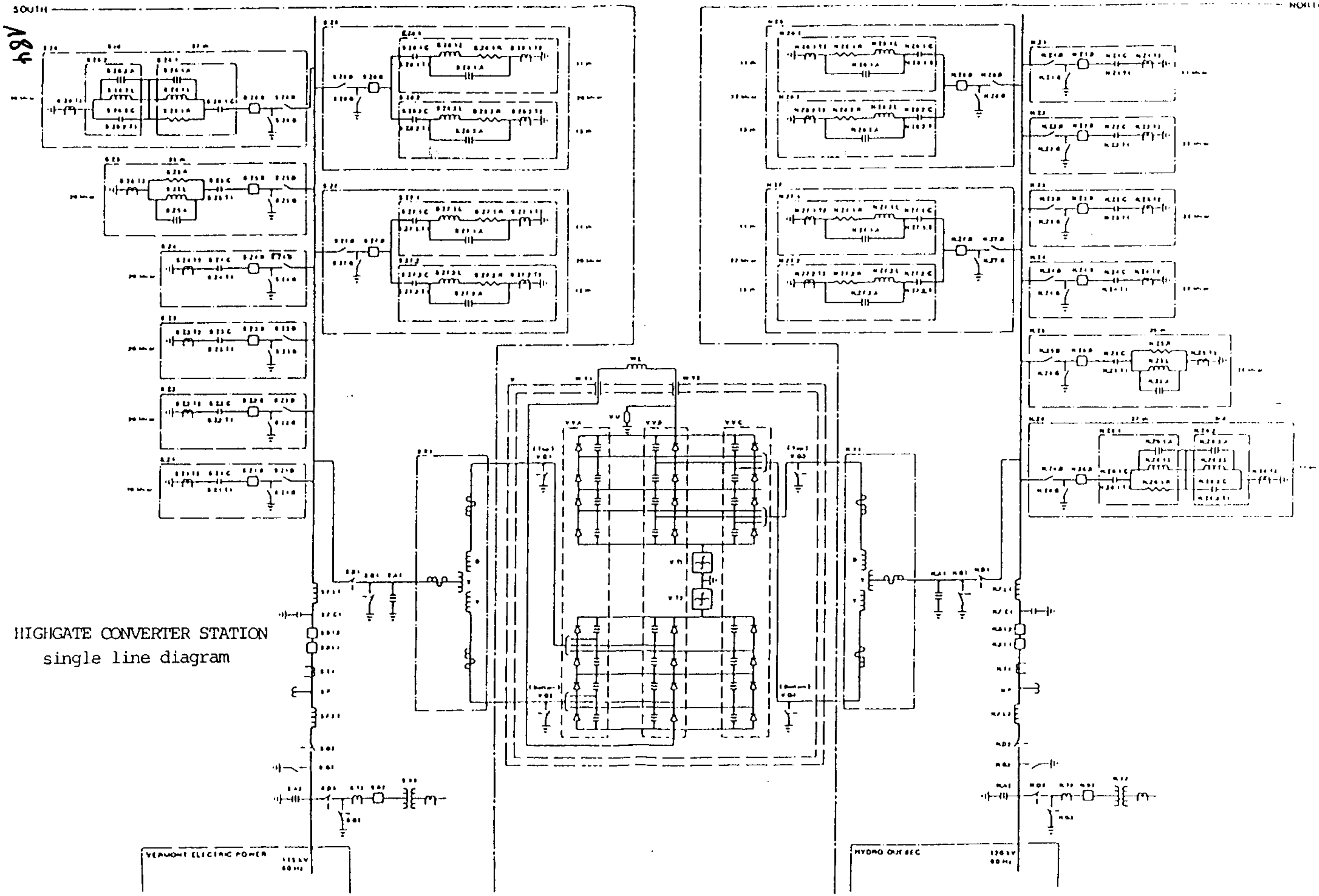
IEEE Power Engineering Society; 10th Conference and Exposition on overhead and Underground Transmission and Distribution; Sept. 14-19, 1986

P A C I F I C   I N T E R T I E (upgrade)

see Nr.9



THE HIGHGATE CONVERTER STATION
Geographic map



HIGHGATE CONVERTER STATION
single line diagram

The Highgate Converter Station

Between:	The Highgate Converter Station is a back to back interconnection between Hydro Quebec and Vermont Electric Power Co. VELCO.
Power Co.:	Hydro Quebec Vermont Electric Power Co. VELCO.
Manufacturer:	ASEA Sweden
Commissioned:	September 1985
Main purpose:	Project to import between 150 and 200 MW from Hydro Quebec to compensate the loss of power caused by the shut down of the Vermont Yankee nuclear plant.
Main data:	Rated power: 200 MW Overload (continous up to + 30°C) 12,5 % Direct voltage: 56 kV Direct current: 3600 A 12 pulse bridge
AC networks:	
Transformers:	Both converter transformers are of identical design. They are three phase transformers rated at 240 MVA. Vermont-side: 115 kV/23,3/23,3 one delta connected H-Q.-side: 120 kV/23,3/23,3 and one wye connected A spare transformer is located at side
Frequency:	Vermont-side: 60 Hz H-Q.-side: 60 Hz

Short circuit ratio:

Vermont-side:
Short circuit capacity min: 500 MVA
ESCR = 1.6 to 1.8

H-Q.-side:
Short circuit capacity min: 500 MVA
ESCR = 1.6 to 1.8

185

A.C. Filters:

Vermont:

11th/13th	harmonics:	2 x 20 MVAr
3rd/27th	harmonics:	10 MVAr
25th	harmonics:	20 MVAr

Quebec:

11th/13th	harmonics:	2 x 22 MVAr
3rd/27th	harmonics:	11 MVAr
25th	harmonics:	21 MVAr

Shunt capacitor banks:

Vermont-side:	1 x 10 MVAr
	3 x 20 MVAr
H-Q.-side:	1 x 11 MVAr
	3 x 22 MVAr

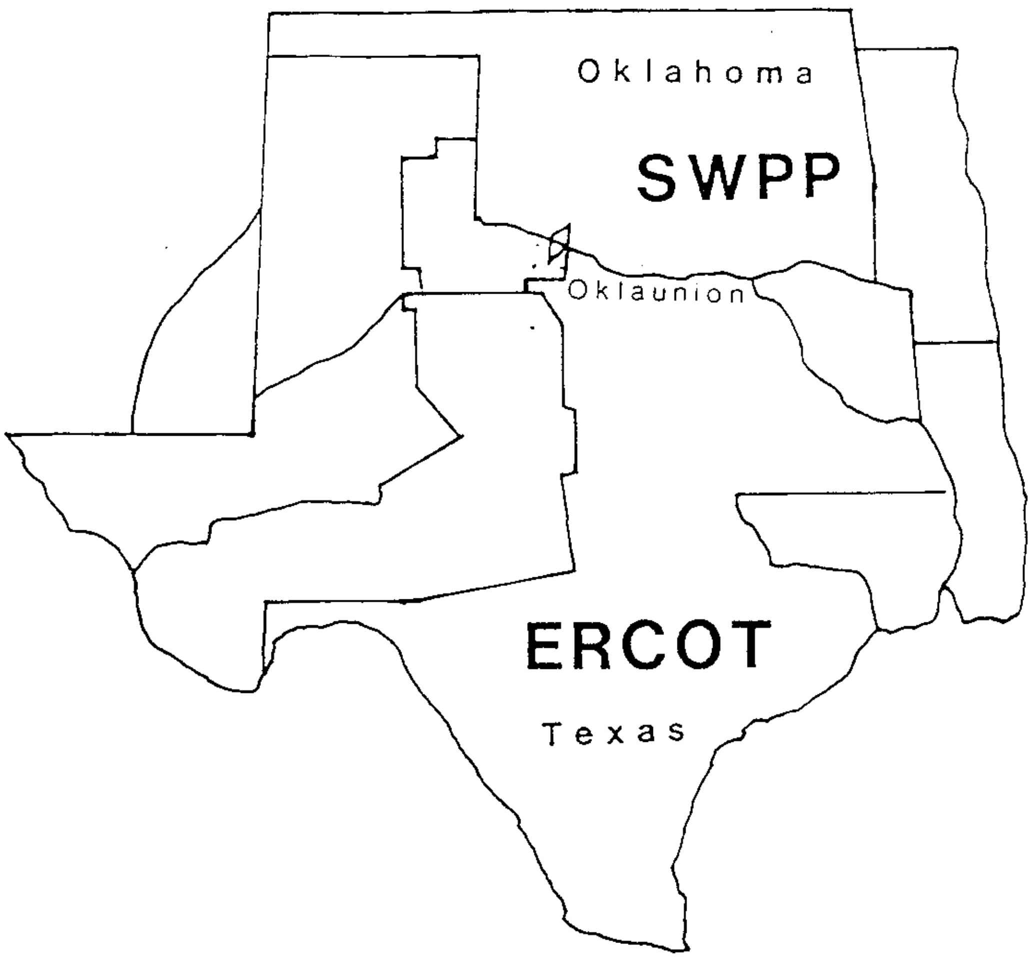
HVDC valves: Thyristor valves arranged in double quadruple configuration i.e. each hanging valve structure contains eight thyristor valves.

Reference:

ASEA Pamphlet A02-0010 E-NL

Layout of Highgate HVDC Converter Station by G. Stensrud, I. Vancers

IEEE Power Engineering Society
10th Conference and Exposition on Overhead and Underground Transmission and Distribution, Sept. 14-19th, 1986

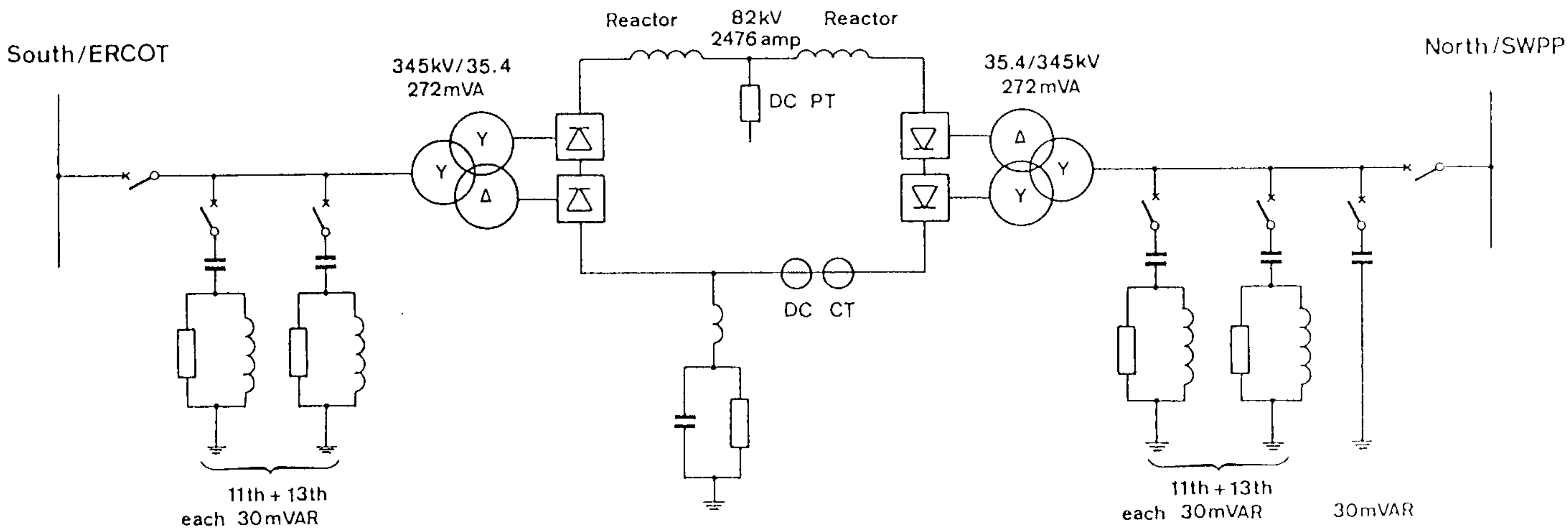


The Oklaunion HVDC System

Geographic map

188

The Oklaunion HVDC System
Simplified single line diagram



The Oklaunion HVDC Converter Station

Between:	The ac systems of (Public Service Company of Oklahoma: PSO) and (West Texas Utilities Company: WTU) 17 miles south of the Red River which divides Oklahoma and Texas.
Power Co:	Operated and maintained by WTU
Manufacturer:	General Electric Company
Commissioned:	December 14, 1984
Main purpose:	A back to back unit which connects the Southwest power pool (SWPP) to the Electric Reliability Council Commission of Texas (ERCOT). Converter enables sister companies, each of which are in different asynchronous power pools, to exchange energy through economic dispatch.
Main data:	One pole 200 MW Overload capacity 1.1 pu (continuously) 1.25 pu (1 hour)
A.C. networks:	North Side (PSO) Two major lines into (SWPP) Voltage 345 KV Transformer One 3 phase 345/35.4 ± KV 17 taps South Side (WTU) Two major lines and power plant into (ERCOT) Voltage 345 KV Transformers One 3 phase 345/35.4 ± KV 17 taps
HVDC System:	Rated Power 200 MW Overload 220 MW (cont.) 250 MW (1 hour) Direct Voltage 82 KV Direct Current 2476 A 12 pulse bridge
HVDC Valves:	Each of the 12 valves on the North (SWPP) and the South (ERCOT) are contained in the valve hall. Two 77 mm SCRs in parallel make up a voltage level. There are eight series voltage

levels per 1000 Lb module. Three modules connected in series or 24 voltage levels comprise a valve. The valve hall contains a total of 1152 air cooled SCRs.

A.C. filters:

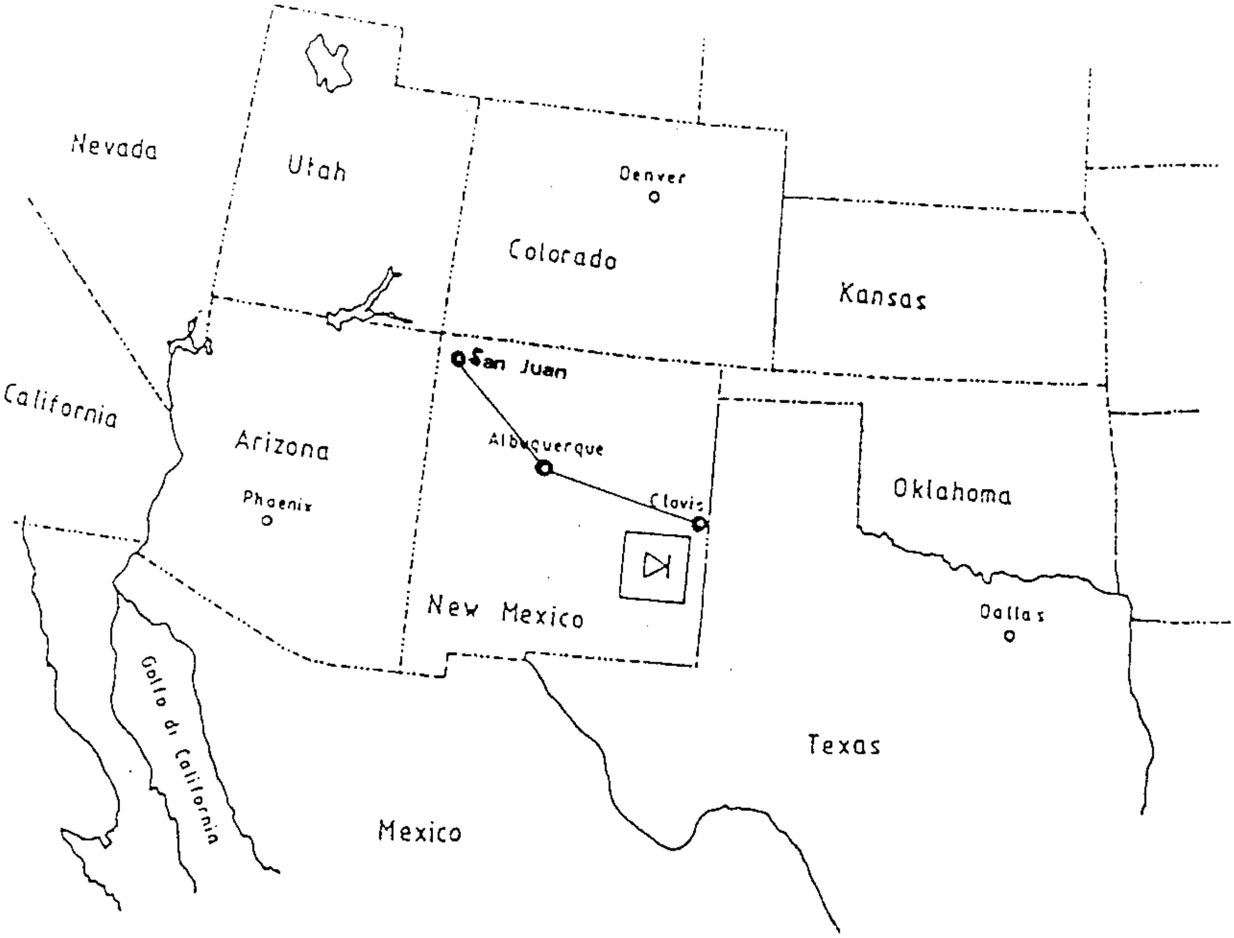
North Side (PSO)
(2) 30 MVAR 11th + 13th high pass filters
(1) 30 MVAR shunt bank

South Side (WTU)
(2) 30 MVAR 11th + 13th high pass filters
(1) 30 MVAR HVDC controlled reactor in South AC switch yard.

References:

Texas HVDC Interconnections by E. Kolodziej, N.G. Hingorani
IEEE/PES Ninth Conference and Exposition on Overhead and Underground Transmission and Distribution; April 29 - May 4, 1984

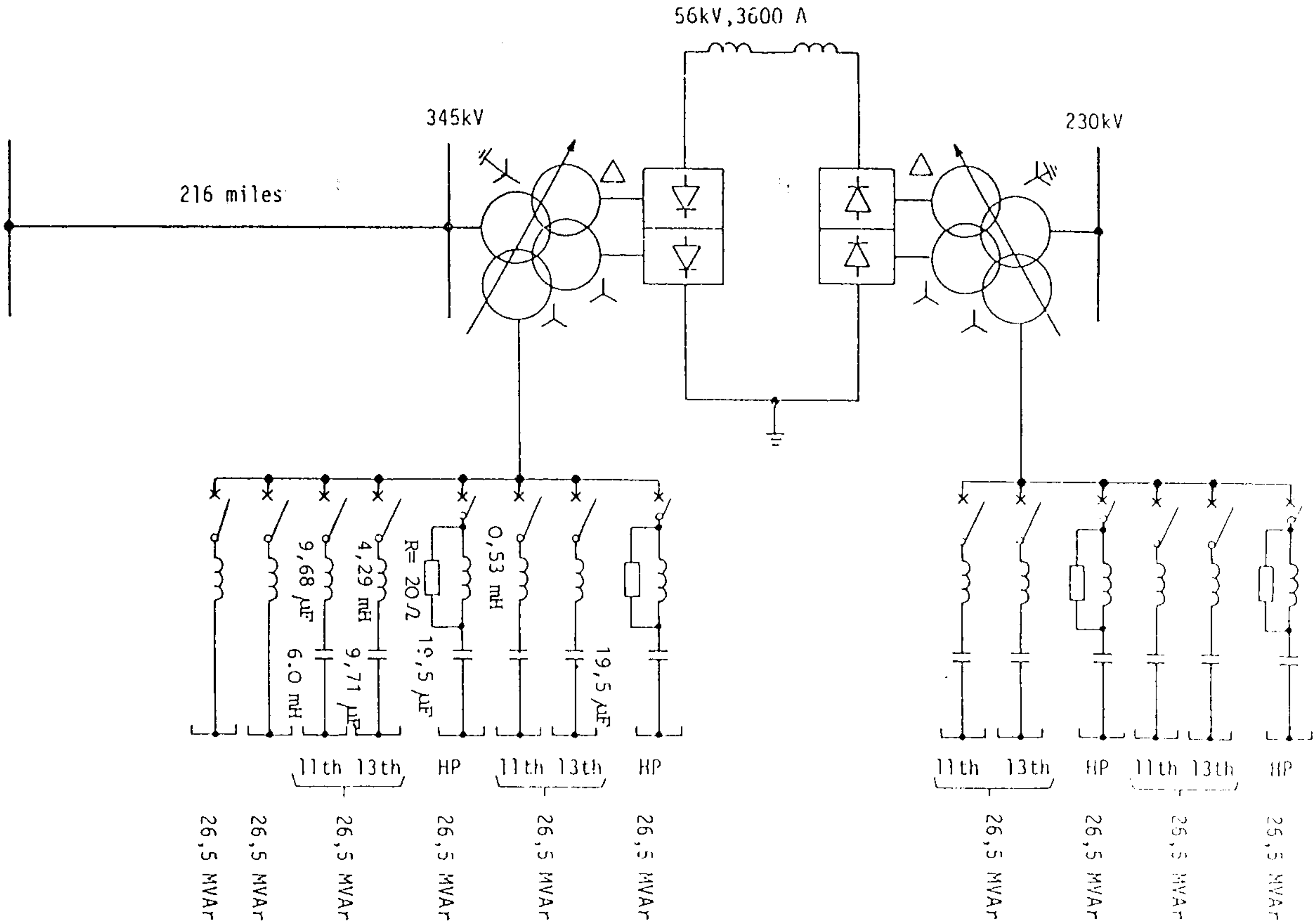
Layout Consideration for the Oklaunion HVDC Tie by E. Kolodziej, N.G. Hingorani
IEEE Power Engineering Society, Tenth Conference and Exposition on Overhead and Underground Transmission and Distribution, September 14-19, 1986



THE BLACKWATER HVDC SYSTEM

Geographic map

A92



BLACKWATER HVDC SYSTEM

Simplified single line diagram

The Blackwater HVDC Converter Station

Between:	The ac system of New Mexico (Public Service Company of New Mexico; PNM and Texas South-western Public Service Company, SPS) near Clovis/New Mexico
Power Co.:	Public Service Company of New Mexico (PNM)
Manufacturer:	BBC Brown Boveri
Commissioned:	January 1, 1985
Main purpose:	The converter Station is designed as a back-to-back HVDC interconnection between the two asynchronuous systems of New Mexico and Texas for power transfer in either direction. The main power direction is from New Mexico to Texas.
Main Data:	One pole, 200 MW, 3600 A d.c. Overload capacity (continuously): 1.10 p.u. maximal allowed
A.C. Networks:	The HVDC converter structure is connected to PNM's electrical system by a single 345 kV transmission line (216 miles) out of a switching station located close to Albuquerque. This substation is fed from San Juan Generating Station. On the other side the station is connected through a 230 kV tie to the SPS system.

At both sides single phase converter transformer units are used, each unit with two secondary windings connected to the converter valves and a tertiary winding for connecting the a.c. filters and shunt reactors.
PNM side : 81.3 MVA, 345 +/- 7% /24/24/60 kV
SPS side : 73 MVA, 230 +/- 7% /24/24/60 kV

Identical a.c. filter circuits are installed on both sides of the interconnection:

- 2 tuned filters (11th harmonics)
- 2 tuned filters (13th harmonics)
- 2 high pass filters

Two shunt reactors are provided on the PNM side. Required ac voltage/reactive power control transiently as well as in the steady state is performed by utilizing the VAr-capability of the HVDC converters and by switching of filter circuits and shunt reactors.

193

HVDC System: Due to the station design (back-to-back) there is no d.c.transmission line.
The smoothing reactors (spare unit connected in the d.c. circuit) of 0.02 H each are located on the high voltage side.

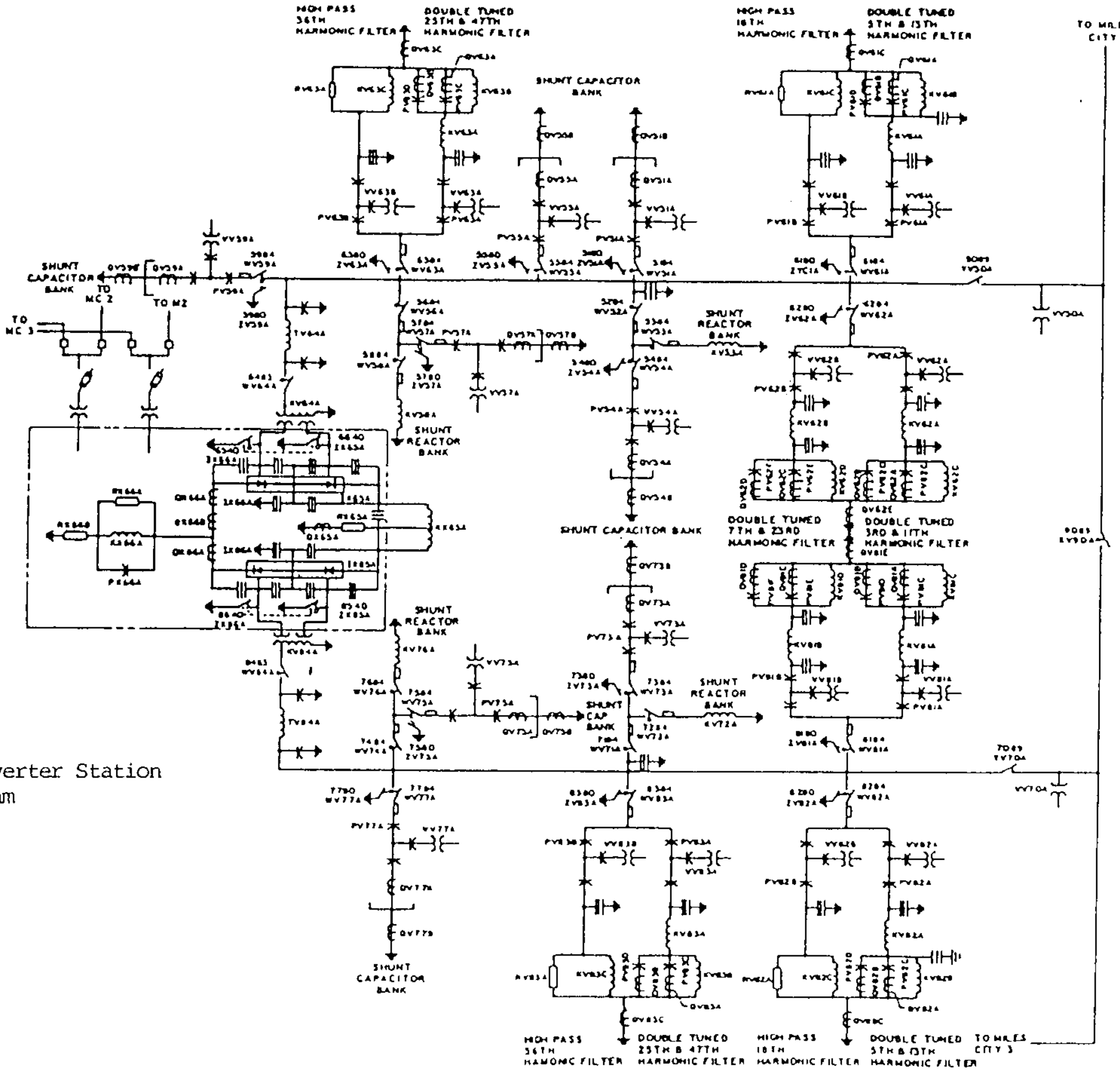
d.c. filters:
No d.c. filters are installed

HVDC valves: Each converter group (rectifier, inverter) consists of two six pulse units connected in series.
The groups are made up of twelve single thyristor valves each. Each valve consists of 19 series connected thyristor levels.
The valves are air insulated and water cooled.

References: The design and construction of a back-to-back HVDC converter station by Gene Wolf
IEEE Power Engineering Society, 10th Conference and Exposition on Overhead and Underground Transmission and Distribution; Sept.14-19, 1986

MILES CITY CONVERTER STATION (MCCS)

Geographic map



Miles City Converter Station
One line diagram

The Miles City Converter Station (MCCS)

Between:	Asynchronous tie connection between east and west United-States-Canadian AC transmission networks
Power Co:	Western Area Power administration
Manufacturer:	General Electric Company USA
Comissioned:	June 1985
Main purpose:	The main purpose of the station is to restore power transfer capability across the Federal system and provide a path of transfer from energy from less expensive generation on one side to the loads of the other side of the east/west boundary.

Main data for the HVDC plant:

Rated Power (MW)	200
Voltage (kVDC)	82
Current (amperes)	
minimum	248
maximum	3 095
normal	2 476

Main data of the ac networks:

	East	West
Bus voltage nominal	230 kV	230 kV
Frequency (asynchronous)	60 Hz	60 Hz

Converter transformers:

The MCCS converter transformers are three-phase three winding units with the secondary delta and wye windings internally connected. A spare three-phase converter transformer unit is readily available to replace either of the on-line units if necessary.

Rating (MVA)	
primary	239
delta	119,5
wye	119,5

Voltage (kV)	
primary	230
delta	34.13
wye	34.13

Load tap changer
range .... +12.5% to -5.7%
steps 32

Reactive compensation

The shunt capacitors for the MCCS are arranged in 15- and 8-MVAR banks and switched by interrupter switches with preinsertion resistors. Four 15- and one 8-MVAR shunt capacitor banks are utilized on the east 230-kV bus, and two 15- and one 8-MVAR shunt capacitor banks ara located on the west 230-kV bus. The shunt capacitor banks are equipped with grounding switches. fault detection, and three-stage cpacitor failure detection system.

The ac harmonic filters provide 75-MVAR of the reactive requirements on each side of the station.

Short circuit ratio:

The weak ac system at Miles City (550-MVA eastside and 450-MVA westside) required the use of special equipment and control features to meet all operating requirements for east-to-west and west-to-east power transfer.

$$SCR = \frac{550}{200} = 2,75 \quad \text{for side east}$$

$$SCR = \frac{450}{200} = 225 \quad \text{for side west}$$

AC Harmonic Filters

The ac harmonic filters for the MCCS are comprised of four double-tuned and two high-pass filters on each of the east and west side 230-kV systems. The filters for each side are identical and tuned to approximately the 3rd and 11th, 5th and 13th, 7th and 23rd, 25th and 47th, high-pass 18th and high-pass 36th ac harmonics with a 60-Hertz (Hz) total reactive rating of 75 MVAR leading (capactive) on each side.

AC HARMONIC FILTER
CHARACTERISTICS

DESIGNATION	VALUE		HARMONIC	60 HZ MVAR
PV62A, PV81A	0.841	uF	3/11	17
KV62A, KV81A	73.2	mH		
PV62C, PV81C	4.235	uF		
PV62D, PV81D	4.235	uF		
KV62C, KV81C	83.8	mH		

198

PV62B, PV81B	0.408	µF	7/23	8
KV62B, KV81B	42.7	mH		
PV62E, PV81E	0.623	µF		
PV62F, PV81F	0.623	µF		
KV62D, KV81D	83.8	mH		
PV61A, PV82A	0.789	µF	5/13	16
KV61A, KV82A	59.6	mH		
PV61C, PV82C	2.662	µF		
PV61D, PV82D	2.662	µF		
KV61B, KV82B	42.7	mH		
PV61B, PV82B	0.469	µF	HP18	9
KV61C, KV82C	55.1	mH		
RV61A, RV82A	738	ohms		
PV63A, PV83A	0.590	µF	25/47	12
KV63A, KV83A	8.10	mH		
PV63C, PV83C	0.866	µF		
PV63D, PV83D	0.866	µF		
KV63B, KV83B	4.06	mH		
PV63B, PV83B	0.631	µF	HP36	13
KV63C, KV83C	8.10	mH		
RV63A, RV83A	738	ohms		

Thyristor valves, cooling system:

The MCCS utilizes a 12-pulse rectifier and inverter arrangement of indoor multiple valve units (MVU) with air insulation and cooling. The MVU assemblies and dc instrumentation are arranged in the building valve hall. The valves are cooled by a forced air primary cooling loop which transfers heat from the valve assamblies to a secondary cooling loop employing a water-glycol solution. The secondary loop transfers heat to the atmosphere via outdoor evaporative coolers.

Smoothing reactor:

The MCCS smoothing reactor is an iron core oilinsulated design located in the high-voltage dc connection between the rectifier and inverter. The outdoor smoothing reactor is located adjacent to the side of the valve hall and has dry-type bushings extending into the building. A spare smoothing reactor is stored at the converter station site and is readily available if necessary.
Inductance L = 74 mH

REFERENCES

(1) T.L. Weaver, L.M. Greiner, and R.K. Johnson, "Miles City DC Tie-Purpose and Need," IEEE 85 TH0122-2 PWR.

(2) T.L. Weaver, L.M. Greiner, and R.K.Johnson, "Observations on Low Short Circuit Capacity Stations - Miles City and Sidney," presented at IEEE Winter Power Conference, February 1985.

(3) R.D. Doherty, R.K. Johnson, S.F. Schweitzer, and T.L.Weaver, "Miles City Converter Station-Early Operating Experience," CIGRE paper, 14-03, 1986.

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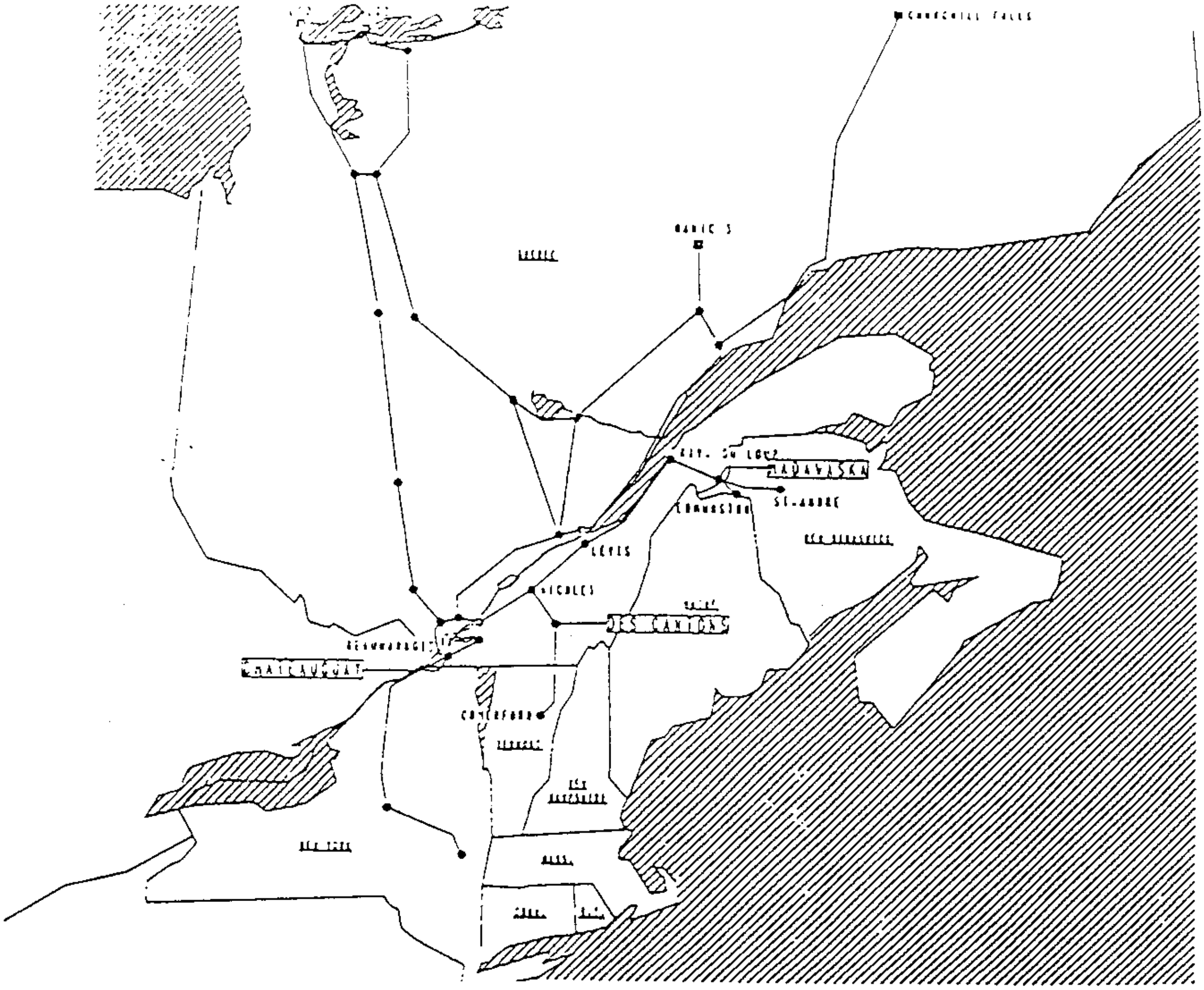
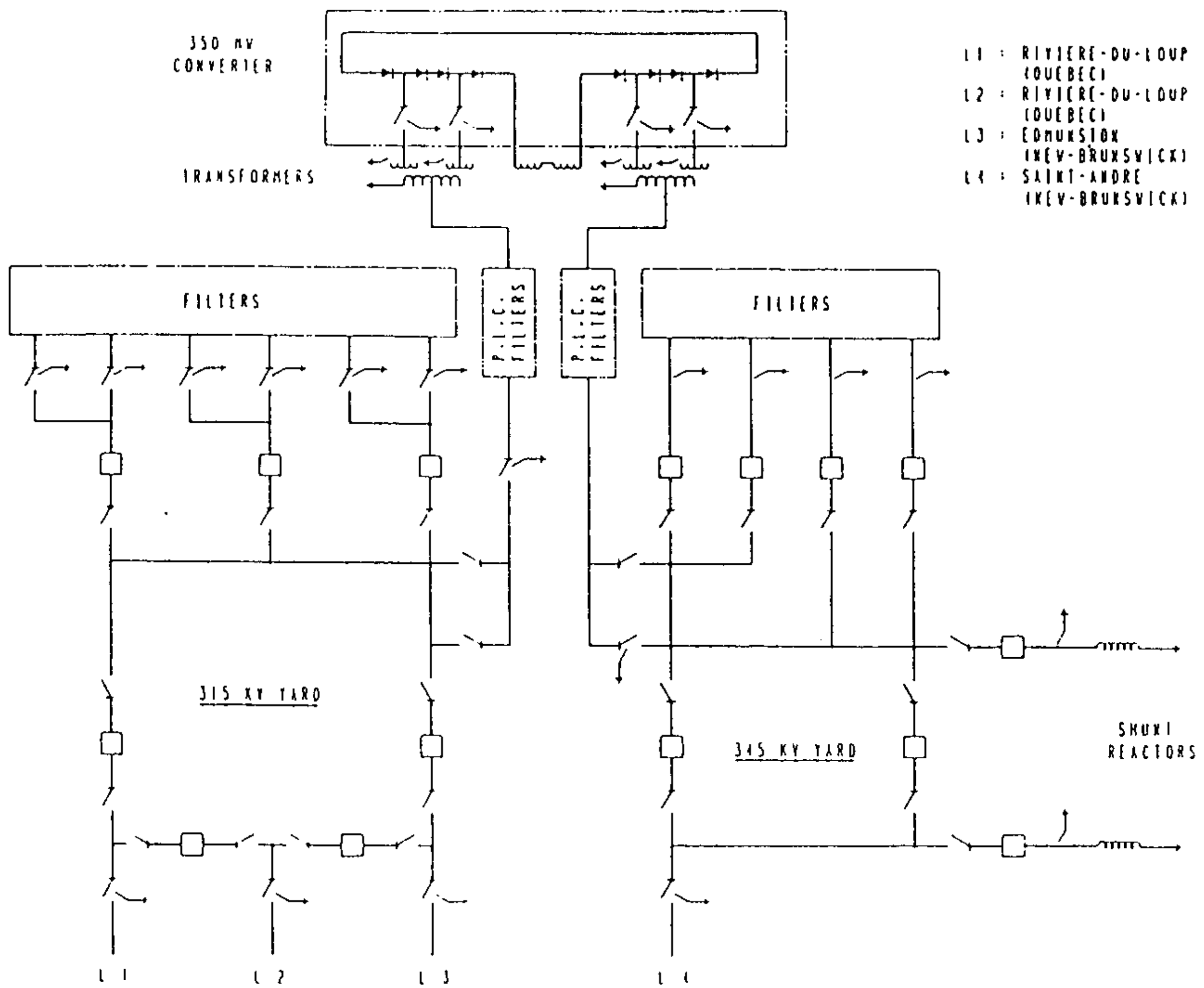


MADAWASKA CONVERTER STATION (SCS)

Geographic map

201



MADAWASKA CONVERTER STATION

Switching diagram

Madawaska

Between:	Network of Hydro Quebec and New Brunswick
Power Co:	Hydro-Quebec
Manufacturer:	Canadian General Electric Company
Comissioned:	1985
Main purpose:	Supply of local load located in New Brunswick
Main data for the HVDC plant:	Rated Power .... 350 MW 40° C Overload .... 435 MW -10° C Current dc (rated) .... 2700 A DC-Voltage .... 130,5 kV

AC Networks:

Transformers: single phase, 3 windings
6 x 134,2 MVA
wye/wye - delta

Voltage: 315/55/55 (HQ side)
345/55/55 (NB side)

On load tap changer: ± 6 %

Short circuit ratio:

About 3 at an overload capacity of 120 %
Short-circuit level .... 31,5 hA

Harmonic Filters

315 kV side (212,1 Mvar)

Harmonic number:	12	24
Rating	3 x 40,6	3 x 30,1

345 kV side (221,8 Mvar)

Harmonic number:	12	24
Rating	2 x 55,6	2 x 55,3

Shunt Reactors:

2 three-phase-55 Mvar 345 kV units

HVDC-System:

HVDC Valves: Number: 6 quadruple
Modules/value: 6
Thyristors/module: 16
Number of thyristors: 2304

203

Cooling system:

primary: air
secondary: water, glycol

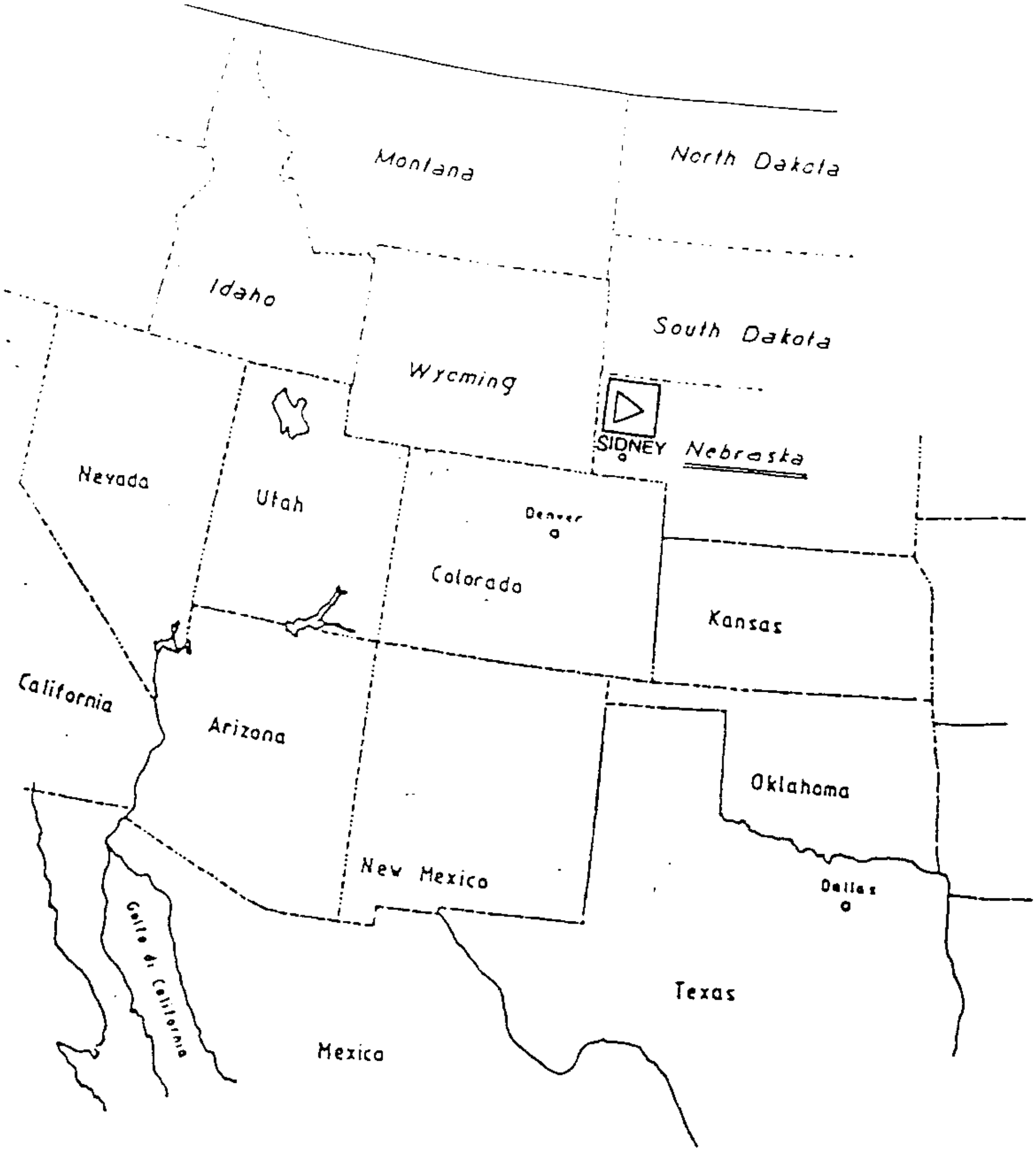
Smoothing reactor:

2 x 50 mH
2500 A
Oil filled

REFERENCES

Aspects regarding the layout of Chateauguay, Madawaska and Des Cantons HVDC converter stations by Claude Durand, Jacques Allaire

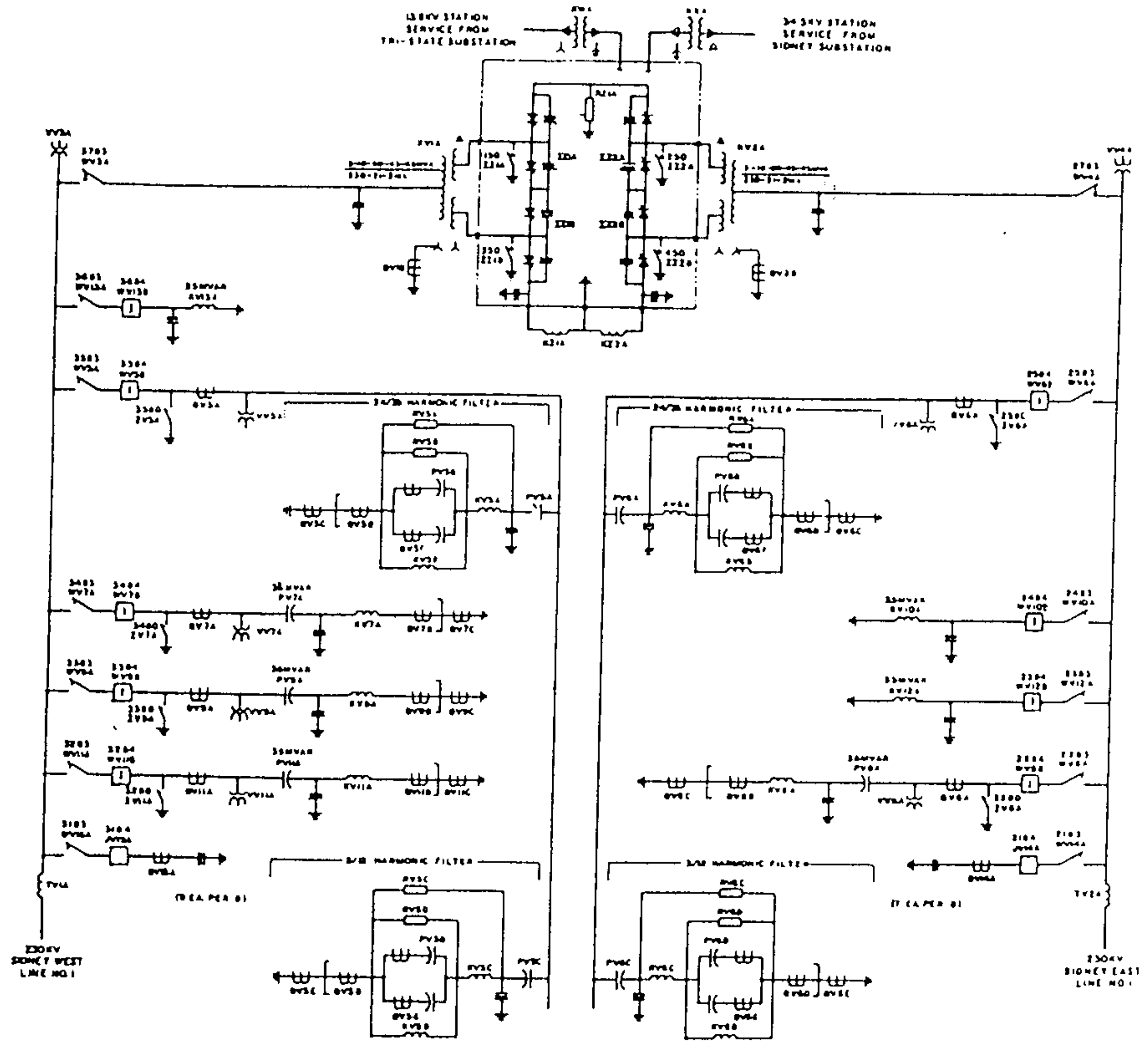
IEEE, 10th conference and exposition on overhead and underground transmission and distribution, 1986



SIDNEY CONVERTER STATION (SCS)

Geographic map

205



S I D N E Y   C O N V E R T E R   S T A T I O N   (SCS)

Switching diagram

The Sidney Converter Station (SCS)

Between:	The back-to-back Sidney Converter Station (SCS) is installed at Sidney, Nebraska, between the eastern and western United States power grids.
Power Co:	Western Area Power Administration
Manufacturer:	SIEMENS
Commissioned:	
Main purpose:	Energy transfer in the either east west or west east direction between the two large power grids, which are operated asynchronously.

Main data for the HVDC plant:

Rated Power (MW)	200 MW
Voltage	50 kVDC
Current	
minimum	414 A
nominal	4 140 A
maximum	6 000 A
Valve Arrangement	12 pulse

Main data of the AC networks:

	East	West
Bus voltage	230 kV	230 kV
Frequency	60 Hz	60 Hz

Transformers:

Single-phase three winding units, externally connected delta and wye

Rating (MVA)

primary	90
delta secondary	45
wye secondary	45

Voltage (kV)

primary	230
secondary	21

On load tap changer
range .... +28% to -17%
steps 35

Reserve: One spare single phase converters transformer

Short circuit ratio:

	East	SCR	West	SCR
Short-Circuit Capacity (MVA)				
minimum	700	3,5	450	2,25
maximum	2200	11	1075	5,38

AC - Filters

Two double-tuned filters on each side
Reactive supply rating (capacitive) 105 MVAR

AC HARMONIC FILTER CHARACTERISTICS

DESIGNATION	VALUE	HARMONIC	60 HZ MVAR
PV5A, PV6A	2.23 uF	24/35	44
KV5A, KV6A	4.16 mH		
PV5A, RV6A	315 ohms		
PV5B, PV6B	14.17 uF		
KV5B, KV6B	0.54 mH		
RV5B, RV6B	65 ohms		
PV5C, PV6C	2.97 uF	3/12	61
KV5C, KV6C	17.03 mH		
PV5C, RV6C	680 ohms		
PV5D, PV6D	74.10 uF		
KV5D, KV6D	10.11 mH		
RV5D, RV6D	50 ohms		

Reactive Compensation

Reactive compensation is provided by shunt capacitors switched to the 230 kV bus and shunt reactors.

	West	East
shunt capacitor:	3 x 35 MVAR	1 x 35 MVAR
shunt reactors: (three phase units)	1 x 35 MVAR	2 x 35 MVAR

208

HVDC Valves:

12 pulse rectifier and inverter arrangement of indoor multiple valve units (MVU) with air insulation

MVU: Number of valves 6

Thyristors valve: Thyristors per valve: 20
Redundancy level: 1

Cooling System:

The valve cooling system incorporates a deionized water cooling loop and heat exchangers where heat is transferred to an outdoor cooling network using water glycol mixture and evaporative cooling towers.

Smoothing reactor:

Dry type air core design; 2x15 mH sections vertically stacked

Spare:	one smoothing reactor
Inductance:	30 mH
Type core:	air
insulation:	air

REFERENCES

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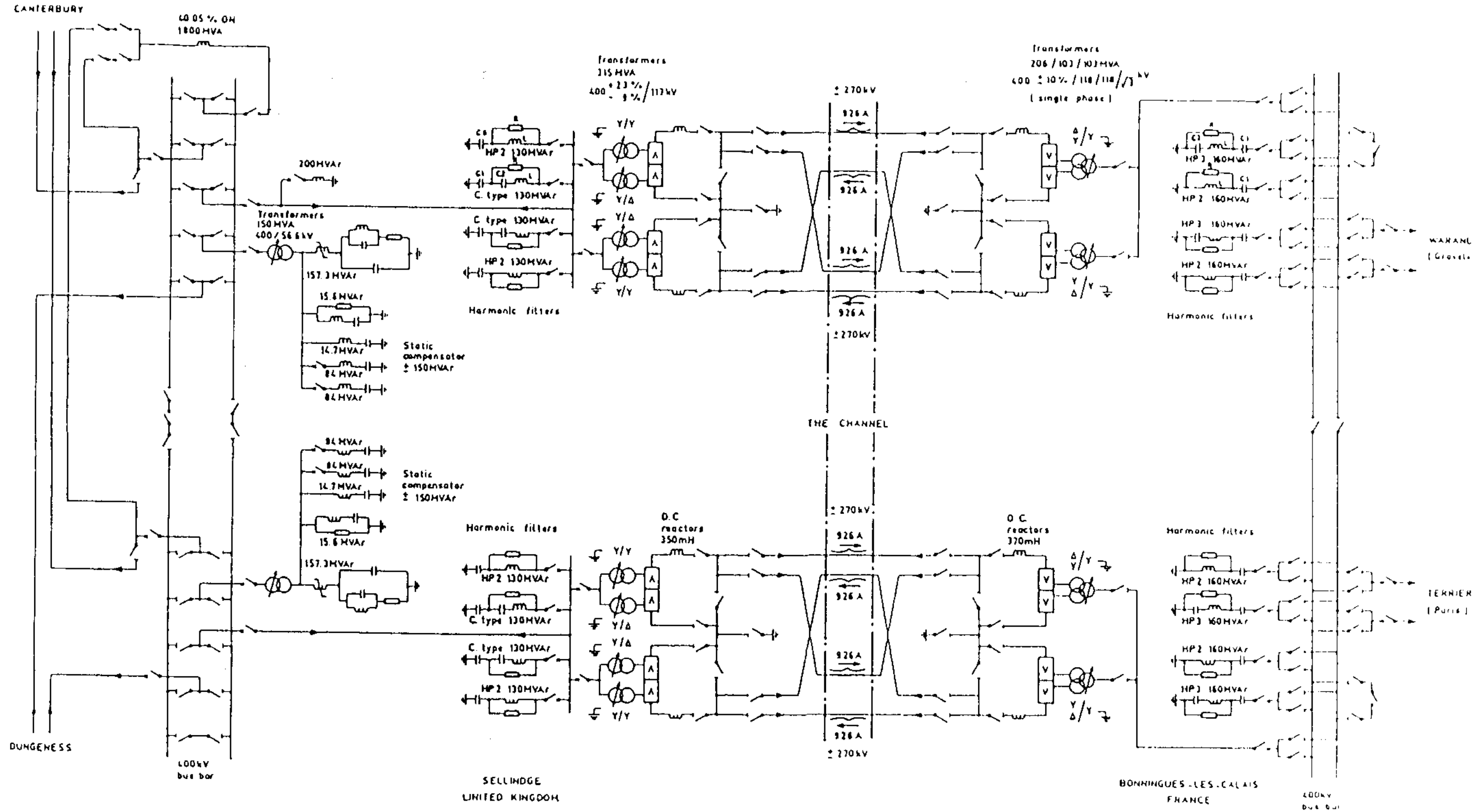
CROSS CHANNEL 2 HVDC SCHEME



CROSS CHANNEL 2

Simplified single line diagram

2000 MW CROSS CHANNEL LINK (2)

Between: SELLINDGE (Kent) - UNITED KINGDOM and BONNINGUES LES CALAIS - FRANCE (name of the substation: Les Mandarins).

Manufacturers:

SELLINDGE

Main plant and 400 kV substation -GEC

Converter Transformers, 400 kV filter disconnectors and DC disconnectors - NEI

DC Reactors - Hawker Siddeley

LES MANDARINS

CGEE-ALSTHOM and ALSTHOM-ATLANTIQUE as main contractors (FRANCE).

Commissioned: First stage: 500 MW March 1985
First bipole: 1000 MW September 1986
Second bipole: 1000 MW October 1986

Main purpose: Energy trading between the CEGB and EDF systems by exploitation of the different daily load curves and generating plant mix (different percentages of a nuclear plant, very little hydro generation in the CEGB)

Main data: Two bipoles, 1000 MW each at $\pm$ 270 kV and 1852 A per pole. When one converter pole is unavailable, cable return is possible. Overload capacity: none.

A.C. Networks:

SELLINDGE

The converter station is connected into the 400 kV double circuit line between Canterbury and Dungeness by means of a fifteen switch, double busbar, 400 kV sulphur hexaflouride insulated substation. Two three-phase transformers per pole feed a twelve pulse bridge.

One transformer is YNy0 and the other is YNd11, both being rated at 315 MVA, 400 + 23%-9% / 117 kV. A spare transformer of each type is available on site.
The minimum short circuit capacity which would normally be expected is 4800 MVA.

LES MANDARINS

Three single phase transformers per pole with two secondary windings feed a twelve pulse bridge. The rating of the transformers are:

206/103/103 MVA 400 $\pm$ 10 %/118/118/ 3 kV

The winding of the 400 kV side is star connected whilst the windings on the valve side are either star connected or delta connected depending on their position. One spare transformer is held on site. The minimum short circuit capacity normally expected is 3800 MVA.

HVDC System: Mean route length: 70 km.
Land cables Total length 25 km (18,5 km in England, 6.35 in France).
Both French and English land cables, of which there are eight, are of the oil filled impregnated paper type. In France the cables of the two bipoles are installed in two different trenches. A single copper conductor type is used on Bipole 1 with a conventional stranded wire conductor with central oil channel for Bipole 2. The copper cross section in both cases is 900 m^2.
In England the cables of each bipole are of different manufacture and are laid in separate routes, both being of 800^2 m copper cross section.
Submarine cables (length 46 km)
The cables of the mass impregnated paper type (solid type) and are laid in pairs along four separate routes spaced about 1 km apart. The cables are embedded for their total length in a 1.5 m deep trench. The copper cross section for both English and French cables is 900^2 m.

D.C. filters: No special D.C. filters are used.

HVDC valves: Air cooled and insulated thyristor valves are used in both terminals.

SELLINDGE

Each pole comprises a twelve pulse converter of three quadrivalves (a vertical stack of four valves), in separate valve halls. Each valve is made up of 125 modules, with two thyristors in parallel, all connected in series.

The rating is 270 kV at 1903 Amperes. There is one d.c. reactor of 350 mH per pole rated at ± 270 kV and 1903 Amperes.

LES MANDARINS

Each pole consists of a twelve pulse converter unit. The twelve valves of a pole are housed in three indoor valve structures. Each valve is composed of twelve modules in series connection. Each module has eight thyristors levels in series and each level has two thyristors in parallel connection in order to reduce the losses.
The converter unit is rated for 270 kV and 1852 A. One d.c. reactor is connected at the high voltage side of the converter. It is rated for 270 kV d.c. and 370 mH at 1852 A.

A.C.Filters: SELLINDGE

The filters are connected at 400 kV and individually switched by sulphur hexaflouride insulated current breaker designed for outdoor use. The total installation is 1040 MVAR divided between eight filters of 130 MVAR each. Each bipole set of four filters consists of two "C" type which are tunded to approximately the third harmonic, and two second order damped, tuned to approximately the eleventh harmonic.

	C_1	C_2	CD	L	R
C	2.6 μF	24 μF		424mH	666 Ω
2nd order			2.6 μF	35.4mH	214 Ω

215

LES MANDARINS

Total installed; 1280 MVAR divided in eight filters of 160 MVAR each. All filters are of the high-pass damped type. One half is designed for harmonics 11. and 13. (2nd order filter) and the other for low-order harmonics (3rd order filter).

	C_1	C_2	L	R
HP2	3.18 μF	none	27.8 mH	234 Ω
HP3	3.25 μF	9.55 μF	74.3 mH	35 Ω

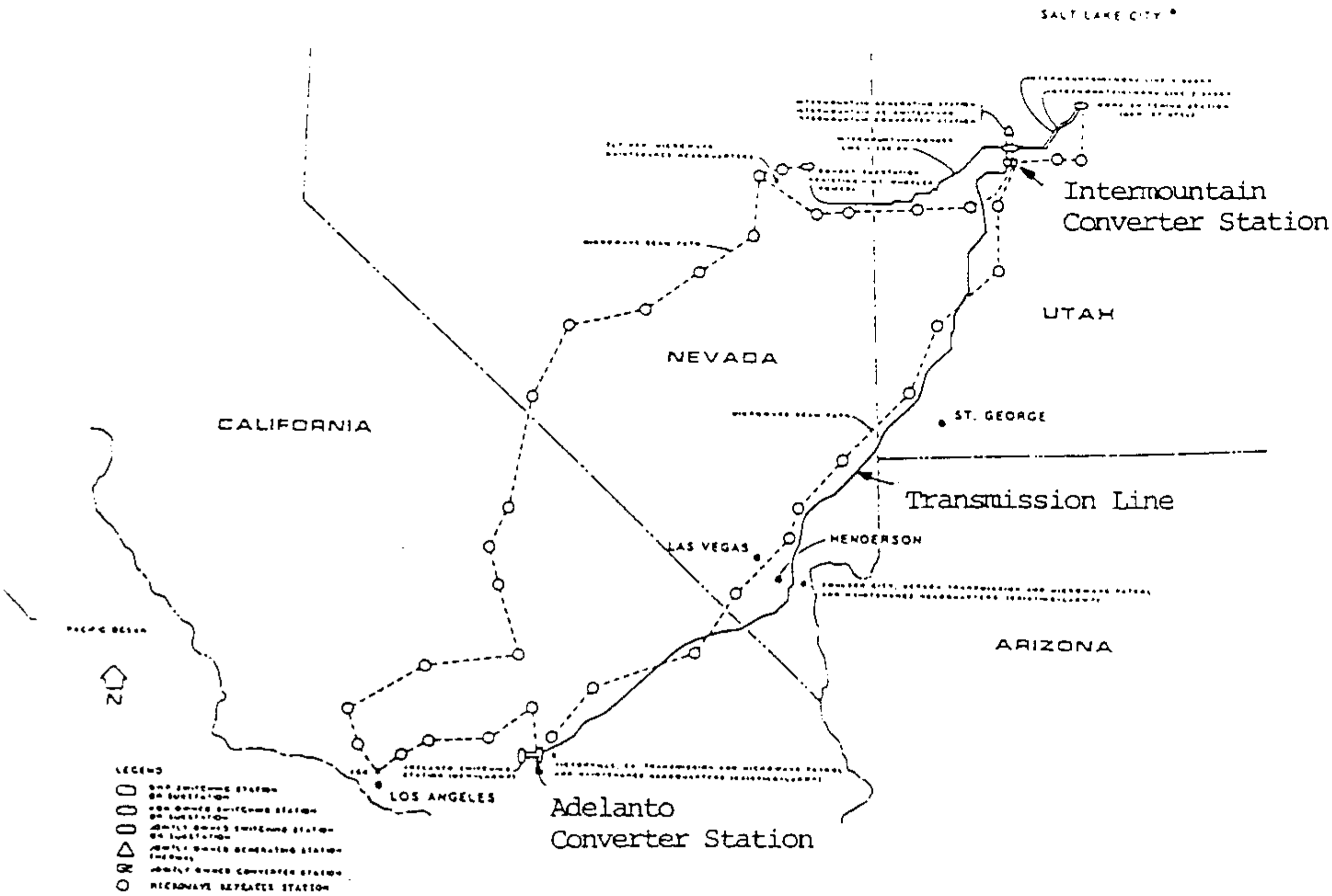
Static Compensators:

Three high speed static compensators of the saturated reactor type are installed on the English side; two at Sellindge and one at Ninfield-Substation.

Each compensator consists of a 157.3 MVAR saturated reactor connected at 56.6 kV via 400/56.6 kV, 150 MVA, 5.83 % reactance step down transformer, in series with a 451 F capacitor.

In parallel with the saturated reactor are three types of filters: an 84 MVAR switched filter (detuned, 3rd harmonic), 14.7 MVAR unswitched filter (detuned 3rd harmonic) and a 15.6 MVAR unswitched filter "C" type filter (2nd harmonic).

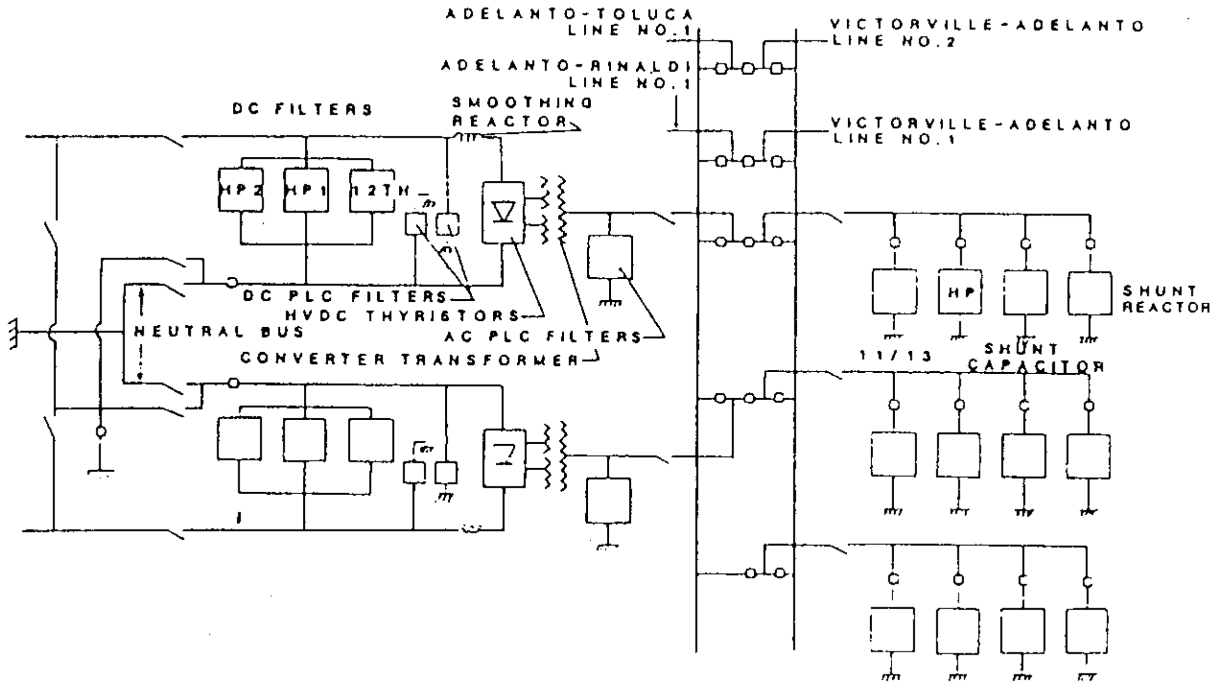
216



INTERMOUNTAIN POWER PROJECT

Geographic map

217



Adelanton Converter Station
One line diagram

The Intermountain Power Project (IPP)

<u>Between:</u> Adelanto (Los Angeles area) and Intermountain (Utah). This system serves as a link between the Intermountain Generation Station, a 1500 MW coal-burning power plant and the Southern California power system.

<u>Power Co:</u> Los Angeles Department of Water and Power

<u>Manufacturer:</u> ASEA/Sweden: primary contractor for both converter stations

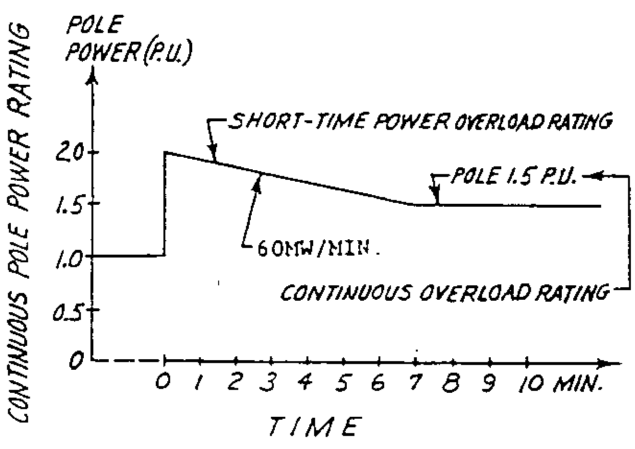
Los Angeles Department of Water and Power: transmission line and ac switching station

<u>Commissioned:</u> 27th March 1986 first stage

<u>Main purpose:</u> Transmission of power to the Los Angeles area from the Intermountain Generation Station in Delta/Utah. It is possible to transmit power in the revers direction with some limitations.

<u>Main data:</u> One bipole of two converter poles: 800 MW each, ± 500 kV dc; making the total capacity: 1600 MW

Overload capability: continuous, each pole 1200 MW
Current: 1600 A rated
Overload: 2560 A, 3680 A, short term



Pole Overload Power Capacity

AC-Network: Adelanto converter station (ACS):

Voltage 500 kV
Frequency 60 Hz

Converter transformer:
number: 6/pole; one spare
rating: 305 MVA
single phase, three winding
primary: 500/ 3 +14/-6 1,25 %
2 secondaries: 202/ 3 152,5 MVA
connected in delta and wye

AC filter and reactive power compensation:

Primary: 500 kV
fundamental reactive power of filter: 980 MVAR
fundamental reactive power of capacitor: 310MVAR

Number	Harm.	MVAR	C=uF	L=mH	R=ohm
	11	73	0,775	71,5	15570
	13	76,3	0,81	51,4	12600
3 x	26	164,3	1,74	5,97	176
	shunt cap.	104.6	1,11		
	shunt reactor	112		5920	

Short circuit ratio:
Minimum short-circuit power: 8500 MVA
Maximum short-circuit power: 35000 MVA

$$SCR = \frac{8500}{1600} = 5,3$$

Intermountain converter station:

Voltage 345 kV
Frequency 60 Hz

Converter transformer:

AC filter and reactive power compensation:
Primary: 345 kV
Fundamental reactive power of filter: 890 MVAR

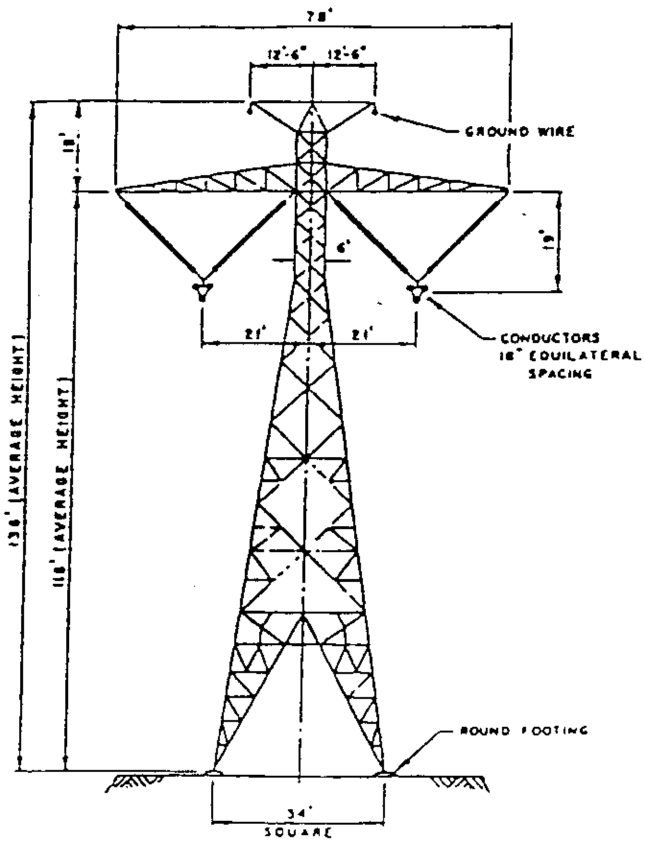
Number	Harm.	MVAR	C=uF	L=mH	R=ohm
3 x	3	58,3	1,3 + 10,7	658	1300
	11	55,2	1,23	47,3	9800
	13	57,9	1,29	32,3	6325
	24	69,6	1,55	7,99	359
	36	55,6	1,24	4,51	181
2 x	shunt reactor	84			3760

Short circuit ratio:
Minimum short-circuit power: 6500 MVA
Maximum short-circuit power: 2500 MVA

$$SCR = \frac{6500}{1600} = 4,1$$

HVDC-plant:

Transmission line
Route length: 489 miles
Overhead line: 2 groundwires



In addition to the conventional bipolar transmission configuration the system can be operated in the following special modes:

* monopolar ground return
* monopolar metallic return
* reduced pole voltage for operation with weakened dc-line insulation

Adelanto converter station:

Thyristors: 144 thyristors in series per valve
4 valves form a quadruple valve
3 quadruple valves form a 12-pulse group

Cooling system: the thyristors are water cooled

Smoothing reactor:

Rated: 0,3 H
oil insulated
1600 A dc nominal
2560 A dc (maximum continuous)
BIL of winding: 1425 kV
BIL of bushing: 1550 kV

DC filters: 2 highpass filters: 24th harmonic and above
3rd/12th harmonic filters
connected between the 500-dc-line and dc neutral bus
DC power line carrier filters are installed, too.

Electrode:

Intermountain converter station:

12

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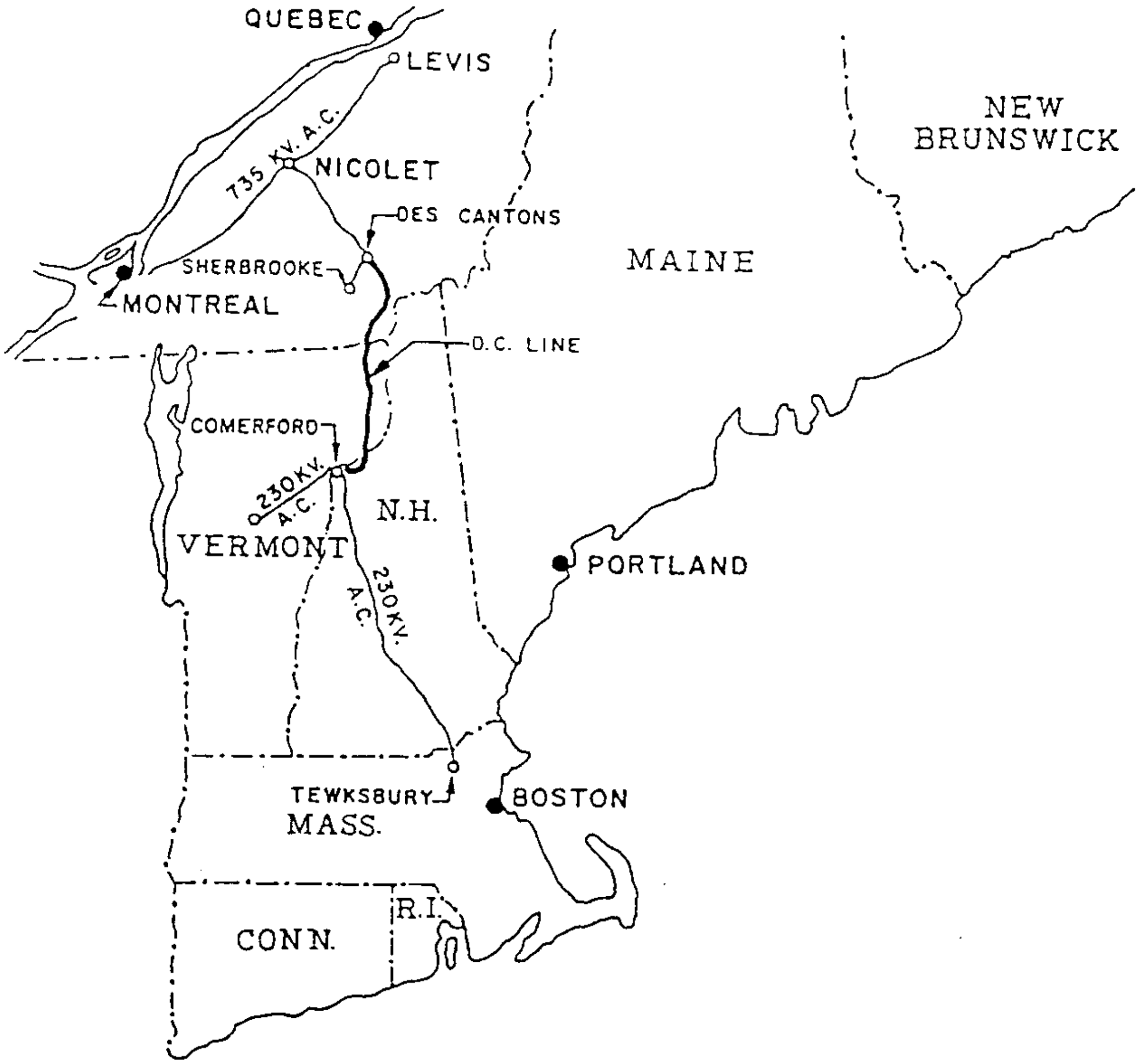
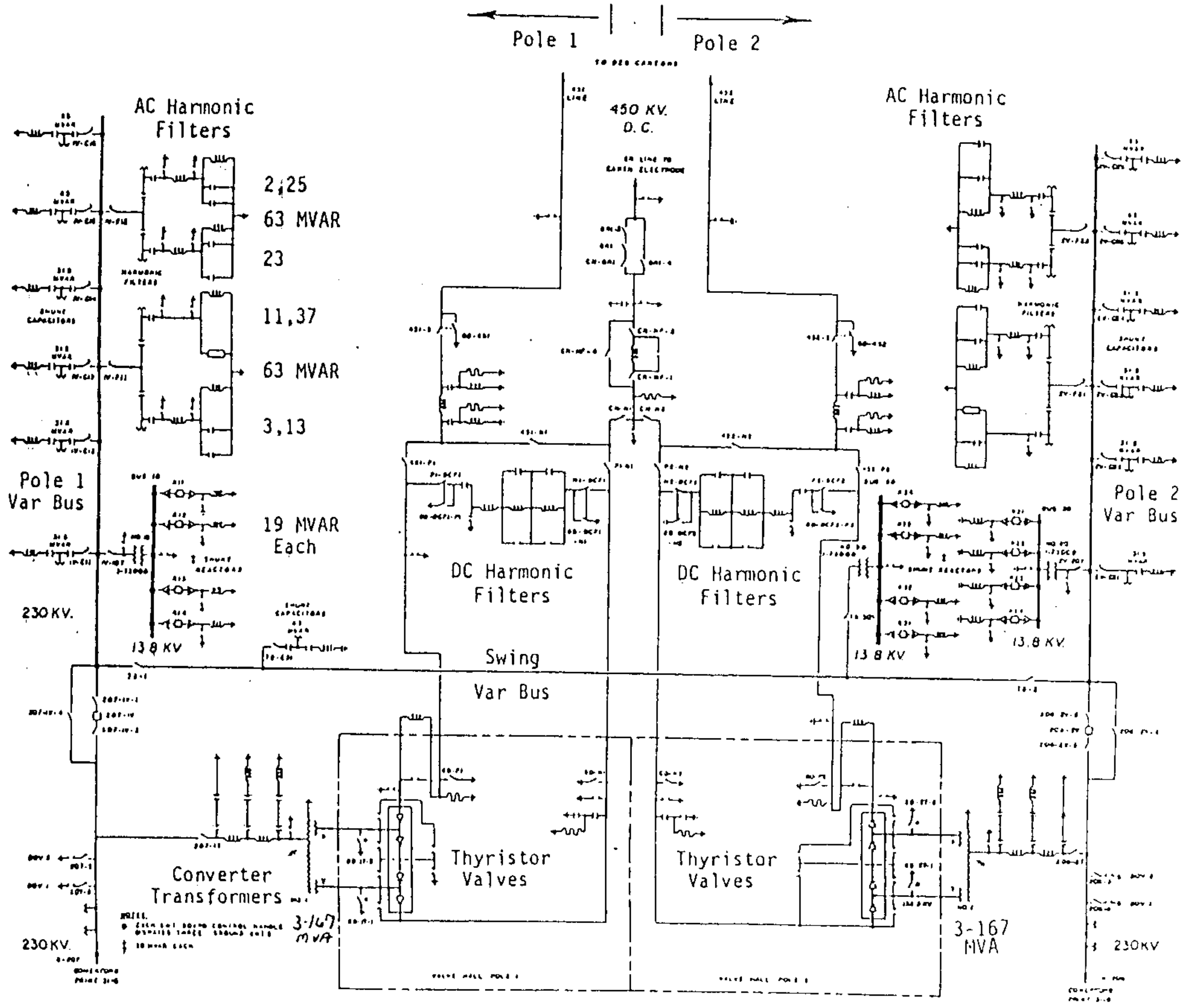
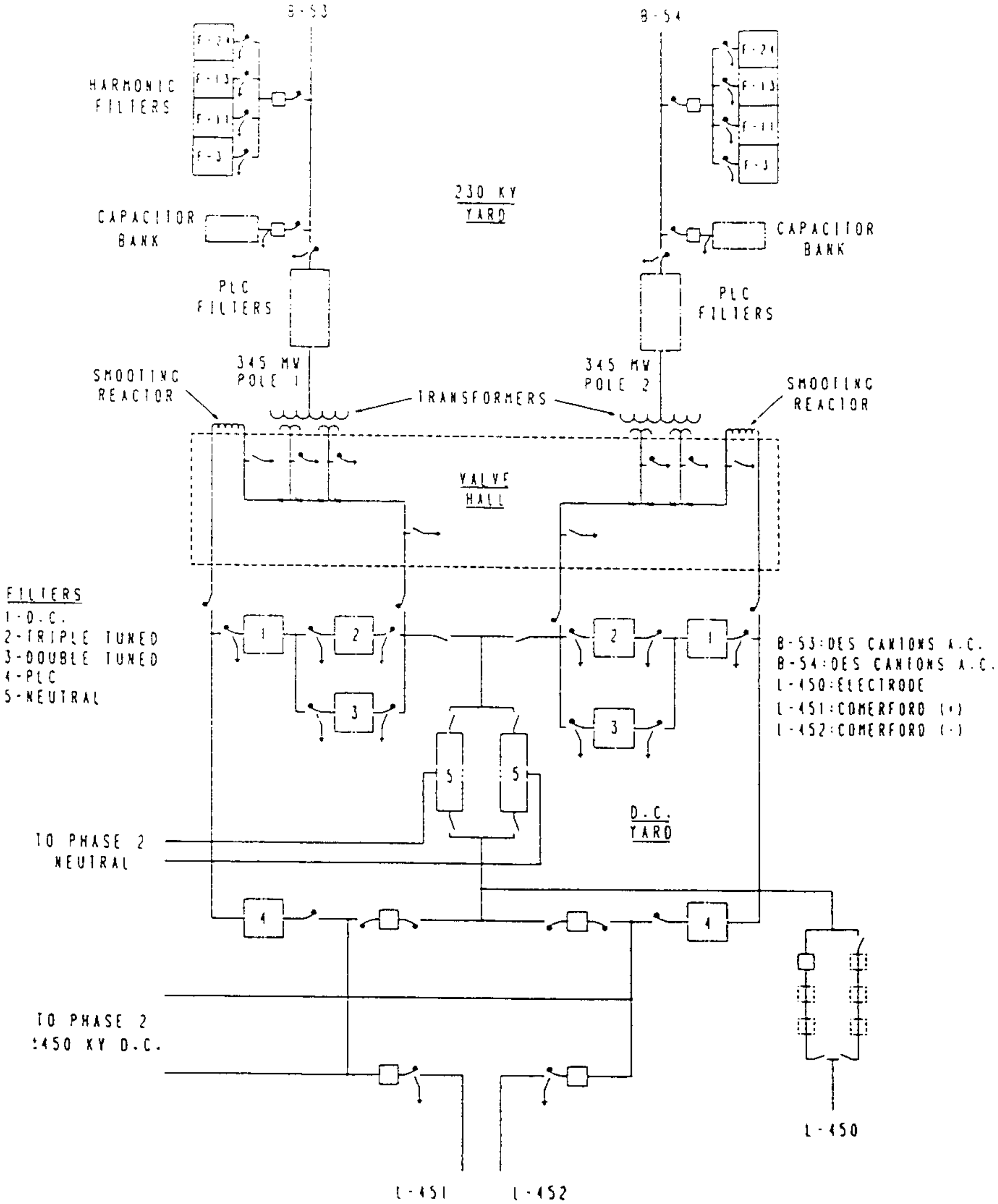


NEW ENGLAND-QUEBEC HVDC INTERCONNECTION
PHASE 1
Geographic Map

225



COMERFORD TERMINAL OF THE NEW ENGLAND TO QUEBEC HVDC INTERCONNECTION
Phase I
Simplified Single Line Diagram



One line diagram

of the Des Cantons Converter

THE
NEW ENGLAND TO QUEBEC
HVDC INTERCONNECTION SCHEME

Phase 1

Between:	Monroe, New Hampshire, USA (Comerford Terminal) and Sherbrooke, Quebec, Canada (Des Cantons Terminal)
Operated by:	US Portion: New England Electric Transmission, Concord, N.H. Canadian Portion: Hydro-Quebec, Montreal, Quebec
Manufacturer:	General Electric Company and Canadian General Electric Company
Commissioned:	August 1986
Main Purpose:	New England has contracted to purchase from Hyro-Quebec 3 million megawatt-hours of surplus hydroelectric energy per year for 11 years.
Main Data:	Bipole: o 690 MW at ±450 kV. Monopolar: o 345 MW for 15 minutes in earth return mode o 345 MW continuously in metallic return mode
AC Networks:	Comerford: Three 167 MVA single phase, three winding, converter transformers per pole. Connected to each of the two VAR busses are: 4 - 31.5 MVAR shunt-connected capacitor banks. 2 - 63 MVAR shunt-connected capacitor banks. 2 - Sets of AC harmonic filters, each rated 63 MVAR. 1 - 75 MVA auxiliary transformer providing the connection for 4 - 19.0 MVAR shunt reactors. 2 - Sets of dynamic overvoltage devices connected phase-to-

phase and phase-to-earth, consisting of multiple metallic oxide arrester columns.

The converter transformers are connected to the 230 kV New England AC system which has a short circuit ratio of 2.4 with all AC lines connected and a short circuit ratio of 1.6 with one AC line out of service.

Des Cantons:

Transformers:
6 x 328,2 MVA, single phase, 3 windings
Wye/wye - delta
Voltage: 230/180.7/180.7
On load tap changer: + 12,4 %
- 7,4 %

Harmonic filters:
Total capacity 244,6 MVAR

Harmonic number	3	11	13	24
Rating	2x13,7	2x30,2	2x29,5	2x48,9

Capacitor banks: 230 kV
Short circuit ratio: 12 with 735 kV line
3,6 without 735 kV line

Length of the overhead DC line: 172 km (total)

The 77 km d.c. transmission line from the Des Cantons terminal to the United States border has steel-lattice towers with 4 1354 kCH ACSR conductors per d.c. pole

Pole spacing: 10 m

HVDC System:

Length of the overhead DC line from Comerford to the United States/Canadian border 95 km, steel H-frame towers with three 5.1 cm diameter ACSR conductors per pole, two 95 mm steel schield wires, and a buried counterpoise.
V-string glass insulators with 25 discs per string, and leakage distance of 2.93 cm/kV.

Electrode-Comerford:

18.2 km from the terminal in Lisbon, N.H.
Electrode design: Six 70 m deep vertically configured earth anodes. Total resistance to true earth is 0.12 ohms. Design will allow monopolar operation with earth return for 15 minutes.

40

Electrode feeder is 2 - 795 kcm aluminium conductors. Each anode is silicon chromium steel, in a 30 cm diameter hole back filled with calcined coke breeze.

Des Cantons: The ground electrode was designed taking also phase 2 into account. It is located at 9 km from the converter station. It consists of a 600 meters ring buried at 2,75 meters.

DC Filters-Comerford: Each pole has one sixth harmonic filter and one twelfth harmonic filter. The filters are composed of both series and shunt connected elements.

Des Cantons: bipolar operation: double tuned
monopolar operation mode: triple tuned

HVDC Valves-Comerford: Air cooled solid-state thyristors are housed indoors, and are disigned as quadravalves forming a 12-pulse converter bridge. Each valve has 4 valve sections in a series connection.

Des Cantons: Valves: Number: 6 quadruple
Number of modules per valve: 16
Number of thyristors per module: 8
Number of thyristors: 3072
primary: air
secondary: water, glycol

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