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RESEARCH SCHEME ON POWER

Electric Power Transmission at Voltages of 1000 kV and above

Plans for Future AC and DC Transmission, Data on Technical and Economic Feasibility and on General Design, Information on Testing Facilities and the Research in Progress

CENTRAL BOARD OF IRRIGATION AND POWER
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(INDIAN NATIONAL COMMITTEE FOR CIGRE)

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ELECTRIC POWER TRANSMISSION AT VOLTAGE OF 1000 kV AND ABOVE

PLANS FOR FUTURE AC AND DC TRANSMISSION, DATA ON TECHNICAL AND ECONOMIC FEASIBILITY AND ON GENERAL DESIGN, INFORMATION ON TESTING FACILITIES AND THE RESEARCH IN PROGRESS

Paper presented by Working Group 31.04(*)
(Transmission at voltages of 1000 kV and above)
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of the Committee
Prof. M. VALTORTA

FOREWORD

Phenomena and technology in the UHV range constitute one of the most active areas of Power System Research and Development. Numerous experts, specialized in the different areas from the fundamental science to the components manufacture, are involved; their work is known through an extensive literature and is the subject of discussion within the electro-technical organizations, generally within their relevant specialised bodies. In particular, this work is reflected in the activity of various CIGRE Study Committees.

The planning engineer envisaging UHV transmission systems needs a more synthetic information to grasp the general features of problems to be solved and to know the main results achieved, the questions still open and the progress of related studies.

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To this aim Study Committee 31 "Power System Planning", during the meeting held in Paris in September 1980, agreed to set up a Working Group (WG 31.04) to provide information on UHV transmission with special reference to these data that are of interest for network planning. More precisely the scopes of the Working Group were defined as follows:

1) Collection of information on plans for future AC and DC UHV transmission systems as well as on existing UHV systems;

2) Collection of data on technical and economic feasibility and on general design of AC and DC UHV transmission;

3) Collection of information on the research in progress in the UHV area, both AC and DC, in the different countries;

4) Collection of information on the related testing facilities.

During the meeting held in Rio de Janeiro in September 1981, the Study Committee, after consideration of a preliminary draft, agreed to limit the survey to the transmission, both AC and DC, at 1000 kV and above.

The information gathered, in the years 1981 and 1982, in a form as homogeneous as possible, from the countries active in this voltage range-Brazil, Canada, Italy, Japan, United States (BPA and AEP/ASEA), USSR - is presented in this report, edited on behalf of the Working Group 31.04, by its convener, Mr. M. Sforzini. The information is given under four main headings corresponding to the above mentioned scopes; for details reference is made to rather large bibliography.

The synthetic but comprehensive view of the state of Research and Development on the UHV power systems shows the number and the difficulty of the problems involved, those of common interest and those arising from particular needs in different countries. It was mentioned how this outlook is a need for the planning engineer, but it can be useful for other engineers not particularly specialised in the UHV field.

The present report gives a picture of the situation in 1981-82; in the future it could be profitable to repeat such a survey sometimes, in order to measure the progress achieved. In this respect, it should be recalled that, after the reorganisation of previous Study Committees 31,32 and 41 into the new Study Committees 37, 38 and 39 a large part of the activity in this field was entrusted to SC 38 "System Analysis and Technology" where a new Working Group 38.04 was set up.

M. VALTORTA
Chairman of SC 31
"System Planning"

1. PLANS AND JUSTIFICATIONS FOR AC AND DC TRANSMISSION AT 1000 kV AND ABOVE

BRAZIL

The need for large power transmission by the 1990's is outlined in Figure 1.

A characteristic of Brazil is the great availability of hydroelectric power and the highly favourable conditions for its harnessment.

The main load concentrations in the country are located in the coastal areas of the Southeast, Northeast and South.

Preliminary investigations have suggested the technical and economical feasibility of long-distance transmission from the Amazon right tributaries into the Northeastern and Southeastern load concentrations, which lack generation. Distances may vary in the range of 1500 km to 2300 km and power block up to 20,000 MW might be considered for transmission in the nineties. Under these circumstances, high capacity UHV AC and/or DC transmission would be required.

Canada-British Columbia Hydro

Technical and economic considerations that led to planning studies in the UHV area may be summarized as follows:

- a large, remote hydroelectric project is planned for service in the 1990's which requires a transmission voltage higher than 550 kV;

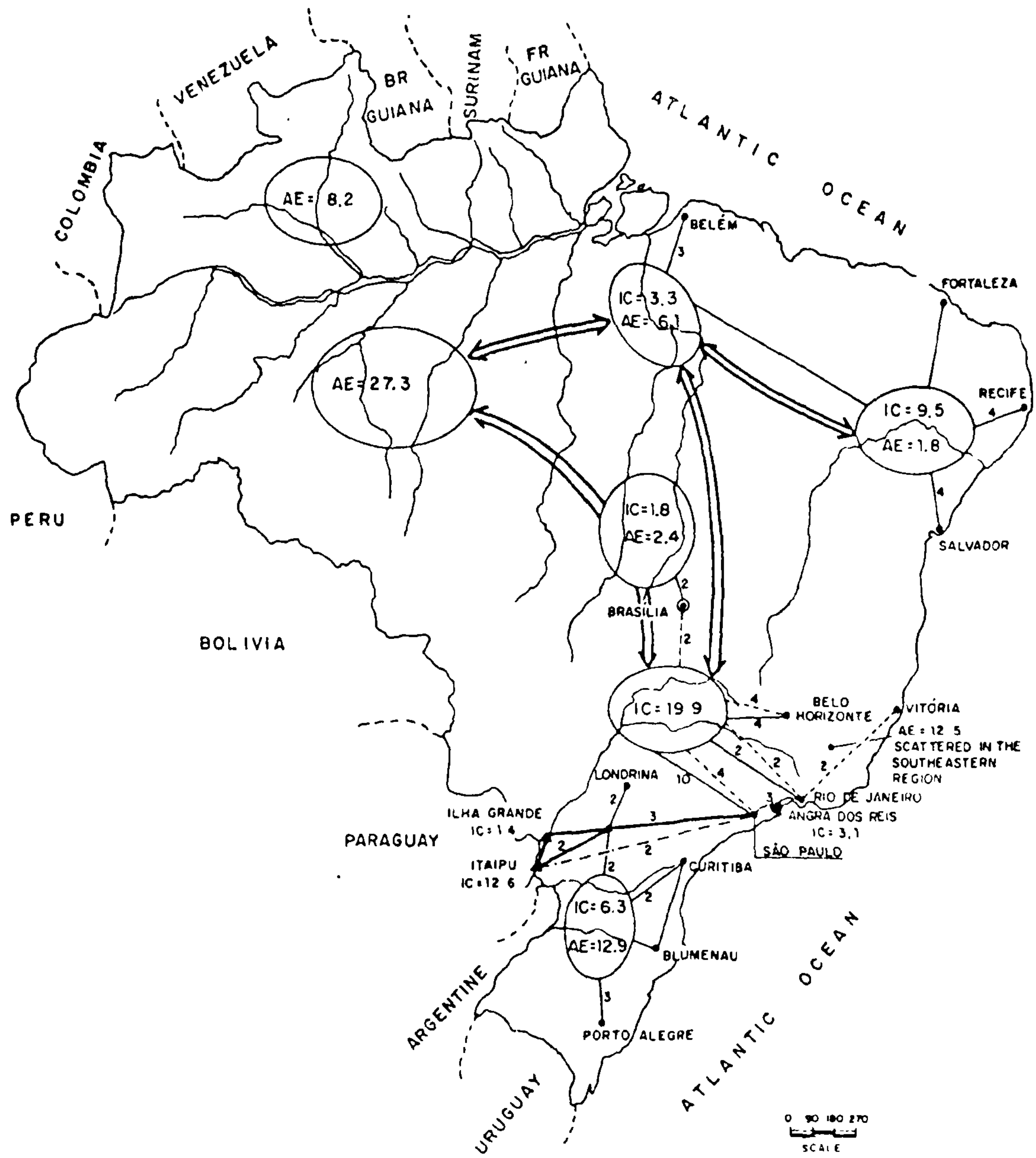

FIGURE 1

Legend

Transmission lines

------ *345 kV*	—·—·— *± 600 kV cc*
——— *440/500 kV*	——— *750 kV*

⇔ *Future HVDC/UHVAC*

○ *Area of hydroelectric developments*

▲ *Hydroelectric plant*

● *Nuclear plant*

IC = 1990 installed capacity connected to the EHV grid, in GW

AE = Available hydroelectric firm energy to be explored beyond 1990, in GW ave.

- an 800 kV two-line system would require series compensation higher than 50 pour cent while a 1200 kV two-line system would require little series compensation but would be relatively expensive. For this reason, a two-line system at an intermediate level in the order of 1000 kV is considered as an alternative to a three-line 800 kV system;

- the 1000 kV alternative is attractive because it would be an acceptable overlay voltage on 550 kV in the long term, it would not require a high degree of series compensation and would offer some reserve capacity for future generation developments and for export opportunities (the 800 kV system would require, on the other hand, less equipment design development and will remain as a possible alternative, pending further studies).

ITALY

The opportunity has been foreseen to install large power generation capabilities in a few sites relatively far from the load areas. At this stage a new voltage level, which has been preliminarily identified around 1000 kV, would possibly be overlaid on the existing 420 kV network.

Reasons for considering such a system are:

- the possible need for transmission of large power blocks between few generation sites (nuclear or coal power plants) and relatively distant load areas;

- the need to limit the density of electric installations over the whole national territory, thus limiting interference with the environment;

- the economic advantage (taking into account capital costs, losses and reliability) of this solution as compared with other solutions, and in particular with the expansion of the existing 420 kV system.

JAPAN

The UHV Outer Trunk transmission system will be overlaid on the existing 500 kV system in the early 1990's (see Figure 2).

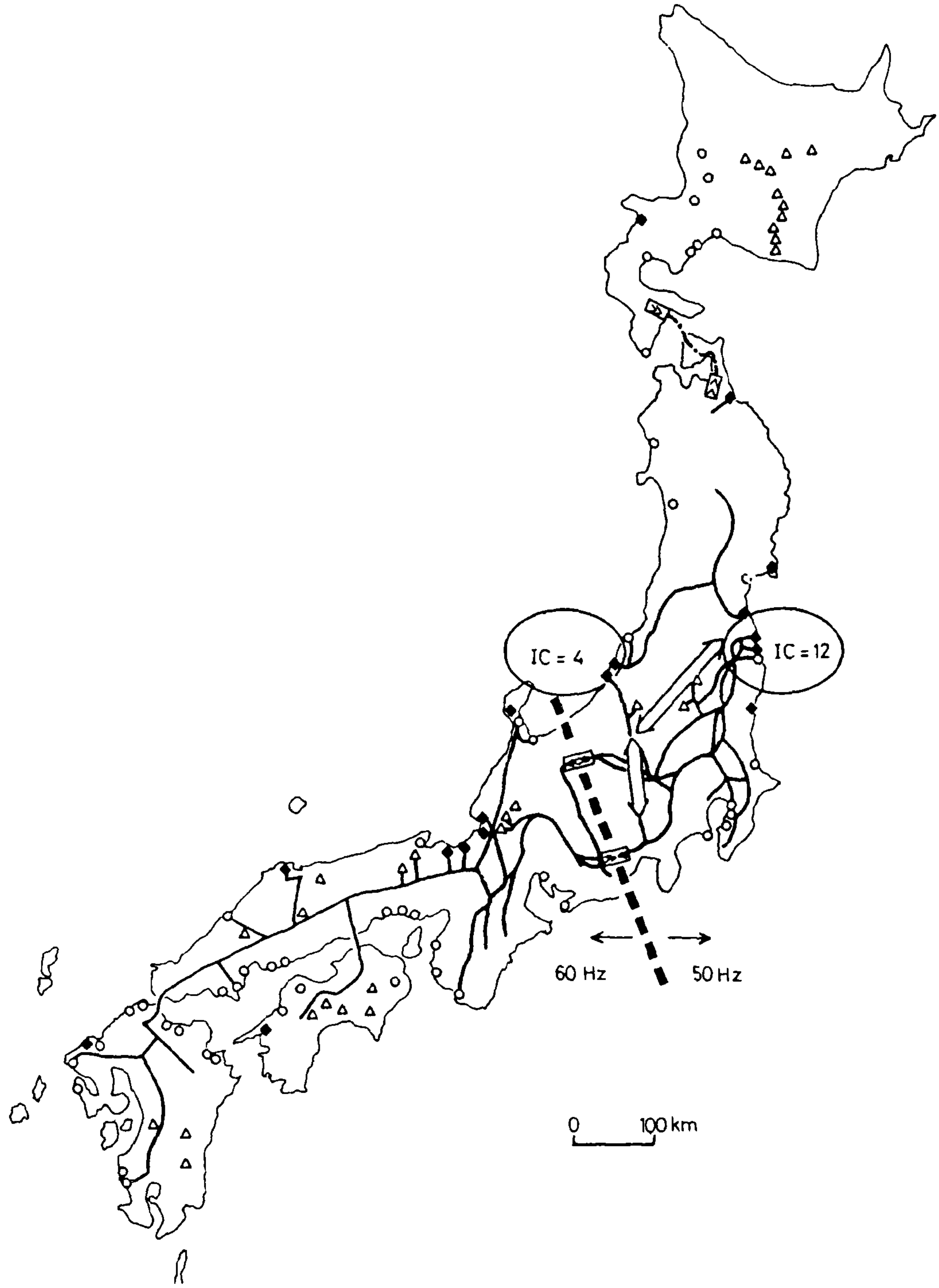

FIGURE 2

± 250 kV DC
500 kV AC

DC links
Area of Nuclear & Thermal Power Plant Developments

Hydro & pumped Storage Power Station
Thermal Power Plant
Nuclear Power Plant
(xxx)*IC = Installed Capacity Connected to the UHV system, in GW.*

Functions of the future UHV system will be:

- to overcome the stability problems of the existing 500 kV bulk power transmission system;

- to obviate the problems of excessive short circuit power in the eastern portion of the system (with the 500 kV transmission network split into several blocks);

- to establish the basis for long-distance bulk transmission in the distant future.

UNITED STATES AEP

The UHV network scheme is not yet finalized. Transmission voltage levels above 1000 kV will be justified when a total internal load of 35,000 MW is approached. This is expected to be in the late 1990's.

The economic evaluation of possible alternatives (considering load growth, generation expansion, land use, flexibility and system reliability) led to system planning and related research in the area of transmission above 1000 kV.

The functions of the future UHV system, for which a voltage level around 1500 kV is foreseen, will be:

- economical transmission of large amounts of power;

- stabilization of the power system to withstand large generation and transmission outages;

- limitation of the number of transmission lines in order to reduce environmental impact and land use.

When going to a higher system voltage, the increased transfer capacity of the line should justify its increased cost: the power transfer capability of a 1500 kV line is 4.2 times larger than that of a 765 kV line whereas its cost increases roughly by a factor of 3.5. Application of 1500 kV transmission also becomes justified when it is necessary to transmit more than 5000 MW over very long distances (450 km or longer).

UNITED STATES BPA (Figure 3)

The transmission capacity across the Cascade Mountains will be increased from about 19,000 MW in 1980 to about 25,000 MW in the year 2000. BPA anticipates having one line, with a capacity of 6,000 to 8,000 MW, in service by that year. This line may be built as early as 1995. Additional lines may be needed at approximately 5 year intervals.

Power transmission at 1100 KV rather than 500 KV offers several advantages:

- better utilisation of rights-of-way;
- reduced environmental impact;
- reduced losses;
- economy of scale.

Studies show that a 300 km length of 1100 KV line will be more economical when the required line transfer capacity exceeds 4000-5000 MW.

The main function of the future UHV system will be the transfer of a large amount of power between two different areas with few corridors.

U.S.S.R.

The power plant capacity of the USSR Integrated Power-System will reach 304 GW in 1985. This figure takes into account the integration of the combined Central Asian power system.

The construction of UHV AC and DC lines is due to the need of strengthening the electrical links between integrated power systems, thus increasing the maneuverability and reliability of these systems, as well as to the need of transmitting great quantities of energy from Ekibastuz, Surgut, and other big thermal,nuclear and hydropower plants to the centres of consumption.

In the years 1975-1980, construction of the Ekibastuz-Tambov 1500 kV DC transmission line was begun.

This line, besides having intersystem functions, will be the link for transmitting large amounts of electric energy to the Urals and the Central Area. By 1985, it is planned to build about 4000 km of 1150 and 1500 kV transmission lines (1500 km at 1150 kV AC and 2400 km at 1500 kV DC).

In the Eastern regions, the most important task in network development is the construction of 1150 kV transmission lines to transmit the power of the Ekibastuz thermal power plants, thus covering the ever-growing deficiency of the Urals united power system. Provision has been made for the construction of a 1150 kV transmission line to transmit power from the Berjozovsk thermal power plant. This line is part of the 1150 kV Siberia-Kazakhstan-Urals trunk line.

2. TECHNICAL AND ECONOMIC FEASIBILITY AND GENERAL DESIGN OF AC AND DC TRANSMISSION AT 1000 kV AND ABOVE

The data on technical and economic feasibility and general design so far available from the various countries, are described in the following paragraphs and summarized in Table I.

2.1 *Transmission capacity of lines. Rated currents, single and three-phase short circuit currents*

ITALY

With reference to a possible 1050 kV system, an initial loading of 3000 MW and an ultimate loading of 5000 MW (10,000 MW in emergency) are foreseen for the transmission lines. Circuit-breakers with interruption ratings of 63 kA and rated currents of 4000 A (6000 A in emergency) are envisaged.

JAPAN

For the 1100 kV double circuit transmission system, an initial loading of approximately 5,000 MW and an ultimate loading as heavy as 18,000 MW of some line sections, are envisaged.

Three-phase short circuit currents of 50 kA or 63 kA are estimated.

TABLE I

Specifications of UHV equipment currently considered in various countries

	ITALY	JAPAN	USA (AEP - ASEA)	USA (B P A)	USSR
Highest voltage for equipment (kV)	1050	1100	1600	1200	1200
Transmission capacity (MW)	3000 initial; 5000 final	5000 initial; 1800 final in some sections (double circuit lines)	n.y.d.	6000 -8000	5000
Rated Current (A)	4000 normal; 6000 emergency	n.a.	n.a.	4000	1000
Short circuit current (kA)	63	50 or 63	40 (63 expected in the future)	25 (40 expected in the future)	40
Size of transformers (MVA)	1200 (400 single phase)initial 2400(800 s.ph.) final	n.y.d.	1000 single-phase	3000; 4500 under consideration	667
Size of reactors (MVAR)	n.a.	n.y.d.	250	260	300
Busbar scheme	Double-bus,the breaker per bay and coupler-One and a half breaker arrangement under study	Double-bus 4 bus-tie	n.y.d.	One breaker and a half	Two sections connected with circuit-breaker
Shunt compensation of lines	70%(for lines longer than 250 km)	Under study	75-100%	70-80%(switchable)	

TABLE I (Contd.)

1	2	3	4	5	6
Statistical switching overvoltage (p.u.)	1.72	n.a.	1.6	1.5	1.8
Maximum temporary overvoltage (p.u.)	1.35	n.a.	1.1	1.3	1.3-1.4
Switching impulse withstand level SIL(kV)	1675	n.y.d.	2400	1800 min.	(see Table II)
Lightning impulse withstand level BIL(kV)	2250	n.y.d.	3000	2175 min.	(see Table II)
Means for overvoltage control	500Ω closing and opening resistors, Z_nO arresters. Shunt reactors for lines longer than 250 km.	Under consideration; closing and opening resistors; metal oxyde arresters.	Under consideration; closing resistors; closing time control shunt reactors; trapped charge decay surge arresters.	Closing and opening resistors, controlled closing.	Arresters, shunt reactors with extra high-speed energizing, closing resistors, impedance at the neutral of reactors
Conductors	8 x 31.5 mm ACSR	n.a.	n.y.d	8 x 42.4mm	-
Type of towers	cyrcus towers	n.a.	n.y.d.	Under consideration; self supporting in delta configuration; cross rope suspension	-
Phase-to-earth clearance (m)	7	n.a.	10.4	6.6	-
Phase-to-phase clearance (m)	14-15	n.y.d.	23.8	22	-

TAPLE I (Concld.)

1	2	3	4	5	6
Minimum length of insulator strings(m)	8 (Phase-to-earth)	n.a.	13	5.6	-
Audible noise (dBA)	56-58 wet conductors; 58-60 under heavy rain(at 15m from outer phase)	n.a.	55 mean value in foul weather (at 38m from outer phase)	50 at edge ot right-of-way in noise sensitive areas	55 under rain at 45 m from outer phase.
Radio interference (dB)	80% level 60(at 0.5 MHz and at 15m from outer phase)	n.a.	58 mean value in foul weather (at 1 MHz and at 38m from outer phase)	n.a.	58 dB at 0.5 MHz according CISPR
Maximum electric field at ground (kV/m)	11 15	n.a.	n.a.	9 near line 5 at edge of right-of-way	15-20

Legenda:

n.a.: no answer; n.y.d.: not yet decided

UNITED STATES - AEP/ASEA

On the basis of present knowledge, rated current should not be a determining factor for UHV lines. Corona performance is likely to call for conductor arrangements providing a high level of current carrying capacity. Economic studies of the cost of losses are in progress, however, to see where larger conductors than those required by corona might be justified.

Interruption ratings of 40 kA for circuit-breakers and disconnect switches are envisaged, with provisions for future ratings of 60 kA.

UNITED STATES - BPA

For 1100 kV lines, an initial loading of 3500 MW and an ultimate loading of 6000 to 8000 MW are considered.

Preliminary studies indicate short circuit currents of 25 kA. Power circuit-breakers with a standard rating of 40 kA will probably be used.

USSR

The transmission capacity of 1200 kV lines in the USSR will be 5000 MW. Circuit-breakers with interruption ratings of 40 kA and rated currents of 4000 A are envisaged.

2.2 *Size of transformers, autotransformers, reactors*

ITALY

The initial size of transformers and autotransformers should be 1200 MVA (400 MVA single phase units with modular columns of 200 MVA). The final size of transformers and autotransformers should be 2400 MVA (800 MVA single phase units).

JAPAN

The size of transformers, autotransformers and reactors has not yet been decided.

UNITED STATES/AEP/ASEA

Single-phase ratings for present technology transformers are limited to 1000 MVA.

The rating of line compensating shunt reactors (modular units) should be 250 Mvar.

UNITED STATES - BPA

Transformer banks rated 3000 MVA and 4500 MVA are being investigated. Considering stages of development, system losses, and series compensation requirements, initial development with two 3000 MVA transformer banks at each end of the line is presently the preferred option.

The size of shunt reactors and series capacitors has not yet been determined.

USSR

Single-phase three-winding power autotransformers with rated voltages of 1150/ $\sqrt{3}$; 500/ $\sqrt{3}$; 20 KV and a rated power of 667 MVA, will be installed.

The size of the first single-phase shunt reactors will be 300 Mvar.

2.3 *Busbar schemes for generation and interconnection substations. Reliability problems for substations. Required reliability of network components*

ITALY

Metal-clad substations are under development and intensive studies are in progress to achieve very high reliability of the components. Present substation design is based on a double bus-bar scheme with one breaker per bay and a coupler. The one-and-a-half breaker scheme is under study for comparison purposes.

JAPAN

The bus-bar scheme for interconnection substations will be the double-bus and 4 bus-tie arrangement.

The reliability of 1100 kV components is required to be higher than that of 500 kV components, which is already high in Japan.

UNITED STATES/AEP/ASEA

The substation design has not yet been made.

At 765 kV level a number of equipment failures have been experienced, particularly on transformers and reactors. The objective is to obtain UHV equipment having reliability levels at least as good as for 345 kV equipment.

UNITED STATES - BPA

Initial development with one line will be a point to point transmission. Substation design for parallel lines is being studied. The 1100 kV system will be required to meet or exceed reliability criteria applicable to existing systems.

USSR

The design criteria for the bus-bar layouts of UHV substations are:

- adequate reliability of consumer power supply and power flows over the transmission lines under normal operating, repair, postfault conditions;

- a limited number of circuit-breakers operating simultaneously: two in the case of a line fault, and three for a transformer fault;

- use of disconnecting switches only for de-energizing the switchgear to be repaired.

For the Itat substation, one of the first substations of the future 1200 kV network, the choice has fallen on a bus-bar scheme consisting of two sections interconnected by circuit-breakers, with each line connected to the bus-bars by means of two circuit breakers and with rigidly connected autotransformers.

At the Kuzbass substation a similar bus-bar scheme will be adopted, with only one bus-bar section.

The one-breaker-and-a-half bus-bar scheme, whose reliability indices are a little higher than those of the two section scheme, was not chosen because of the greater number of equipment units and the more extensive land occupation involved.

Arrangements providing for a single bus-bar and a transfer, as well as double-bus-bar systems were not considered at all, since they did not comply with the above-mentioned requirements.

2.4 *Reactive power compensation. Acceptable voltage profiles. Overvoltages. Insulation levels.*

ITALY

The operating voltage should lie between 950 kV and 1050 kV.

Shunt compensation is only foreseen for lines longer than 250 km. The opportunity of adopting static var system (SVS) compensation is being considered.

Only single-phase autoreclosing is foreseen (with grounding switches for arc-quenching).

Expected overvoltage levels are:

- maximum temporary overvoltage : 1.35 p.u.
- statistical switching overvoltage (U_2 percent) [1] 1.72 p.u.

The following means of overvoltage control are considered:

- 1-step, 500-Ω preinsertion resistors;
- 500-Ω opening resistors (only for some terminals of the future network);
- zinc oxide arresters;

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(1) Overvoltage level having a 2 percent probability of being exceeded.

- line connected reactors (for lines longer than 250 km).

The insulation levels foreseen for substation equipment are:

SIL 1675 kV
BIL 2250 kV

The preliminary specifications established for line insulation, with reference to the circus tower, are the following:

- phase-to-earth insulation 50 percent sparkover voltage:2.3 p.u.
- phase-to-earth clearance: 7m;
- phase-to-phase clearance: 14-15 m;
- phase-to-earth insulator string length : 8 m;
- minimum mid span clearance to ground at 55°C (2) :15m;
- minimum mid span clearance to ground at 70°C (3) 8.5m.

JAPAN

Adequate capacity and allocation of shunt reactors are being studied to prevent the system voltage from:

a) exceeding the specified maximum voltage,

b) reactive power from flowing into generators,

c) to prevent the occurrence of resonant overvoltages.

Fast multi-phase autoreclosing is being considered.

The switching overvoltage level should be as low as the inherent ground fault surge level. Metal-oxide surge arresters and circuit breaker opening and closing resistors are considered as suitable means to control overvoltages.

UNITED STATES/AEP/ASEA

A 75-100 percent shunt reactive compensation is foreseen. Autòreclosing will be at ultra-high speed(1/2 second); it can be

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(2) For switching overvoltage withstand requirements.

(3) For operating voltage withstand requirements.

either one-phase or three-phase with trap charge decay.

Present objectives are to limit temporary and switching overvoltages to 1.1 and 1.6 p.u., respectively. The use of circuit breaker closing resistors, breaker closing time control, shunt reactors, trap charge decay and arresters is being examined.

1500 kV protected equipment is being specified to have.

an SIL of atleast 2400 kV

an BIL of atleast 3000 kV

The following clearances are suggested for the line, for a maximum 1.6 p.u. overvoltage:

10.4 m phase-to-earth clearance

24.0 m minimum clearance to ground

23.8 m phase-to-phase clearance

Minimum length of insulator strings:13.0 m.

UNITED STATES/BPA

The voltage at the terminal ends of a line should not exceed 1200 kV on a continuous basis. Elsewhere along the line, the maximum operating voltage will be permitted to exceed 1200 kV by 1 - 2 percent due to unusual loading conditions.

Shunt reactors, permanently connected to the terminal ends of the line, will provide for 70 - 80 percent compensation. Series compensation will amount to 30 percent or more between 500 kV buses.

The statistical switching overvoltage for the transmission line, U_2 percent, will be 1.5 per unit and the maximum switching overvoltage for substation equipment 1.5 per unit. Gas and oil insulated substation equipment will have a minimum BIL of 2175 kV and a minimum SIL of 1800 kV.

USSR

In the 1200 kV network the insulation level of the equipment is determined on the basis of a permissible switching surge factor which is taken equal to

$$1.8\ U_{p.u.}\ \text{with}\ U_{p.u.} = \frac{1200\ \sqrt{2}}{\sqrt{3}}\ \text{kV}$$

The acceptable level of temporary overvoltages is 1.3-1.4 p.u. The protection system against switching surges, which ensures the 1.8 p.u. factor, includes the following :

- surge arresters, also of the zinc-oxide type;
- shunt reactors with extra-high-speed energizing;
- fast operation of the surge arresters of shunt reactors during extra-high-speed energization;
- closing resistors on circuit-breakers;
- inductive and ohmic resistors in the reactor neutrals;
- protective relays against voltage rise, automatic switching-sequence programmers, etc.

For non-polluted areas, the external insulation creepage path of all substation equipment is taken equal to 1.5 cm/kV, with reference to the maximum system voltage.

The withstand voltages of 1200 kV electric equipment are given in Table II.

2.5 *UHV line design : transmission capacity, land occupation, corona and lightning performance.*

ITALY

Bundles of eight 31.5 mm diameter ACSR conductors and non-conventional supports (circus towers) are envisaged for the 1050 kV lines.

The transmission capacities of these lines are approximately:

- thermal capacity 10,000 MVA
- surge impedance loading 4500 MVA

Expected audible noise values at 15 m from the outer conductor are 56 - 58 dBA for wet conductors (after rain conditions) and

TABLE II

USSR 1200 kV project. Withstand voltages of electrical equipment

Insulation	Withstand voltage kV					
	Power frequency voltage			LIWL		SIWL
	1 mm	1 h	smooth rise	full wave	chopped wave	
Power trans-formers, auto-transformers and shunt re-actors.	1100	900	1300	2550	2800	2100
Bushings for power trans-formers and shunt reactors	1150	-	1300	2700	3000	2100
Switchgear, current trans-formers, capa-citor type pot-ential trans-formers, insu-lators (except for bushings)	1150	-	1300	2900	3200	2100
Between open contacts of:						
a) air blast circuit breaker	2000	-	2000	2900	3200	2100
b) disconnect-ing switch	-	-	1500	3300	-	2400

58 - 60 dBA under rain.

The radio interference (RI) level at 15 m from the outer conductor - 80 percent value of the overall statistical distribution - is 60 dB (above 1μ V/m).

The maximum electric field at ground, with a 15 m height of the conductors above ground, is between 11 and 15 kV/m.

As regards the lightning performance of a line, a maximum shielding failure current of 15 kA and no back flashovers in the vicinity of substations are foreseen.

UNITED STATES - AEP/ASEA

The design of conductors for 1500-1600 kV lines is not finalized yet. Regular bundle conductors with 18 and 9 ACSR subconductors have been studied. Regular bundles with 10 ACSR subconductors and lines with non-conventional conductors are under investigation.

The right-of-way for a 1500-1600 KV line is estimated to be around 125 m. Based on the performance of the AEP 765 kV system, which has generally been acceptable to the public, the criterion for UHV conductors is that audible noise should be less than 55 dBA at the edge of right-of-way. It is believed that, with the audible noise of a 1500 KV line limited to 55 dBA, RI will not exceed 58 dB (at 1 MHz) at the edge of the right-of-way and the three-phase corona loss will be about 130 kW/km in foul weather.

UNITED STATES - BPA

Bundles of eight 42.4 mm conductors are envisaged for the 1100 kV lines. The bundle diameter is 107 cm.

Self supporting towers in delta configuration and cross rope suspension towers are being considered.

Audible noise levels will meet State noise regulations and will be limited to maximum 50 dBA at the edge of the right-of-way in noise sensitive areas.

The 1100 kV line will be designed for a lightning caused outage rate of less than 0.1 per 100 km and year, which is equivalent to criteria for 500 kV lines.

USSR

As regards audible noise, the 50 percent level must not exceed 55 dBA at 45 m from the outer phase under rain.

The corresponding level of radio interference is 58 dB at 0.5 MHz, measured in accordance with CISPR recommendations.

Gradients of 3÷ 5 kV/m may be considered a safe level for determining the right-of-way required width.

However, the distance from the outer phase to the edge of the right-of-way for 1200 kV lines in USSR is above 75 m and the actual gradient at the edge about 0.5 kV/m.

3. RESEARCH IN PROGRESS IN THE AREA OF AC AND DC TRANSMISSION ABOVE 1000 kV

3.1 *Internal and lightning overvoltages*

ITALY

Present objectives of internal and lightning overvoltage studies are:

1) To evaluate the switching overvoltage distributions for various configurations expected in the development of the system, and the risks of insulation failures for different insulation levels of the line.

2) To evaluate the technical and economic advantages of various means for controlling switching overvoltages, and the limits imposed to this control by overvoltages due to line-to-line and line-to-earth fault inception (the latter overvoltages cannot be controlled, in practice).

3) To evaluate the effect of zinc-oxide surge arresters on internal overvoltages and to provide criteria for the choice of the most suitable rated voltage for these arresters.

4) To determine the lightning overvoltage stresses in gas insulated substations and the optimum position and number of surge arresters as well as the insulation level of substation components.

Network simulation is made by means of CESI's TNA and of digital programs.

As regards, in particular, the lightning performance of UHV lines, the research has the following objectives:

- obtain more accurate criteria (both mathematical methods and analogic models) for determining lightning stresses on line insulation;

- optimize the shielding of UHV overhead lines;

- determine the behaviour of insulation subjected to lightning overvoltages.

JAPAN

Switching, lightning and temporary overvoltages are being studied for various system operating conditions.

UNITED STATES - AEP/ASEA

Research is in progress as regards the means of controlling temporary and switching overvoltages (use of circuit-breaker closing resistors, breaker closing time control, shunt reactors, trap charge decay and surge arresters).

Digital studies have been performed by means of ASEA's TRANSO program and AEP's in-house computer program. The transient network analyzer facility at IREQ was used for an extensive study.

UNITED STATES - BPA

Study objectives are to determine:

1) Statistical distribution of amplitudes and wave shapes for phase-to-ground and phase-to-phase overvoltages;

2) temporary overvoltages;

3) maximum fault induced overvoltages and relevant wave shapes.

Sensitivity analyses will be conducted relative to source impedance, transformer impedance, line length, size of series capacitors, line configuration, etc.

3.2 *External and internal insulation*

CANADA-HYDRO QUEBEC

Air insulation tests on substation and line configurations for transmission voltages of upto 1500 kV were performed in IREQ's high-voltage laboratory (although the tests were performed indoors, the dimensions of the high-voltage hall - 67 x 82 x 51 m high - are large enough to ensure representative results):

- Tower windows with conductor-to-tower clearances of up to 9 m were tested with switching impulses of various fronts. These tests allowed the U characteristics of the corresponding air gaps to be produced and the critical impulse front to be determined.

- Making use of the same window, tests were performed with impulses of various steepnesses and a large number of voltage applications, in an attempt to determine the standard deviation of the breakdown probability as a function of the time-to-crest with relatively narrow confidence limits. These tests enabled the dependence of the standard deviation on the front of the impulse to be detected.

- Tests were carried out on phase-to-ground and phase-to-phase insulation of substation configurations with gap lengths to ground and between phases of up to 15 m and 16 m, respectively. During these tests the coordination of phase-to-ground and phase-to-phase gaps was studied.

For rod-plane gaps of upto 20 m, the breakdown voltage was determined as a function of both the clearance and the time-to-crest of the impulse.

These tests made it possible to deduce the voltage-clearance characteristic for impulses of critical front.

- Tests were performed also on line and substation insulating clearances for DC systems of nominal voltages upto + 1200 kV using composite voltages (DC+impulse) and taking account of the proximity of the second pole, energized or not.

- The co-ordination of terminal-to-ground with terminal-to-terminal insulation of a 735 kV disconnecting switch was studied. The conclusions of this work are also applicable to higher-voltage disconnecting switches.

ITALY

The main research areas are herewith summarized:

- Switching impulse behaviour of air gaps. The research in progress follows two main objectives : to produce more accurate semiempirical methods for predetermination of the gap strength; and to check the phase-to-earth and phase-to-phase behaviour of air gaps typical of UHV substations and lines.

- Behaviour of phase-to-earth and phase-to-phase surface insulation of UHV systems in polluted atmosphere. Tests are performed at CESI HV Laboratory using artificial pollution and steam fog. They are mainly intended to investigate possible non linear phenomena connected with very long insulator arrangements.

- Performance of SF_6 insulation. The objective of the research is to provide predetermination criteria for SF_6 insulation as a function of electrode geometry, pressure of the gas, roughness of the electrode surface, presence of insulating baffles and impurities in the gas.

- Development of non conventional insulators (plastic insulators, semi-conducting glaze insulators). Because of their good performance in polluted atmosphere, these insulators are particularly suitable for lines with non-conventional supports. Research in this area is carried out by ENEL in collaboration with the manufacturers, with the specific aim of obtaining insulation with satisfactory long term performance in service.

JAPAN

Extensive studies using impulse generators will be undertaken before long, especially in order to determine the phase-to-phase clearance of UHV transmission lines. Non conventional insulators, for example glass-fiber insulators, will not be introduced in the Japanese UHV transmission lines.

Tests for determining the AC flashover characteristics of full-sized bushings and long insulator strings under contaminated conditions are being carried out. Details and results are given in References 5.3 and 5.4, respectively.

UNITED STATES - AEP/ASEA

UHV insulation testing has been performed at the Frank B. Black Laboratory of the Ohio Brass Co. and the high voltage test facilities of IREQ. Details and results are given in References 5.3 and 5.4, respectively.

UNITED STATES - BPA

The objective of the study on switching and lightning impulse insulation is to obtain full-scale laboratory test data on the dielectric strength of 1100 kV transmission lines.

Laboratory tests on various air gap geometries with and without insulators have been performed and the influence of air gap length, insulator string length, tower width and impulse wave shape studied.

Some of the results obtained are:

- switching impulse data agrees quite well with that of Paris and Cortina, which is the basis for clearances in National Electric Safety Code (ANSI, C_2 - 1981);

- negative polarity switching impulse CFO levels are 35 to 50 percent higher than the positive polarity levels;

- addition of a second ground plane reduces the positive polarity CFO level by about 7 percent from the level with a single ground plane;

- tower air gaps flashover levels are only slightly affected by the conductor to ground clearance when this exceeds two times the tower air gap;

- during dry conditions, the CFO level of a 29-unit insulator string (1750 kV) is within 3 percent of the level achievable without insulators present;

- during artificial rain tests the CFO level curve appears to saturate for strings longer than 25 units. During these tests the CFO level of a 29-unit string (1620 kV) is nearly 10 percent lower than the level without insulators present;

- during the limited number of natural rain tests the CFO levels were closer to the dry test levels than to the artificial rain test levels;

- as the tower width is decreased, the positive polarity critical flashover voltage increases while the negative polarity CFO decreases. Since positive impulses are controlling, this improves performance;

- the number of anomalous flashovers increases as the ground plane width is reduced.

Power frequency tests have been conducted in the Carey High Voltage Laboratory at voltages up to 1.1 MV line - to-ground and on the prototype 3-phase 1200 kV test line at Lyons. The Lyons test line has, from the beginning, had a combination of porcelain, glass, and non-ceramic insulators (NCI). Over the years,the test program for observing the 60 Hz performance of these insulators has included the use of nightviewing devices and high speed photography.

In October of 1979 the ceramic insulators on one tower were contaminated in place by spraying them with a salt-clay-alcohol solution. A fuse wire was placed across the last unit near the grounded end of each string, as an indicator. One insulator flashover was reported later that year.

The following are some of the observations:

- in general the performance of ceramic insulators has been as expected.

- surface erosion has occurred of NCI's due to corona discharges and arcing in cases when the ends of the strings were not adequately shielded by corona grading rings.

- an NCI string with poor shed design flashed over during a wet snow storm. Inspection revealed no damage to the insulators.

- damage was done to one NCI by maintenance personnel during phase pull together work. The insulator remains operational.

- dead end and center phase ceramic insulators were sprayed with light contamination.

But were repeatedly washed by rain before any meaningful test could take place. A time exposure movie system that is capable of recording low amplitude corona and dry band arcing was successfully used for the first time during this test.

UNITED STATES GE/EPRI; PROJECT UHV

Extensive switching impulse tests on many different types of line and substation insulation and power frequency tests on contaminated insulators were performed at UHV voltages, particularly for 1200 kV AC systems during the period between 1968 and 1979. The results of these tests have been included in the second edition of the EPRI "Transmission Line Reference Book - 345 kV and Above".

3.3 *Corona performance of conductors, insulators, fittings.*

CANADA-HYDRO QUEBEC

As part of a study to evaluate 1200 kV AC as a possible option for transmission of power from James Bay project of Hydro-Quebec, IREQ has conducted studies on the corona performance of four conductor bundles, namely 8 x 41.4 mm, 6 x 46.53 mm, 8 x 46.53 mm and 6 x 50.75 mm, in the outdoor test cages. The parameters measured in this study included corona losses, radio interference and audible noise, mainly under conditions of heavy artificial rain. The 6 x 46.53 mm conductor bundle has been selected on the basis of the cage tests for further studies on the outdoor test line of IREQ.

In addition to the specific study on conductor bundles for 1200 kV transmission as described above, a general study has also been carried out in the test cages of IREQ to evaluate the conductor bundles having from 1 to 16 conductors, with the conductor sizes varying from 23.5 mm to 77.2 mm. Analytical methods have been developed on the basis of results of this study for the predetermination of the corona performance of practical transmission lines.

As part of an extensive EPRI project, IREQ has also studied, over the past six years, the corona, electric field and ion current performance of DC transmission lines in the range of ± 600 kV to ± 1200 kV.

ITALY

Continuous recording of corona losses, audible noise and radio interference is carried out at the 1 km experimental line of Suvereto. Three conductor bundles are tested one after the other with 24 hour intervals; each bundle is energized at an "equivalent" voltage simulating the conductor surface gradient of a three-phase 1050 kV line. The statistical distributions of the recordings, made in different meteorological conditions, are investigated together with the correlations with the meteorological parameters.

Three types of symmetrical conductor bundles have been fully tested so far, namely 6 x 31.5/450 mm, 8 x 31.5/450 mm and 10 x 31.5/450 mm. In the near future, new conductor bundles will be installed and tested, in particular, and 8 x 31.5 mm asymmetrical bundle and a 10 x 26.9 symmetrical bundle.

At the test cage of Suvereto, corona losses, audible noise and RI are measured under dry conditions, artificial rain and during the drying transients, at different conductor gradients. In particular, recordings on conductor bundles of the same type as those installed on the experimental line were made to check the validity of the cage tests.

So far cage tests have been made on:

- symmetrical bundles of upto 14 x 31.5 mm diameter subconductor;

- asymmetrical bundles of 6 x 31.5 and 8 x 31.5 mm diameter subconductors, with different asymmetry degrees;

- symmetrical 8 conductor bundles with conductor diameters 22.8, 26.9 and 31.5 mm;

- tubular conductors with diameters 200, 400 and 600 mm.

Other conductor types, including bundles with subconductor diameters of 42.2 and 56 mm, will be tested in the future.

Research is in progress on the interference levels (radio and television interference and audible noise) produced by UHV insulators and fittings. RI recordings have been performed on various string configurations using ceramic and non-ceramic long rod insulators and cap-and-pin insulators. Studies are also made on shielding devices for the correct screening of insulator strings; in particular, suitable configurations of the conductor bundle at the point where it is connected to the insulator string are investigated, in view of obtaining an adequate shielding of the insulators by means of the bundle itself.

JAPAN

Basic data are being collected by using the experimental full-size UHV transmission lines of both CRIEPI and the manufacturers (see Table III).

UNITED STATES - AEP/ASEA

AEP started testing UHV conductor configurations in 1977. To date, the following configurations have been subjected to long term testing on the single phase UHV test line; an 18 conductor bundle of 3.05 cm diameter subconductors in a 1.2 m diameter bundle, a 9 conductor bundle using the same subconductors and bundle diameters, and a 10 conductor bundle of 4.57 cm diameter subconductors in a 1.2 m diameter bundle.

Other non-conventional types of conductors are being investigated as alternatives for the regular ACSR bundles.

Line fittings are designed to be essentially corona-free under dry conditions. They should not go into corona before the line conductors. Due to their relatively small size, corona losses on fittings and insulators are not economically important.

UNITED STATES - BPA

Research and studies of corona on conductors, insulators, and hardware are carried out both in the Carey Laboratory and on the Lyons 1200 kV test line.

Long term monitoring is made of audible noise, radio noise, ozone generation, television interference, and corona losses.

The data collected since initial energization of the Lyons 1200 kV line have been used to develop prediction formulas.

Some results of studies of corona on conductors are shown below; the corona effects are given for different line configurations at the Lyons test facilities and at an operating voltage of 1150 kV.

In 1980, tests were performed to compare corona onset and visual corona on UHV suspension hardware assemblies inside the UHV laboratory with a similar arrangement as on two of the phases on a suspension tower at Lyons. Special corona rings were developed and 60 Hz voltage tests were performed to correlate their performance inside the UHV laboratory, in the outdoor test tower, and on the test line at Lyons. The tests inside the UHV laboratory provided an indication of the influence of humidity, dust and the laboratory floor, walls, and test transformer on corona performance.

The highlights of these tests on the suspension hardware were:

TABLE III

UHV Research and development in Japan

Experimental Equipment	Institute & Manufacturer	UHV Research & Development: Aims of Experiment	Experimental Period	Characteristics of Experimental Equipment
Akagi full-size experimental transmission line	Central Research Institute of Electric Power Industry (CRIEPI)	o Study of mechanical stability of UHV transmission pylons o Study of construction & maintenance of transmission line	Dec. 1980 -	o AC 1000 KV class o Double Circuit Transmission line o $810mm^2 x10$ conductors o 3 towers/600m
		o Insulation test of transmission line o Environmental study and counter-measures of transmission line	After Autumn 1981	o Three transformers, 900kV L-G (1500 kV L-L) o AN, RI, TVI, measuring devices
UHV Experimental Transmission Line on Mt. Takaishi	The Tokyo Electric Power Co., Inc. The Fujikura Cable Works, Ltd.	o Observation of ice loading on transmission line o Design taking account of ice loading	Jun. 1978 - Mar. 1982	o $810mm^2 x10$ conductors o 4 towers/230m o Installing 2 phases
UHV Experimental Transmission Line	The Furukawa Electric Co., Ltd.	o Observation of ice loading on UHV transmission line	Nov. 1979 -	o $810mm^2 x10$ conductors, 3 towers per 360m o Installing 2 phases
	Hitachi Cable, Ltd.	o Weight loading test of UHV transmission line outdoors	After Autumn 1981	o $810mm^2 x10$ conductors, 3 towers per 1000m o Installing 1 phase
	The Fujikura Cable Works, Ltd.	o Testing full size conductors in factory (ex. tension, wind noise, etc.)	Dec. 1977 -	o $810mm^2 x10$ conductors, 3 towers per 400m o Installing 1 phase
	Sumitomo Electric Industries, Ltd.		Oct. 1979 -	o $810mm^2 x10$ conductors, 2 towers per 300m o Installing 1 phase
Fog Room for testing insulators	CRIEPI	o Voltage test of polluted UHV insulators	Feb. 1979 -	o WxHxD; 26x35x35m o This fog room can test maximum 20m heigh insulator
	NGK Insulators, Ltd.	o AC voltage test of polluted UHV insulators in fog	1978 -	o WxHxD; 25x30x30m o This fog room can test maximum 1500KV class insulator
UHV Prototype Transformers	Mitsubishi Electric Co.	o Check of conventional design of insulation	Nov. 1978 -	o Capacity; 1/10 of 1000MVA per one phase o Voltage; AC 1800KV class
	Toshiba Corp.	o Check of reliability of new design of insulation by full-sized models	May 1979 -	o Capacity; 1/3 of 1000MVA per one phase o Voltage; AC 1200KV class
	HITACHI, Ltd.			o Capacity; 1/3 of 1000MVA per one phase o Voltage; AC 1150KV class

	Line Configuration (1) I	II	III	IV	V
Electrical Effect					
AN - A-wt.L_{50} level during rain (dBA), 15 m from outside phase	53	47	50.5	56.5	61.0
RI-QPL_{50} level (dB,μV/m), 15 m from outside phase					
a) 1 MHz,ANSI,Fair/Rain	42/61				50/71
b) 0.5 MHz,CISPR,Fair/Rain		43/62	46/64	54/73	
	46/65	47/68	50/68	58/77	54/75
TVI-75 MHz, QPL_{50} during rain (dB,μV/m), 40 m from outside phase	13	12	13	12	9
Ozone - (ppb)	None	None	None	None	-
Corona Loss- L_{50} level, kW/km,during rain,2 or 3 phases	-	22	24	43	45

(1)

Line configuration	Bundle	Type of energization	Midspan Clearance (m)	Interphase Clearance (m)
I	8x41mm	all 3 phases energized	24.4	22
II	7x41mm	2 phases energized one phase grounded	22.9	22
III	7x41mm	2 phases energized one phase grounded	19.8	22
IV	7x41mm	all 3 phases energized	16.8	22
V	7x41mm	all 3 phases energized	16.2	12.9

- tests performed to determine influence of ground plane width showed the difference in corona onset voltage between a 0.1 m ground plane and a 1.8 m ground plane was less than 2 percent;

- raising the humidity can lower the corona onset voltage even though visible moisture was not present on the rings;

- conductor height does not significantly influence the corona onset voltage if the conductor height above ground is at least 2.5 times the conductor-steel air gap clearance;

- observations at Lyons showed that the rings performed essentially the same as in the outdoor test tower;

- except for the effects of the test transformers, proximity effects in the indoor laboratory led to conservative results relative to the performance at Lyons;

- a dry test for visual corona on UHV suspension hardware, which correlates with performance at Lyons, has been developed for laboratory use. Similar techniques are being developed for dead-end hardware. Corona activity observed at Lyons on dead-end insulator hardware has not correlated well with laboratory results. Preliminary investigations indicate that these differences are related to three-phase operation versus single-phase testing;

- inboard mounting of non ceramic insulators to avoid the need for corona shield rings has thus for proven to be successful in that the conductors do grade the insulators.

UNITED STATES - GE/EPRI - PROJECT UHV

Eleven different UHV line and conductor configurations were tested, using a 3-phase line, from January '75 to December '79.

Conductor diameters varied from 3.3 to 5.6 cm, number of subconductors in a bundle varied from 6 to 16, nominal line-to-line voltage varied from 950 kV to 1450 kV.

Horizontal and triangular line configurations were tested.

Radio noise, audible noise, corona loss, electric field at ground, ozone, television interference were measured in different weather conditions. The results were used to develop comprehensive design rules, included in the second edition of EPRI's "Transmission Line Reference Book - 345 kV and Above".

3.4 *Mechanical and structural problems of lines and conductors*

CANADA - IREQ

The following mechanical engineering projects were conducted in relation to UHV transmission:

1) Wind tunnel measurements of aerodynamic forces (drag, lift and derivatives) on 4-, 6- and 8- conductor bundles. The data obtained are crucial for calculating the aeroelastic stability of conductor bundles. This project was carried out in collaboration with the National Research Council.

2) Preliminary study of the dynamic performance of a 6-conductor bundle exposed to the wind. This work was performed on the Magdalen Islands test line.

3) Study of the aeroelastic performance of a 12-conductor bundle equipped with different spacers. This study, also carried out on the Magdalen Islands test lines, was undertaken for the American Electric Power Corporation.

ITALY

The research in progress in this area concerns :

- vibratory behaviour of conductors: wind tunnel tests are performed on conductor bundle models to define the energy introduced by the wind into a vibrating system.

Comparisons are made between analytical models and experimental results obtained at Suvereto,Pradarena, Brugherio (see paragraph 3.7) and at sections of operating lines;

- vibration dampers and spacers: tests are carried out in the laboratory and at the experimental lines of Suvereto and Pradarena;

- tubular and quasi-tubular conductors, suspension fittings and joints: tests will be performed on prototypes and an experimental span will be set up to study the relevant mechanical problems;

- effects of the wind on phase-to-phase clearances: measurements will be taken of the diplacement of line conductors and comparisons made with analytical models;

- static and dynamic behaviour of non conventional lines (circus, V-circus and cluster towers); research is conducted on reduced scale models and analytical models, tests are carried out on prototypes of non conventional towers, construction and assembly methods for non conventional supports are developed and analized;

- foundations (mainly guy-foundations) for non-conventional towers: theoretical and experimental research will be carried out to calculate and check the foundations and to define the equipment for construction and proof testing;

- integration of UHV lines in the environment: procedures are developed for choosing the routes and for optimizing the tower distribution, with special reference to non conventional lines.

JAPAN

Basic data are being collected by using the experimental full-size UHV transmission lines of CRIEPI and the manufacturers (see Table III).

Since double-circuit lines are under consideration in Japan, the mechanical strength of towers, the construction and maintenance techniques as well as the environmental problems are particularly important items to be investigated.

UNITED STATES - AEP/ASEA

The original 18 conductor bundle installed at the UHV test station exhibited substantial subconductor oscillation and created some concern about the practical design of future lines. To this end, AEP contracted with IREQ to utilize their Magdalen Island Test Facility for tests on 12 conductor bundles using various spacer designs and arrangements. From the four different types of spacers tested during the winter of 1978-79, the spring friction type proved to be quite acceptable and was stable for wind speeds of up to 11 m/sec (40 km/h). This work is described in Reference (5.23).

In general, it is felt that bundle conductor designs should avoid rigid connections, and the spacer and support systems should provide flexibility and energy absorption patterns to minimize oscillations.

In the matter of linedesign, work is underway on the development of chainette or circus support type tower systems and trial installation is going forward at 800 kV. This experience will be of value to AEP-ASEA UHV program.

UNITED STATES/BPA

The mechanical and structural test program entails studies of line loadings (wind and ice load), conductor motion (aeolian vibration, subconductor oscillation, galloping), construction and maintenance techniques, and comparison of all-aluminium to ACSR conductor performance.

The two major goals in this program are:

1) To gain knowledge about the structural/mechanical aspects of overhead 1100 kV transmission design so that future commercial lines can be optimized and troublefree;

2) To advance the general state-of-the-art of transmission design at all voltage levels.

Mechanical and structural tests are performed in the Mangan mechanical-electrical laboratory and at the Moro mechanical test line.

Ice conditions at the Moro mechanical test site have enabled studies of shapes of ice on conductors and effects of conductor and tower geometries. Up to 115 mm of radial ice on the conductors has been monitored. Measures to control aeolian vibration and subconductor oscillations have been employed successfully.

Activities related to transmission line maintenance for 1100 kV lines were concentrated on the need for hot line maintenance, switching impulse and 60 Hz performance of hot sticks, clearance requirements, maintenance techniques, and cost of hot line maintenance.

3.5 *Environmental impact of lines and substations (audible noise and electric field, physiological effect, visual impact, etc.)*

ITALY

As regards the problem of the biological effect of electric fields, research is conducted both in the laboratory and in natural conditions at the experimental station in Suvereto. Laboratory experiments have been performed on small animals (mice, rats, rabbits and dogs) using uniform fields created by two 1.5 x 2 m steel plates. The animals were exposed to various field intensities by varying the applied voltage and the distance between the plates. Exposures lasting a few minutes to 8 hours per day with 50 Hz electric fields of upto 100 kV/m, were carried out over periods of upto 2 months. Basic cardiovescular variables (i.e., blood pressure, electrocardiogram, heart rate, and cardiac output), blood morphology and chemistry, growth and fertility, teratology, and changes in resistance to induced infections were investigated.

The analysis of the results indicated no effects after exposure to fields below 10 kV/m. Above this value some slight blood changes were found in dogs and rats chronically exposed (8 hours a day) to 25 kV/m and 100 kV/m, respectively. Above 25 kV/m, the slope of the growth curve of the rats appears to slightly decrease in respect of that of the control group. Fertility and resistance to experimental infections in rats and mice were not influenced by two month's exposure to 100 and 25 kV/m, respectively. No teratogenic effects were found in rats exposed to 100 kV/m for upto 48 days.

As regards investigations in a natural environment, experiments are in progress under the test line of Suvereto in order to study the following items:

- analysis of the behaviour of dogs (to be followed by other animals);
- evaluation of hematochemical and hematological variables of the dog;
- investigation on the productivity, fertility and development of chickens.

As regards the physiological effect of the corona noise, an extensive research in the anechoic chamber has been conducted to assess the physiological response to this noise. Corrections factors to the usual weighting scales (in particular the dBA scale) have been proposed.

A general research which considers the environmental interferences as factors in the overall optimization of transmission lines has been undertaken;

JAPAN

UHV transmission lines and substations will be strategically located and constructed in order to minimize their impact on the environment. Except in special areas, UHV transmission lines will be designed as double circuit lines minimizing the width of transmission corridors. For the best environmental harmony, UHV SF_6 GIS will be applied to UHV substations.

UNITED STATES AEP/ASEA

Present general criteria are that the environmental impacts of future UHV lines should be approximately the same as those associated with the existing 765 kV system. AEP 765 kV lines have maximum ground level field strengths of 12 kV/m and 10 kV/m in inaccessible areas and farming areas, respectively.

Edge of right-of-way field strengths are approximately 4 kV/m. Mean foul weather AN levels are 55 dBA at the edge of the right-of-way. These levels have been generally acceptable bus additional research is underway to provide further verification.

Psychoacoustic effects of transmission line audible noise are being investigated in cooperation with the University of Western Ontario, Canada.Growth and yield of field crops in the proximity of the UHV test line and the effects of electromagnetic fields on farm animals near 765 kV lines have been studied through independent contracts with professors from Purdue University, West Lafayette, Indiana. It was determined that animals and crop growth were not affected by the fields associated with these facilities.

Another investigation, a two-year study of some biological life by the University of Notre Dame, concluded that "There is no demonstrated effect from the UHV line on any of the systems tested". The "systems" selected for study were cell division in onion roots, germination of corn seeds, the dry weight of wheat plants, and the amount of chlorophyl in rye, soybeans and clover.

UNITED STATES - BPA

The objective of the 1200 kV biological study is to determine if the prototype line has any measurable effects on crops, natural vegetation, honeybees, wildlife and cattle.

Of primary interest are possible effects on plant growth and animal behaviour. No major impact on crop growth has been observed in electric fields of upto 12 kV/m. Results of germination tests on barley seed from plants grown in electric fields upto 12 kV/ showed no effect. Some adverse effects on honeybees in the form of reduced colony weight and higher mortality have been noticed in electric fields of around 8 kV/m and above. Effects appear to be shock related.

Continued observations of Lyons indicate that the 1200 kV line has had no noticeable effect on bird abundance or species diversity.

Cattle showed no reluctance to graze and drink in fields upto 12 kV/m. Corona damage has been found on some fir trees that were intentionally left close to the line.

USA - GE/EPRI PROJECT UHV

The following studies related to electric field effects of UHV transmission lines were made: statistical measurements of voltage and currents induced in vehicles under UHV lines; nature, frequency of occurrence, and effects of spark discharges; possibility of fuel ignition; burning of wood poles or dead trees; corona from grounded objects; methods of shielding parts of the right-of-way or the areas outside the right-of-way.

Human response to audible noise, and to different types of television interference was also studied.

The results have been included in the second edition of EPRI's "Transmission Line Reference Book - 345 kV and Above".

3.6 *Electric equipment*

ITALY

The research and development activities in the area of UHV electric equipment are mainly carried out at the experimental testing station of Suvereto, in the framework of the international 1000 kV Project. Tests and basic research are also carried out at the CESI laboratories.

After having solved the basic problems connected with the design and construction of prototypes, the following equipment was installed at Suvereto for carrying out simulated operation tests, which should last until the end of 1983.

1) A single-phase autotransformer rated 200/200/50 MVA,

$$\frac{1000}{\sqrt{3}} \Big| \frac{400}{\sqrt{3}} \Big| 24 \text{ kV}.$$

The autotransformer operates alternatively in short circuit conditions (current upto 1.1 times the rated value) and in no-load conditions (voltage upto 1.05 times the rated value). Periodically, the unit is also submitted to lightning impulse withstand tests at 80 percent of its rated insulation level.

The layout of the autotransformer test circuit is given in Figure 4.

2) A 200 m section of oil-filled high-pressure cable for highest system voltages upto 1100 kV. The cable, arranged in a loop system, is completed with sealing ends and straight joints.

External water cooling and internal forced oil cooling systems are provided to permit the three-phase transmission of at least 3 GVA and 8 GVA, respectively.

Voltage tests and thermal test cycles are in progress on the loop. The aim of these tests is to check the long-term performance of the cable and its accessories by monitoring a certain number of meaningful quantities.

The layout of the test area is drawn in Figure 5.

In addition, electric equipment components for an SF_6 metal-clad substation are either under construction at the manufacturer's or under test at CESI laboratory. These components include: circuit breaker, earthing switch, disconnector, earthing disconnector, straight section and crossover connectors, flexible joint, current transformer, voltage transformer. Some components will be installed at Suvereto for accelerated life tests on the insulating structures.

As regards UHV zinc oxide-surge arresters, a few EHV units are being installed and checked in service on the 420-kV network before starting tests on UHV units.

In December 1980, during the tests carried out at the experimental testing station of Suvereto, a failure occurred on the 200 MVA auto-transformer unit when operating at rated voltage. The cause of the failure was of dielectric nature and involved the insulation between a tank wall and the first pressed board barrier. The machine was untanked and repaired on site and reenergized after three months.

As far as the 1100 kV cable is concerned, the experience so far gained is limited but satisfactory.

Starting from 1985, a pilot plant will be constructed consisting of an SF_6 metal-clad substation bay, with the bus-bar system

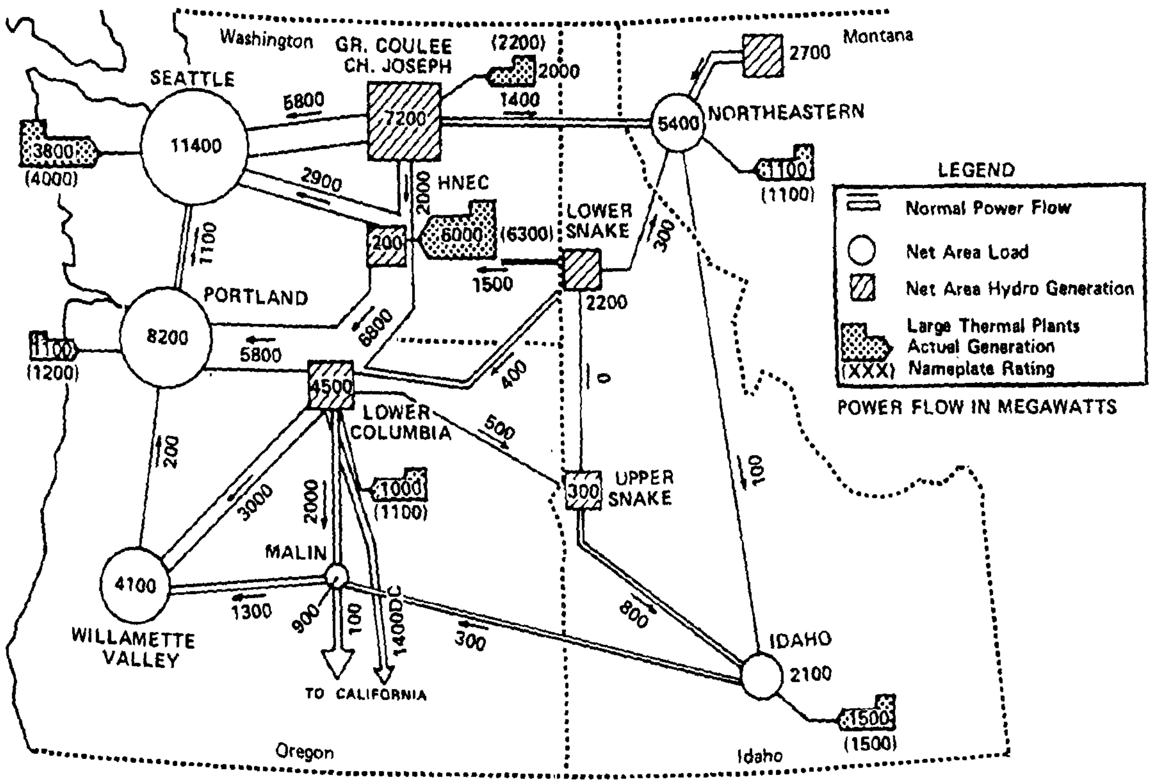


FIGURE 3

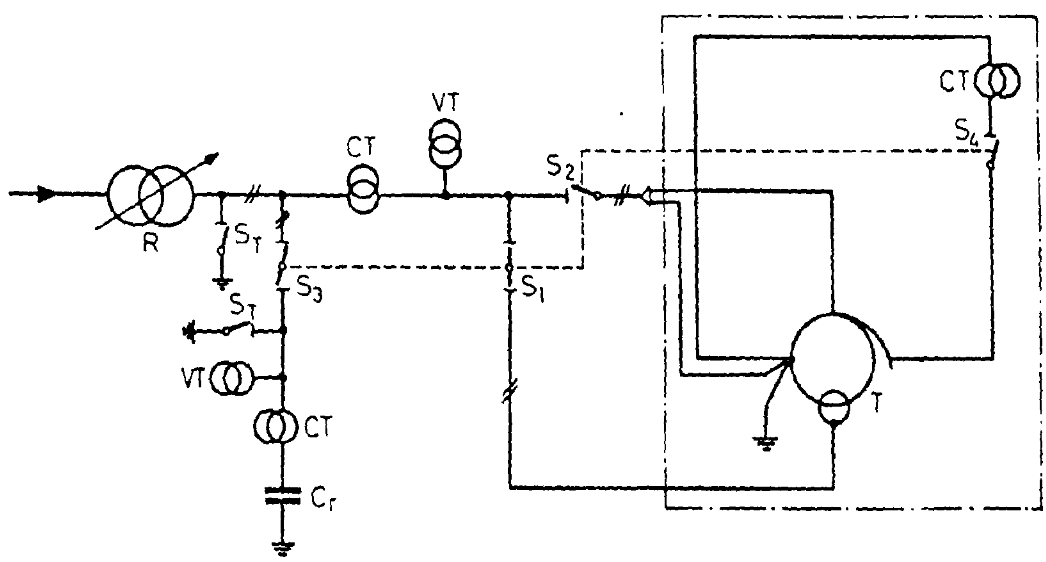
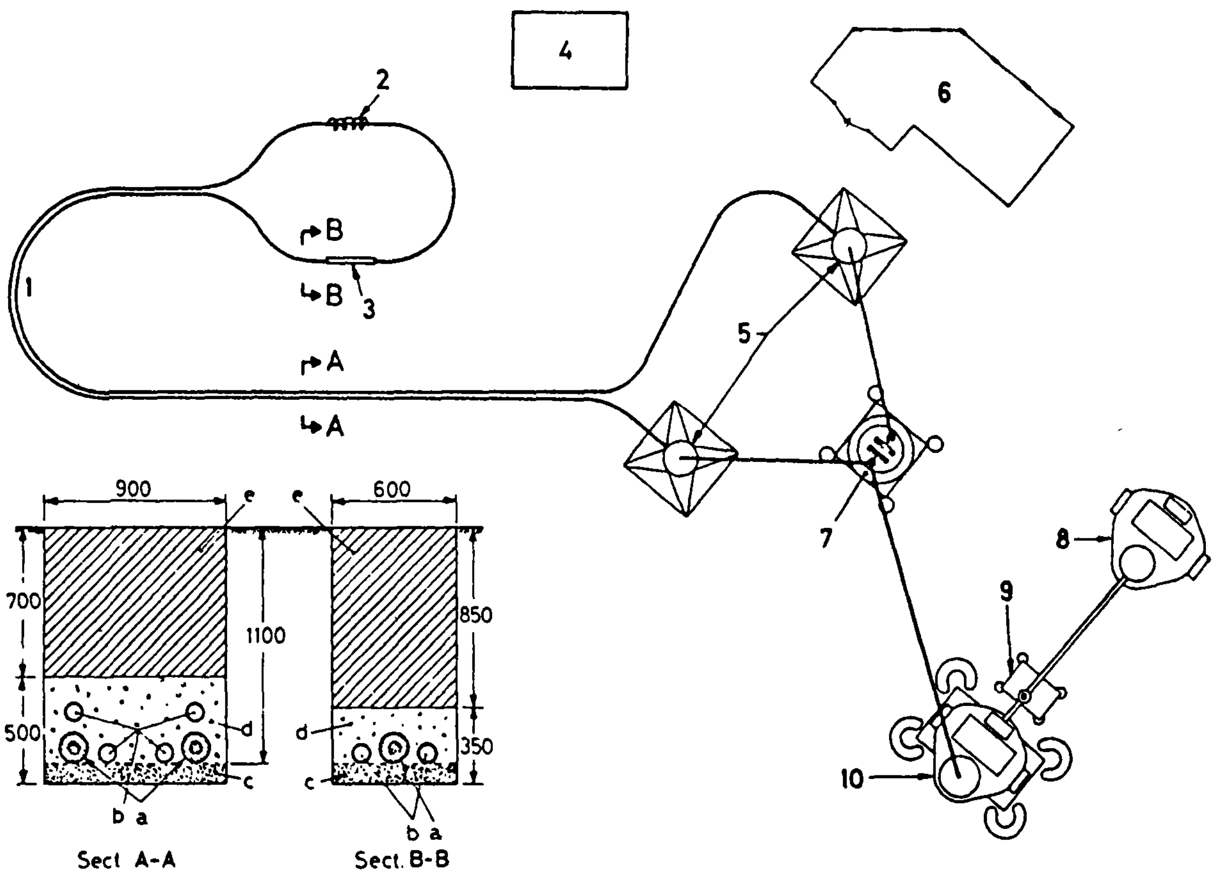


FIGURE 4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Sect. B-B

FIGURE 5

included, and of a bank of three singlephase 400 MVA autotransformers connecting the UHV bay with the 420 kV busbar system of Suvereto. The substation bay will be connected to a 20 km line, which will be energized at 1050 kV ph. to ph. under no load conditions for about two years. At the end of this period, a second substation bay should be put into operation at the far end of the 1050 kV line section, connecting this section with the 420 kV system through autotransformers, so that the pilot plant will operate between two nodes of the existing 420 kV network.

JAPAN

The basic specifications for UHV equipment are not yet decided, but Japanese major manufacturers are involved in the development of this equipment and are reaching the end of the preliminary stage.

UNITED STATES - AEP/ASEA

It is planned to install a single-phase 100 MVA shunt reactor and GIS equipment at the UHV test station. The equipment will be designed for a 1600 kV system but be capable of withstanding a steady state 60-Hz voltage of 1800 kV.

ASEA is performing developmental testing to determine and varify insulation design, and the installation at the test station will check long-term service performance at rated voltage and above. For the GIS equipment, design emphasis is on internal support insulators, entrance bushings and the effects of varying gas quality and pressure. Load current will be simulated at the test station and temperature rises determined for a range of solar radiation and other ambient conditions.

The performance of the Ohio Brass Hi-lite insulators used on the test line has been satisfactory to date. Conical shaped solid insulators made of epoxy resins have been designed for the GIS equipment.

UNITED STATES - BPA

The research and tests on substation equipment are mainly performed at the Lyons 1200 kV test facilities and include evaluation of substation noise and electric fields, evaluation of the performance of transformers and arresters, and installation and evaluation of 1200 kV prototype equipment as it becomes available from DOE and EPRI R&D programs.

One of the 50 MVA, 230/1200 kV transformers at Lyons failed in 1978 but was repaired at the factory and successfully reinstalled and energized at the test site.

The cause of the failure was attributed to dielectric breakdown of the winding insulation due to partial discharges, which in turn were caused by poor workmanship.

A number of flashovers has been experienced of conventional 1200 kV surge arresters, caused by inadequate shielding and voltage distribution. These arresters have now been replaced with ZnO surge arresters. Experience with these is satisfactory, so far.

With reference to 1100 kV prototype equipment, the U.S. Department of Energy is funding several projects which will lead to prototype SF_6 equipment. Most of the apparatus will be installed at the Lyons test facilities as it becomes available. The apparatus to be installed include 1200 kV air-to-gas bushing, SF_6 surge arrester, semiflexible and rigid SF_6 cables and SF_6 instrument transformers.

4. DESCRIPTION OF THE TESTING FACILITIES AVAILABLE IN VARIOUS COUNTRIES FOR RESEARCH IN THE AREA OF AC AND DC TRANSMISSION ABOVE 1000 kV

BRAZIL

The electrical equipment laboratory of CEPEL, at Adrianopolis, is equipped with an outdoor area for dielectric tests for UHV research. In this area it is possible to carry out dielectric tests at full scale on line and substation components for system voltages upto 1500 kV AC.

The main facilities available in the testing area are:

- an impulse generator of 6.4 MV, with relevant voltage divider and load capacity. When necessary, a second impulse generator can also be installed, as well as a cascade of transformers;

- a movable artificial rain device;

- a platform in the middle of the testing area where different full scale or mock-ups of transmission line towers, equipment under test or needed for the tests, can be fixed.

In the near future (next two years) an experimental line and cage will be available.

The experimental line and cage are foreseen to be used upto 1500 kV AC and ± 1000 kV DC.

The experimental line will have a 360 m length span. The dead-end structures will be able to support two bundle conductors with 42 tons of maximum strength each. The bundle conductors separation will cover the range between 8 to 24 m, while the height of the dead-end towers will range from 18 to 38 m; the former at intervals of 1 metre and the latter at 2 metre intervals. A completely automatic system will be provided to set the conductors at proper positions.

The cage will have 60 meters of effective length plus 5 meters at each end, with 7.5 x 7.5 m of cross-section area. The end parts will be insulated from the central part and grounded. The maximum mechanical strength of the bundle conductors will be 20 tons.

The shielding for line, cage, source and measuring equipment is designed to operate satisfactorily at the maximum voltage level of the facilities during heavy-rain conditions. The facilities are designed to test bundles of upto 16 subconductors.

The lines will be energized through a maximum of 2 x 1.2 MVA, 600 kV cascade transformers, with a voltage regulator at the low-voltage side. A corona free coupling capacitor, a standard capacitor and optical fiber and telemetering system together with suitable meters will monitor the conducted radio noise and corona loss. The DC tests will be performed using a cascade rectifier (± 1000 kV maximum voltage output), with additional coupling capacitors and optical plus telemetering systems to monitor conducted radio noise and corona loss.

Audible noise, radio noise, electric field, ion currents, ozone and meteorological conditions will be monitored directly under the central part of the line by a set of suitable meters. All the measuring system will be linked to an automatic data acquisition system that will adequately collect, analyze, select and gather the data for later analysis.

The cage is designed to operate at voltages of upto 600 kV, enough to cover the range of transmission voltage levels upto 1500 kV phase-to-phase. Similarly to the experimental line it will be provided with an automatic measuring system to collect data during artificial rain conditions. For the automatic data acquisition system of the line and cage, a total of 130 channels are provided, not to be operated simultaneously.

CANADA - IREQ

The main test hall of the HV laboratory, where most of the extra-high-voltage testing is performed, is 82 m long, 67 m wide and 50 m high. Electrically shielded to act as a Faraday cage, it is designed for research and tests on transmission system equipment operating at rated voltages of upto 1500 kV r.m.s.

The hall is divided into three separate test areas, each with its own control room, but it lends itself to different arrangements and can be used as a single test area when the dimensions or voltage level of a test object require it.

The major test equipment comprises:

- one 6.4-MV, 400 kJ impulse generator;
- one 3.2-MV, 200 kJ impulse generator;
- one 2-MV, 80 kJ impulse generator;

- two 1.2-MV, 125-mA cascade rectifiers;
- six 550-kV, 1.25-A high-voltage cascade transformers which can be connected in various arrangements so as to obtain voltages of upto 2.1 MV r.m.s., 60 Hz.
- an 800-kV SF_6 test cell;
- two test tanks, one rated 500 kV, the other 1500 kV;
- artificial-rain apparatus with adjustable flow rates of 1.5, 3 and 5 mm/min for testing equipment rated upto 765 kV.

The rain produced is a mixture of demineralized water (from two 27 m^3 tanks) and tap water; its resistivity can be adjusted in order to comply with different applicable test standards;

- various spark gaps for producing chopped impulse voltages;
- other equipment required for the multitude of tests IREQ conducts for its clients.

ITALY

Numerous testing facilities for UHV research and development are available in various experimental stations and laboratories as follows:

1) The testing area at Suvereto includes the main testing facilities of the 1000 kV Project.

These are:

- Two 800-kV, 20 MVA, test transformers, that can operate both in cascade or independently. They are used for power frequency voltage tests (upto 1600 kV r.m.s., 50 Hz) or as long wave impulse generators (by discharging capacitor banks in the two primary windings) for switching impulse tests on the 1 km test line.

- A 30 stage lightning and switching impulse generator, rated 6-MV, 500-KJ.

- Two 350-kV, 500 kVA test transformers, connected in cascade, for power frequency tests on the cage.

- A 1 km long test line, with a 500 m central span and two 250 m semi-spans. The structures of the test line were designed to support upto three bundles with 12 ACSR 31.5 mm subconductors. The central bundle can automatically be moved horizontally along the beams of the supporting structures, while all the three bundles can automatically be moved vertically in respect of ground. On this line, phase-to-phase and phase-to-earth switching impulse tests are performed. Single-phase 50-Hz tests (long term recording and instantaneous measurements) are also carried out to investigate corona losses, audible noise, radio and television interference.

- A UHV line model (cage) for corona tests.
The total length of the cage is 40 m, but the active part is only 30-m long. The shape is cylindrical with a diameter of 7 m. Bundle conductors having upto 18 subconductors, evenly or unevenly spaced, can be tested.

1) The cage is supplied through the two 350 KVA transformers in cascade.

2) The testing facilities at Pradarena pass are specially devoted to mechanical tests. They include a 525-m long span which is equipped with a single conductor for ice and wind loadings during the winter and with conductor bundles for studies on vibration, sub-span galloping and spacer performance during the summer. Bundles with upto eight 31.5 mm subconductors can be tested.

3) At the mechanical laboratory of Brugherio (Milan), a vibration exciter of the electrodynamic type, with a frequency range of 5 to 300 Hz, can be applied to line elements and single or bundle conductors over a span of upto 300 m in length. A chamber is also available for thermo-mechanical tests on insulator strings, during which the load can be varied from 0 to 30 t and the temperature from - 35 to + 120°C.

4) Four natural pollution testing stations are in operation in different regions of Italy to investigate different types of contamination (marine, industrial and mixed contamination).

5) Two experimental stations for investigation on lightning are in operation in two areas of high keraunic level.

6) Tests in the UHV field are also performed at CESI laboratories in Milan, where the following main facilities are available:

- High power laboratory, for electrodynamic tests on line and substation components (currents of upto 70 kA r.m.s. and durations of upto 1 sec.).
- High power synthetic test laboratory, to test breaking units or fractions of UHV circuit-breaker poles (maximum equivalent short-circuit power:30,000 MVA single-phase, with maximum available current of 150 kA).
- For room for artificial pollution tests on external insulation, with maximum testing voltage of 900 kV to earth.

JAPAN

The main UHV testing facilities in Japan are summarized hereafter.

a) Testing facilities of CRIEPI

- UHV fog room for testing of polluted insulators. The main characteristics of the fog room are the following:Floor space:35 m x 26 m. Ceiling height: 35 m. Testing transformer: primary voltage to ground 66 kV; secondary voltage to ground 900 kV; short-circuit current 50 A; voltage drop of the total system less than 3 percent at a leakage current of 3A.

Steam fog generated from 200 nozzles and steam boiler of 4,800 kg/hour.

- Long term insulator exposure UHV testing facility.

A new testing facility for AC-UHV and DC-500 kV insulator testing under continuous energization in natural conditions will be constructed at the sea coast.

- UHV AC full scale test line. A double circuit full scale test line has been constructed. Its scheme is outlined in Figure 6. Major design criteria for this test line are: design voltage 1000 kV AC (converible to ± 500 + 650 kV DC); total length 600 m; 2 spans; 3 towers; suspension insulators with mechanical and electrical strengths of 42 tons and 54 tons, 38 and 32 units in one string, respectively.

Conductors; ACSR 810 mm^2 (38.5 mm in diameter), 10 conductor bundles, convertible to 8 and 12 conductor bundles.

Ground wires: two ACSR 810 mm^2 conductors. The static induction shielding wire is a steel stranded wire with aluminium coating (cross-section 100 mm^2). The maximum electric field strength at ground is 4.5 kV/m when 6 shielding wires are adopted,and 3 kV/m in the case of 10 shielding wires.

On the UHV test line, the behaviour of conductors and towers is measured under strong wind, earthquake and artificial shaking tests. Also, audible noise caused by strong wind, and lightning performance will be investigated.

Construction and maintenance techniques and environmental problems will also be studied using this line.

In the future, testing transformers for three-phase energizations and electrical measurement instruments will be installed, and corona audible noise, radio interference, television interference and electric field strength will be investigated. The effect of electric field on vegetation and cattle will also be investigated.

- Corona cage

The corona cage at CRIEPI, mainly used for A.N. tests, has a cross-section of 8 m by 8 m and a length of 25 m.

b) Takaishiyama test line of Tepco

This test line has been designed for ice and wind tests. Two spans with ten ACSR conductor bundles (810 mm^2, 40 cm subspacing) and and ground wire of the same conductor type are strung approximately erpendicular to the winter wind having the prevailing direction of NNW.

One of the two spans is equipped with a galloping control device while the other has no control system; they are separated by an independent tower to eliminate the disturbance introduced by the other span.

Recording of dynamic phenomena, such as tension and displacement amplitudes of conductors and insulator assemblies, is performed automatically on the test line.

c) UHV testing equipment of NGK

Corona testing equipment

Corona tests (visual corona, interference measurements) are performed in a 40 m x 40 m x 30 m high room, electrostatically shielded (75 dB attenuation at 1 MHz). The room is equipped with testing transformers in cascade connection, rated at 1650 kV and free from corona upto 1000 kV.

Pollution testing equipment

The 1000 kV pollution testing equipment has been constructed at NGK High Voltage Laboratory, and its operation was started in January, 1979.

The main characteristics are as follows:

- Dimensions of the fog room: 25 m x 30 m x 30 m (height)
- Generator rating: 30 MVA.
- Transformer rating: 1000 kV to ground, 5000 kVA.
- Voltage drop of total system: less than 5 percent at 3A for 600-1000 kV.
- Short-circuit current: 40 A r.m.s. at 1000 kV.
- Artificial fog generated from 150 nozzles and a steam boiler of 3600 kg/hour.

The fog room is electrostatically shielded, which results in 65 dB attenuation at 1 MHz, so that RIV and AN tests on insulator assemblies under polluted conditions can be made.

UNITED STATES - AEP/ASEA

The UHV test station is located near South Bend, Indiana, adjacent to a 765 kV substation of the AEP network. Basically this station has the capability of testing single phase conductor bundles upto a test voltage of 2255 $\sqrt{3}$ kV. It includes a test line (consisting of 3 spans each 305 m long) and a transformer (manufactured by ASEA and rated at 420/835/1785 kV, three-phase equivalents, and 333 MVA). The transformer is designed with one wound limb and constitutes a prototype for a three-limbed 1000 MVA power transformer. A low-range connection provides 1110 to 1817 kV and a high-range connection provides 1619 to 2255 kV (three-phase equivalents).The lower range is designed for corona performance tests to be compared with other UHV project data, while the higher range is provided to explore the 1500-1600 kV voltage levels for AEP future lines. Reference (5.10) includes a detailed description.

In addition, two cages are operated for simultaneous, yet independent, testing and comparison of two different conductor configurations or of two samples of the same configuration.

They are electrically independent of the test line. The test cages will be used to compare the performance of one conductor with another in a shorter time. Each cage is 30.5 m long. The cages have a square section and their dimensions can vary between 6.1 x 6.1 m and 9.1 x 9.1 m. The maximum test voltage is 900 kV.

Test station instrumentation is described in Reference (5.9).

UNITED STATES - BPA

The full-scale, three-phase, 1200 kV prototype line near Lyons, Oregon is 2 km long over 7 spans. It is energized from a 230/1200 kV auto transformer consisting of three single-phase units, each rated 50 MVA. Special surge arresters rated 768 kV of the current limiting design were used initially. They were later replaced by ZnO surge arresters. The SIL and BIL of the 1200 kV transformer windings are 1800 and 2050 kV, respectively.

The transformer is equipped with no-load taps for a voltage range from 1100 kV to 1250 kV on the high side and down to 236 kV on the low voltage side.

Audible noise, radio and television interference, ozone, and corona loss levels are monitored continuously at the test site together with weather and atmospheric data. A 256 channel data acquisition system is used to gather the data which are transmitted via microwave communications lines to a CDC 6500 computer in Portland.

The test facilities at the Carey high voltage laboratory include a low frequency 1.1 MV single phase power supply. Tests are conducted on air gaps, insulators and hardware. In addition an indoor 1.8 MV, 43 kJ impulse generator with 12 stages, an outdoor 5.6 MV, 448 kJ impulse generator with 28 stages, and a portal test tower measuring 36 m x 36 m and equipped with water spray racks and adjustable ground plane panels to simulate tower windows are available.

The Moro mechanical test line, especially designed to allow simultaneous testing of two bundles configurations with upto eight 46.1 mm conductors per phase, is 1.8 km long and consists of two dead-ends and four suspension lattice steel structures. The test line was initially strung with 40.7 mm ACSR Chukar conductors in single, twin and 8 bundle configurations.

In 1979, the twin Chukar bundle was replaced with an 8 Cowslip all-aluminium conductor bundle which has a diameter of 760 mm. Both conductor bundles are capable of being remotely rotated $\pm 17^{o}$ from their normal symmetrical position in order to evaluate the effects of bundle orientation on wind induced conductor motion. Both spacer-dampers and rigid spacers have been used on the bundles at staggered and equal spacings. The data collected on the line are transmitted to a CDC 6500 computer in Portland.

Mechanical and structural studies are also performed at the Mangan Laboratory where the following facilities are available:

- A 2.2. MN horizontal test machine capable of testing specimens upto 38 m in length. For cyclic testing, frequencies range from 0.002 to 100 cycles per minute.

- An environmental test chamber is available for tests at ambient temperatures from - 45° C to + 95°C at various relative humidities. One of the main features of this facility is its modular construction.

A 50 m long conductor study and fatigue span capable of stressing conductors upto a horizontal load to 450 kN. A fatigue test machine is available for tests on hardware in compression or tension with full range of 535 kN.

UNITED STATES - GE/EPRI PROJECT UHV

Existing facilities at Project UHV in Lenox, Mass., which can be used for 3-phase AC overhead transmission research, can now be used also for HVDC research. New equipment has been installed as part of this Project to make possible a comprehensive research program with test voltages upto ± 1500 kV. The HVDC facilities in place at Project UHV include:

- A bipolar test line 520 m long, with the capability of varying pole spacing and height above ground.

- Equipment to energize the test line with bipolar voltages upto ± 1500 kV. Two 1500 kV high voltage sets are available, one being a voltage doubler installed in 1978 for the Department of Energy and the other being a symmetrical cascade rectifier set, installed in 1979 for this Project.

- Instrumentation to measure radio noise, audible noise, television interference, ozone, corona loss, electric field, ion currents and meteorological variables.

A bipolar short test line, 160 m long, for research on corona, field, and ion effects of HVDC transmission lines upto ± 600 kV.

- A bipolar conductor test bay, 60 m long, and a monopolar cage, 13.7 m long, for basic electrical research on HVDC conductors.

- A UHV test chamber, 24.5 m high, and 24.5 m in diameter for flashover tests on insulators. The voltage capability of the test chamber is $\pm$ 1100 kV.

- An auxiliary $\pm$ 375 kV test set for dielectric tests on insulators and for research on field and ion effects using the short test line, the bipolar conductor test bay and the monopolar cage.

The facilities for HVDC research available at Project UHV are shown in the plan of Figure 7.

The new HVDC facilities extend the UHV AC capabilities, which include:

- three-phase test equipment for line tests with AC voltages upto 1500 kV (r.m.s., line-to-line);

- conductor cages for simultaneous corona tests of upto five bundles in natural weather conditions;

- equipment for tests on contaminated insulators upto 850 kV (r.m.s., line-to-ground);

- switching surge equipment for voltages with time to crest of 500 to 2000 μs, crest of 2500 kV (phase to-ground), 3300 kV (phase-to-phase), applicable directly to the UHV test line.

USSR

A 1200-kV experimental test plant was set up at the Bely Rast substation. It consists of a three-phase 1170-m-long line with the appropriate 1200 kV switchyard.

Two phases of the line are fed from single-phase $\frac{1140}{\sqrt{3}} / \frac{500}{\sqrt{3}} /$ 18 kV, 210 MVA autotransformers, and the third phase from a cascade consisting of:

1) one or two single-phase $\frac{750}{\sqrt{3}} / \frac{500}{\sqrt{3}}$ /10 kV,

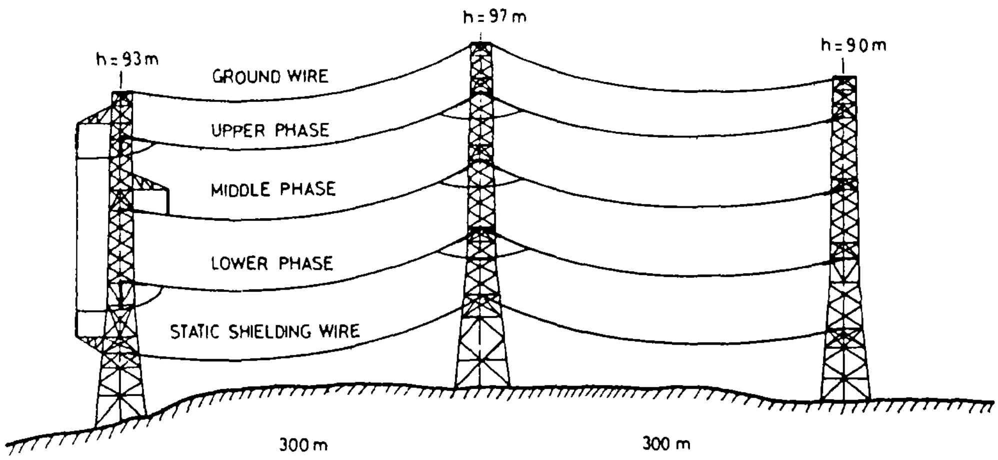

FIGURE 6

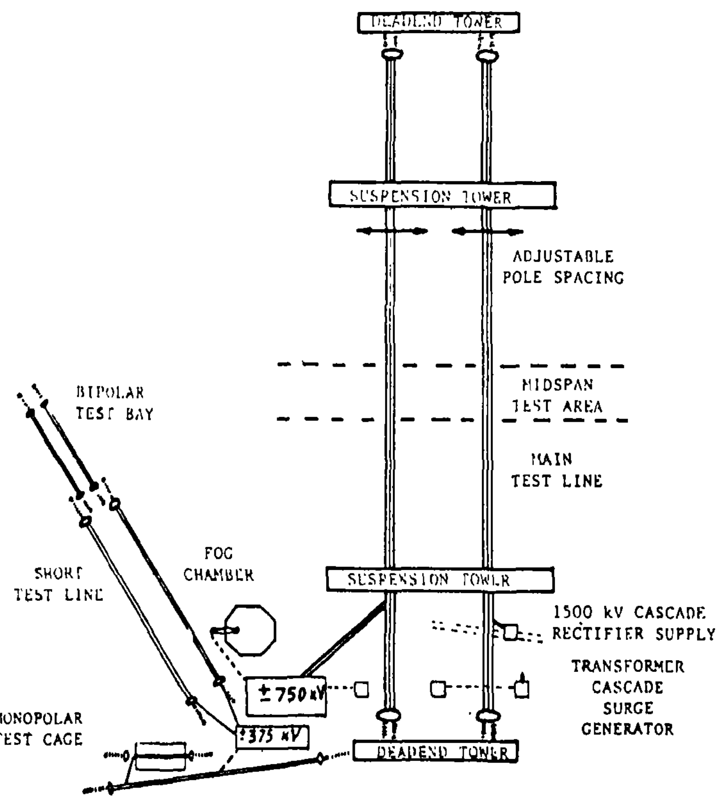

FIGURE 7

417 MVA autotransformers, with voltage regulation under load ($\pm$ 5 percent) in the neutral, and of:

2) a single-phase $\frac{500}{\sqrt{3}} / \frac{200}{\sqrt{3}}$ /35 kV, 110 MVA autotransformers.

The different alternatives for autotransformer connection in a cascade enable the voltage at the cascade terminal to be varied between 300 and 1250 kV.

The 1200 kV installation is fed from the 500 kV switchyard of the Bely Rast substation through a group of 750/500/10 kV, 3 x 417 MVA autotransformers.

The 1200 kV test line consists of four (260, 325, 325 and 260 m) spans.

The 1200 kV switchyard was designed as a prototype of the future line-bay. A circuit-breaker with 5 arc quenching modules, a disconnector, voltage and current transformers, and a lightning-arrester were installed. A phase-to-phase clearance of 12 m, a phase-to-structure clearance of 7.5 m, and a phase-to-ground distance of 13 m were applied.

The studies carried out with the help of the experimental facility of Bely Rast were on the following subjects:

- tests of the internal and external insulation of electrical equipment, both at power-frequency and at switching surges with simultaneous heating and cooling of internal insulation by the operating current flow;
- measurement of switching surges;
- measurement and recording of radio interference and audible noise;
- pollution impact on longitudinal voltage distribution;
- bus-bar arrangement and insulation for 1200 kV substations;
- electrical fields at a substation;
- collected experience in installation and maintenance of equipment;

- detection, in the process of operation and tests, of *faults and design defects among test specimens of the* equipment in order to avoid these faults when manufacturing commercial equipment.

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