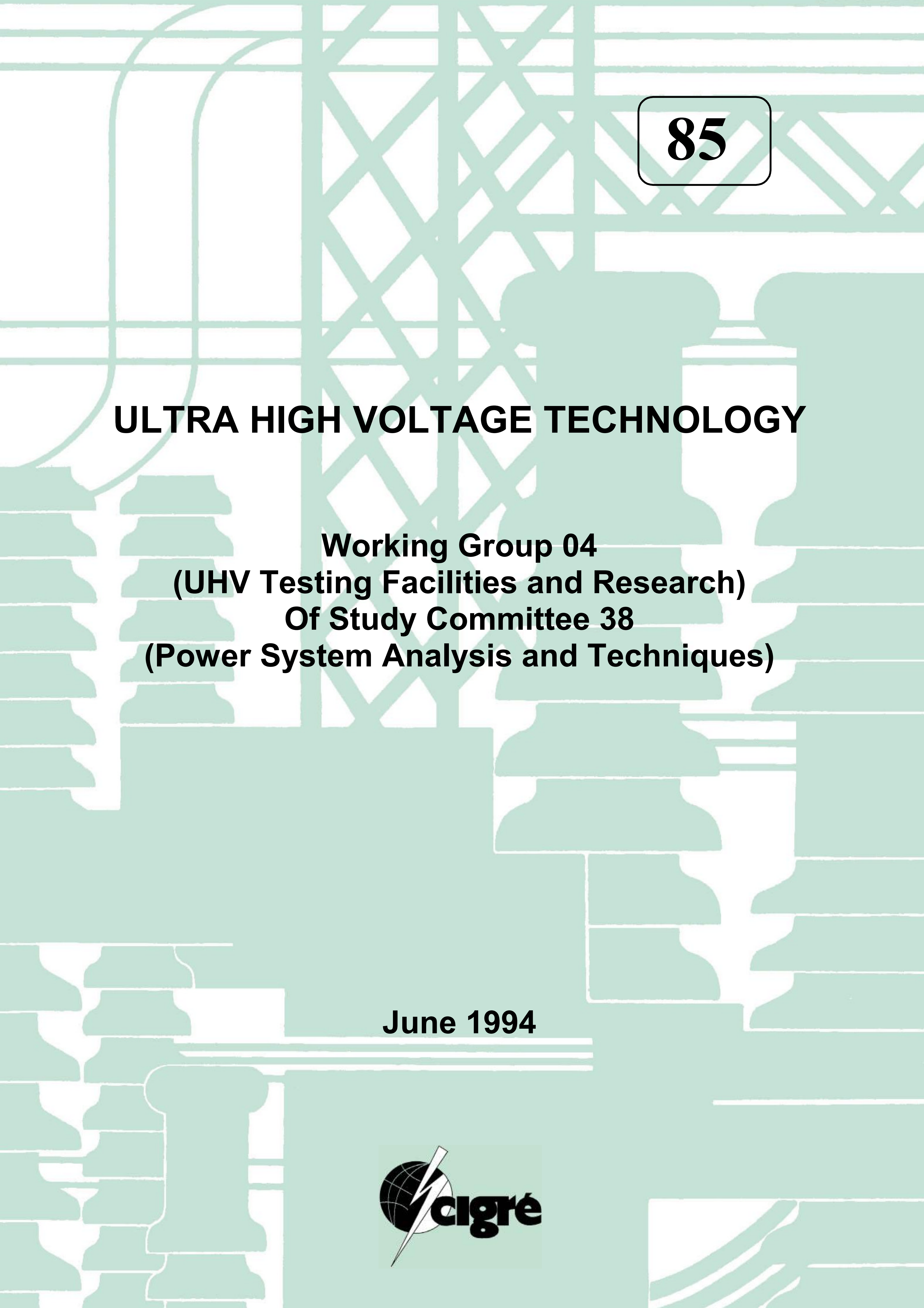

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ULTRA HIGH VOLTAGE TECHNOLOGY

Working Group 04
(UHV Testing Facilities and Research)
Of Study Committee 38
(Power System Analysis and Techniques)

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Ultra High Voltage Technology

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Preface

This brochure is intended for system planners to get on state-of-the-art on UHV Technology. A summary of this paper is presented at the CIGRE conterence 1994 joint session SC 37/38. This paper contains the detailed background information used by the WG in concluding on the state-of-the-art UHV Technology.

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ULTRA HIGH VOLTAGE TECHNOLOGY
PAPER PRESENTED IN THE NAME OF STUDY COMMITTEE 38
(POWER SYSTEM ANALYSIS AND TECHNIQUES)
BY
WG 38.04 - UHV TESTING FACILITIES AND RESEARCH

1.0 - INTRODUCTION

The state-of-the-art of UHV Technology was the subject of two previous CIGRÉ reports, issued by the former working groups 31.04 [1] and 38.04 [2] in 1983 and 1988, respectively.
In 1988 the SC 38 formed a new WG 38.04 (UHV Testing Facilities and Research), assigning to it the preparation of an updated version of the 1988 report [2]. The new WG launched then four task forces to study and report about the following areas of interest included in the scope of its activities, namely:

TF 38.04.01 - UHV System Planning, Performance and Reliability Aspects

TF 38.04.02 - UHV Transmission Lines

TF 38.04.03 - UHV Substation and Equipment

TF 38.04.04 - UHV Testing Facilities and New Technology

The findings of the task forces are included in this report with the same titles as given above, therefore constituting the bulk of this paper. A separate section reporting about the present status of the existing plans to build UHV transmission systems in diferent parts of the world has been included in the beginning, having been prepared by the Working Group on the basis of enquiries conducted and of a compilation of published information.
Due to the sluggish situation of the economy prevailing in most parts of the world since 1988, development in the field of the UHV Technology are happening at a slower pace than in the previous decade. The progress reported in this paper has been mainly achieved in a few countries (esp. Japan, Brazil and the CIS - the former USSR) where steps were taken in the last five years for the implementation or planning of commercial applications of UHV.
Due to the above fact this report has not been limited to the description of new developments, being rather an updated consolidation of the previous reports, in which the discussion of some topics that had not been treated in references [1,2] in a systematic way were incorporated.

Key-words

Transmission - UHV - Research.

2.0 - PLANS FOR UHV TRANSMISSION

2.1. BRAZIL

As hydroelectric power resources available near the country's major load centers (particularly concentrated in the Southeastern, Southern and Northeastern regions) are almost fully exploited, the hydroelectric potential of the Amazon basin at the North of the country becomes the obvious choice for the supply of extra power in the first decade of the next century.

When implemented, the mentioned expansion will involve the transmission of large blocks of power, between 30000 and 35000MW, along with distances in the range from 2000 to 2800km. This is clearly a situation calling for the study of alternatives of transmission in AC or DC with voltage levels in the UHV range (i.e, above 800kV AC or +/- 600kV DC). A Study Commission (CPTA) has, accordingly, been organized by ELETROBRÁS, the central goverment's main agency for electricity. The following transmission alternatives have been considered by that Commission [3]:

AC Transmission
. Ultra High Voltage (1050 to 1200kV)
. Extra High Voltage (800kV) with compact lines
. Half - Wavelength Transmission (800 to 1200kV)
. Six - Phase Transmission (317 to 577kV)

DC Transmission
. Ultra High Voltage (above +/- 600kV)
. Extra High Voltage (+/- 600kV)
. Multiterminal Systems

Although a definite choice of the technology has not been warranted by the studies so far reported [3], the contents of the referred paper indicate that alternatives involving the use of UHV stand with a good chance of being selected in the second stage of the CPTA study. The final decision will take into consideration, besides technical advantages / disadvantages and costs, the environmental impact of each alternative, the capacity of the Brazilian and foreign industries to supply the equipment needed and the existence of testing facilities capable of carrying out the tests required in each case.
To inform the ongoing studies, some measuring stations are to be build in prospective corridors to collect information on winds, lightning, pollution and corrosion.
The selection of the prospective corridors is to be made on the basis of an environmental survey with the aid of pictures taken by satellite.

2.2. CHINA

The extension of this country's territory and the existence of unexploited hydroeletric potential in regions remote from main load centers are reasons compelling the Chinese government to consider the use of ultra-high-voltage alternatives of power transmission. The construction of laboratories to make possible the study of this possibility has been reported in [2]. Unfortunately, no further news of the Chinese progress in this respect have reached the WG since this publication.

2.3. ITALY

In Italy, ENEL, after completing the first two stages (Research and Prototypes) of its 1000kV Project, is now completing the third stage (Demonstration) with the construction of a 1050kV pilot plan, consisting of a 2.8 km long 1050kV overhead line and a 420/1050kV, 1200 MVA (SF_6) substation [4]. The line has been already erected, the three single phase autotransformers (400 MVA each) and all the SF_6 substation components have been manufactured, while assembly operations and acceptance tests are in progress. The pilot plant is expected to be completed by the end of 1993.
At present there are no plans for the introduction in Italy of a new voltage level higher than the existing 400kV [5].

2.4. JAPAN

The construction by the Tokyo Electric Power Company of the first 140 km of a double - circuit transmission line designed for 1100kV has been completed in 1992. An extension of 50 km shall be added by the end of 1993. This line has been envisaged to carry power from a remote nuclear power plant on the Sea of Japan to the Southwestern tip of the existing 500kV system, some 250 km away. These lines are planned to be in 500kV operation at first stage, and upgraded to 1000kV in the first few years of the 21st century. [2]

2.5. CIS

The sole case of a UHV system in commercial operation in the world was designed to interconnect, by means of four 1200kV AC transmission line sections, a large part of the territory of the CIS, stretching between the Urals and Siberia in Russia to Kazakhstan. This system, commissioned from 1982 to 1988, has at present two lines of about 900 km operating at 1200kV and two lines of about 100 km operating at a reduced voltage (500kV).
A UHV-DC Transmission System with transmission lines of about 2400 km is scheduled to be commissioned in few years from now [16], [17], [18].
No information on plans for futher employment of the UHV technology in the new countries that emerged from the former USSR could unfortunately be obtained.

2.6. SWEDEN

So far there are no plans in Sweden to introduce UHV. The main interest concerning the transmission technique in Sweden now involves the use of HVDC-cable transmission to the Central-European network. As fairly long cables are needed (~200 kilometers) massimpregnated sea-cables will have to be used, and for such cables the highest voltage is 400-500kV, which is below UHV.
For overhead transmission lines the Swedish have a research project under progress. This project is aiming at an AC-line design which can be converted to HVDC in the future.
The pole is of the triangular type with the phases in a triangle inside the pole construction. For DC the two bundles of pole conductors will also be placed inside the pole. Their main interest concerns corona losses by a small bundle separation up to about +/- 500kV DC. This

is of little interest for the normal HVDC design with the earthed pole construction between the two HVDC conductors.

2.7. U.S.A.

Due to the low load-growth rates in the last years, the prospects for the introduction of UHV AC or DC in the USA are now still dimmer than reported in [2]. As no concrete plans are under consideration at this stage, it may be anticipated that only well after the year 2000 the first UHV American project will come true.

3.0 - PLANNING AND RELIABILITY ASPECTS OF UHV TRANSMISSION

This item was prepared for the purpose of outlining the various features that govern the planning and reliability aspects of transmission systems in general and UHV in particular. These considerations are presented under the following headings:

. Definition of Transmission Planning
. Transmission Planning Methodology
. The Influence of Costs
. The Influence of Design Criteria
. The Influence of Performance Data

3.1. Definition of Transmission Planning

The object of transmission planning is a network which is economical, realiable and in harmony with its environment. These three attributes are evidently related and the creative work of planning is to find the right balance between them. The search for this balance involves an understanding and an evaluation of the requisites and constraints that form the ingredients of system planning.

3.1.1. Requisites

The requisites that govern the plannig process are those qualities which characterize a well-ordered system. They have been reduced to the following five: criteria, proportion, reserves, flexibility and simplicity.

- Criteria

One would expect the system design to conform to certain standards and these we call our criteria. They relate to the performance of the system under steady-state and transient conditions.
Under steady-state conditions, we expect that the voltage and frequency will be maintained close to their nominal values and that the electrical and magnetic field effects and audible noise and radio interference will be within acceptable standards.
Under transient conditions, we identify two kinds of disturbances to which the system can be subjected: normal and extreme. Normal contingencies are those embedded in the design of the network and with which the system can cope without load or generation shedding. Extreme contingencies, on the other hand, such as the loss of a substation or all the lines in a corridor, usually involve loss of load or generation or both.

- Proportion

Most dictionaries define proportion as the comparative relation between things as to size and quantity. This sense of proportion is more often evident in generation planning such as in the relation between unit sizes and the system load. Equally important, however, but often neglected, is the proportion between generation and transmission facilities since generation is usually regarded as a good and transmission as an expense.
In the transmission system itself there is a need for that desirable proportion between the size of generator transformers, the size of substations and especially between the loading of transmission lines and the size of the system load. It takes a very large system to justify a 5000MW circuit.

- Reserves

Reserves are an integral part of the transmission system design and are usually provided through spare units in service or in a central equipment bank. Basic reserves in lines, transformation, compensation and switching equipment are usually defined by the design criteria itself, in particular by the definition of a normal contingency such as N-1.
There are, in fact, other contingencies which can be coped with quite effectively by a judicious measure of transmission reserves, bearing in mind, however, that at the higher voltages the forced unavailability tends to be higher and the reserve requirements greater, particularly with respect to power transformers. It is encouraging to note, however, that a task force composed of the principal users of 765kV transformers has initiated a series of reforms with the result that the recent performance of these transformers has considerably improved.

- Flexibility

Flexibility in the planning context generally refers to the ability of the long-range plans to adapt to changing conditions, the most significant of which is probably changes in the rate of growth of the load. One should be able to slow down or accelerate the installation plans as required and this is particularly true when large generating complexes are involved. To cushion this effect somewhat, the planner often relies on interconnection planning: the sharing of surplus or shortfall to accomodate fluctuations in the demand.
Interconnection planning has become a very refined science as a result of large and rapid variations in demand and has placed a special mission on the transmission system for this purpose. This includes both AC and DC interconnections, radial operation of

generating stations, voltage support equipment in strategic locations and an adherence to the design and operating criteria of the wider power pool of which the transmission system, by virtue of its interconnections, is now an integral part.

- Simplicity

The most significant and least appreciated requisite, this property of a system should reflect the planner's care in delivering a transmission system that is demonstrably operable. There is no doubt that as the system is expanded to include EHV lines and stations, series and shunt compensation and DC facilities, the complexity of the system is increased and so also are the operating skills required.

One should try to avoid, therefore, too great a reliance on special protection systems. In fact one should limit their use to extreme contingencies and allow the normal controls and protection systems to carry out the system operation. In this respect the planner should provide the operator with an operating philosophy which could be, in fact, an expert system to cope with the multiplicity of events that are normally encoutred in system operation.

3.1.2. Constraints

The constraints that govern the system planning process or more accurately define its limitations, have been identified quite arbitrarily as the following five:
environmental, financial, available resources, technology and geography.

- Environmental

Whether the respect for the environment should be a constraint or a requisite is a moot point. For the planner it is, of course, the first constraint. In fact, respect for the earth is now everyone's first concern.

The burden is on the planner, therefore, to be open to all aspects of a problem and to analyze them thoroughly so that decisions can be taken on the basis of facts: all the facts.

This process is generally referred to as open planning whereby all interested parties can be consulted with respect to any given project and a consensus developed with at least some degree of unanimity and public acceptability.

- Financial

The most severe constraint on system development is of cource the availability of funds to finance long-term plans. As it happens, this constraint often results in the postponement of large-scale projects in favour of more realizable ones of smaller scale, often of reduced efficiency. Only the rich can afford to economize.

While this constraint is most evident in generation planning, it is also a determining factor in transmission planning. It is reflected in the design of lines and stations: lower voltages, smaller conductors, inadequate equipment, all related to the shortage of funds. Furthermore, underdeveloped systems usually exhibit high losses and this represents a heavy cost which perpetuates itself and can only be rectified by massive reinforcements.

- Available Resources

The natural resources available to any power system naturally influence the generation and transmission pattern. This is particularly evident in countries such as Canada where large hydroelectric developments have been associated with major transmission systems such as the 500kV system of the Peace River in British Columbia, the 450kV DC system of the Nelson River in Manitoba and the 735kV system of Manicouagan and James Bay in Québec.

Where resources are more centrally located, the move to EHV transmission has not gone beyond the 400kV level established by Sweden forty years ago. Only in the CIS is UHV a reality and indeed the first 1200kV line is already in operation. Much effort and expense has been dedicated to the development of UHV in North America over the last twenty years at the Bonneville Power Administration at the American Electric Power and at General Electric but no 1200kV system is in sight. Technology is not always the whole answer.

- Technology

Technology constraints have the effect of limiting the planner to certains types of equipment. Technology constraints are in fact financial constraints in that today's technology has not produced the economy that was promised: an instance of the triumph of hope over experience. As already suggested, UHV lines and equipment are costly, particularly when we consider the performance of 735kV equipment and the number of spares required. HVDC also has its limitations and long-distance cable systems have proven to be uneconomic in some cases.

The idea that technology can solve every problem is now being questioned and rightly so. The planner must make use of all available disciplines: one cannot confine oneself to one's own field of expertise. Finally, as each plateau of technology is reached in any system development, it should be maintained as such for a number of years and the urge to optimize should be severely resisted.

- Geography

The geographical context in which a power system operates has a determining effect on the design of the lines and stations and in this connection we could mention pollution, elevation and weather.

High pollution levels, such as heavy sand or salt deposits, require longer and special insulators both for the lines and stations. Since the pollution level determines the power-frequency response of the insulation one has no choice but to add more insulation with greater pollution. This will affect the cost and possibly even the choice of voltage level, particularly for DC which is especially sensitive to pollution.

Air insulation at high altitude tends to become weaker and lines intended for operation in such areas can be relatively expensive. Here the response of the insulation is to the switching overvoltage but even after all corrective actions have been taken to control this overvoltage, the fact remains that the required clearances will be greater.

In areas where there is well-known adverse weather such as ice storms, special heavy-duty lines are required - lines with a higher steel-to-aluminium ratio for the conductors - resulting in more costly towers. Similarly, areas of high keraunic level may require lines with shielding and special grounding features so as to mitigate the effect of lightning on the overall reliability performance of the system.

3.2. Transmission Planning Methodology

An outline of the methodology for AC transmission planning is shown in Figure 1 and consists essentially in selecting and analyzing those alternatives which will satisfy all the requisites and constraints. The experienced planner will convert these requisites and constraints into a class of plans which are likely to meet these requirements.

The DC transmission planning is not quite the same, as can be seen in reference [22], where an example of a methodology is given.

Since standard voltage levels are relatively few in number, it is possible to narrow down the choice to two or three reasonable alternatives. The choice of voltage levels and the mode of transmission (AC or DC) will depend to a large extent on the power to be transmitted and the distance involved. This brings us to the actual methodology of planning and in this connection we must distinguish between deterministic and probabilistic methodologies.

3.2.1. Deterministic Methodology

Most utilities have always used deterministic methods for transmision planning at least up to the present time. This is particularly true of North America where the utilities from coast to coast are members of one of the reliability councils of NERC (North American Electric Reliability Council) and conform to a set of criteria for design and operation. The most common criterion for design purposes is a three-phase fault which is generally accepted for two reasons:

- It is easy to define and test for,
- it is an umbrella type of criterion which covers a wide range of contingencies

In strongly-knit systems, such a criterion would be more than adequate since normal contingencies are no problem and extreme contingencies very rare because of the nature of the system. It would be wrong, however, to ascribe too much physical significance to this concept of a three-phase fault because it is essentially a concept.

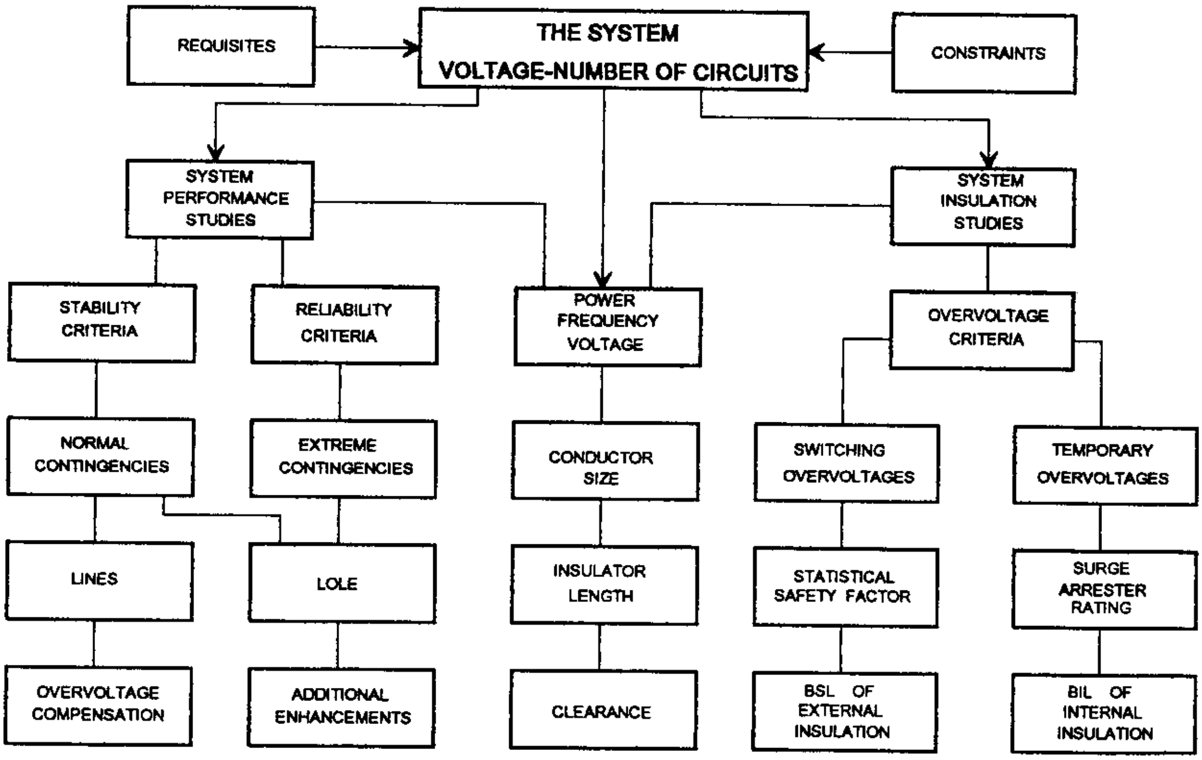


Figure 1 - TRANSMISSION PLANNING METHODOLOGY

3.2.2. Probabilistic Methodology

The probabilistic approach is widely used for generation planning and indices such as LOLE (Loss-of-Load Expectation) and LOLP (Loss-of-Load Probability) are universally accepted. In the field of transmission planning, the application of probability methods is still in the formative stage mainly because of the existence of power pools with their own criteria.

Nevertheless, in assessing the relative performance of EHV (or UHV) systems, both normal and extreme contingencies must be considered and their effects evaluated. These can be significant if we are dealing with long transmission systems that are not closely knit and where extreme contingencies have some probability of occurrence.

The evaluation of the LOLE and LOLP for an EHV (or UHV) system can be considered in two stages:

- In the first stage, one can evaluate the effect of normal contingencies such as the loss of an element. This would be reflected in the loss of capacity until the element is replaced and the effect would depend on the failure rate and repair rate of the element involved.

- In the second stage, one can evaluate the effect of extreme contingencies such as loss of a corridor of lines, provided one has an estimate of the probability of ocurrence of such events.

It can be appreciated that the evaluation of the reliability of alternative transmission schemes by this probabilistic method may involve some surprises. It may turn out in fact that the most economical scheme based on deterministic criteria is not the most reliable and may even lose its preferred place once the necessary reinforcements have been added to make it as reliable as its competitors.

3.2.3. Combined Methodology

There is no question that where UHV transmission is being considered as an option, there must be an evaluation of the reliability performance of this option as well as of those with which it is being compared. It is not enough any more to compare schemes solely on the basis of deterministic criteria.

The estimation of the contribution of the transmission system to the overall LOLE has been termed "Composite System Reliability Evaluation".

There is some concern that the application of this methodology could lead to possible overdesign of the transmission system. In general, however, it has been demonstrated that a design on N-1 will cover most of the reliability requirements.

3.3. The Influence of Costs

As a general approximation and discounting local conditions, it would seem that a 1200kV line would cost twice as much as an 800kV line. This appears reasonable since there are twice as many conductors of the same size which in turn basically determines the cost of the line. If we consider distances in the order of 1000 km, the line costs will be about seventy-five percent of the total transmission cost, assuming air insulation for the station equipment. Naturally, if the land space is critical, then GIS stations (and even double-circuit lines) may be justified depending on the amount of power involved. If we confine ourselves to a situation of available land space, then we can make some general comparisons of least-cost transmission alternatives for various power transfers.

An example of such a generalized result is illustrated in Figure 2 in which it is shown that for a specific study the least-cost voltage level as a function of power and distance for one given set of criteria: two-line minimum, 60% maximum series compensation, 50% maximum SVC, three-phase six-cycle fault, temporary overvoltage (TOV) of 1.3-1.5 p.u.

It can be seen from this figure that for this particular study there is a wide range of application of 735kV from 3 to 15 GW and up to 1500 km. Above 15 GW, 1200kV is more attractive at least up to 1000 km where HVDC is to be preferred.

It has been suggested that the application of flexible AC transmission systems (FACTS) may lead to increased transmission transfer capability and improve the performance of UHV systems. This is certainly possible but such improvements would also be obtained at EHV level. The basic problem facing UHV is really the conductor size based on corona, AN and RI requirements.

From this preliminary picture, it would appear that the justification for UHV will have to encompass more than a simple analysis of line and equipment costs. It will have to include a consideration of the plurality of aspirations of the general public.

3.4. The Influence of Design Criteria

Figure 3 shows an example of a transmission cost in $/kW as a function of distance for different power levels from 3 to 15 GW. The cost varies linearly with distance as would be expected and is held within a narrow bandwidth for the economic voltage. This curve was initially produced using the same criteria as in Figure 2. The criteria were then subsequently varied to determine their effect on the cost of transmission.

In this particular study after numerous simulations, it was observed that there was little effect of either the stability or overvoltage criterion on the cost.The stability criterion covered clearing times from one to six cycles to simulate types of faults. The overvoltage criterion (TOV) was varied from 1.5 to 2.0 p.u. There were some exceptions but the basic form of Figure 3 remained intact.

This phenomenon can be attributed to the requirements of the steady-state voltage before and after a system fault. In a long transmission system, the principal problem is one of voltage instability: the need to maintain flat voltage at all times. This requires significant amounts of SVC. Likewise, the control of temporary overvoltage on very long lines requires a considerable amount of series compensation: shunt compensation (SVC) is not sufficient for this purpose.

Thus it is that when these two requirements are fulfilled, namely flat voltage and TOV, there is sufficient reactive power in the system to cope with even a three-phase fault. In a sense, therefore, the stability performance comes as a fringe benefit: it is an output of a good design rather than an input.

This result reinforces the fact that one of the main occupations of transmission planning is the management of reactive power. Fortunately the planner is provided with a wide range of compensation techniques for this purpose. In the future, these techniques will be enhanced by the development of power electronics and their application to such devices as electronic synchronous condensers and variable series compensation.

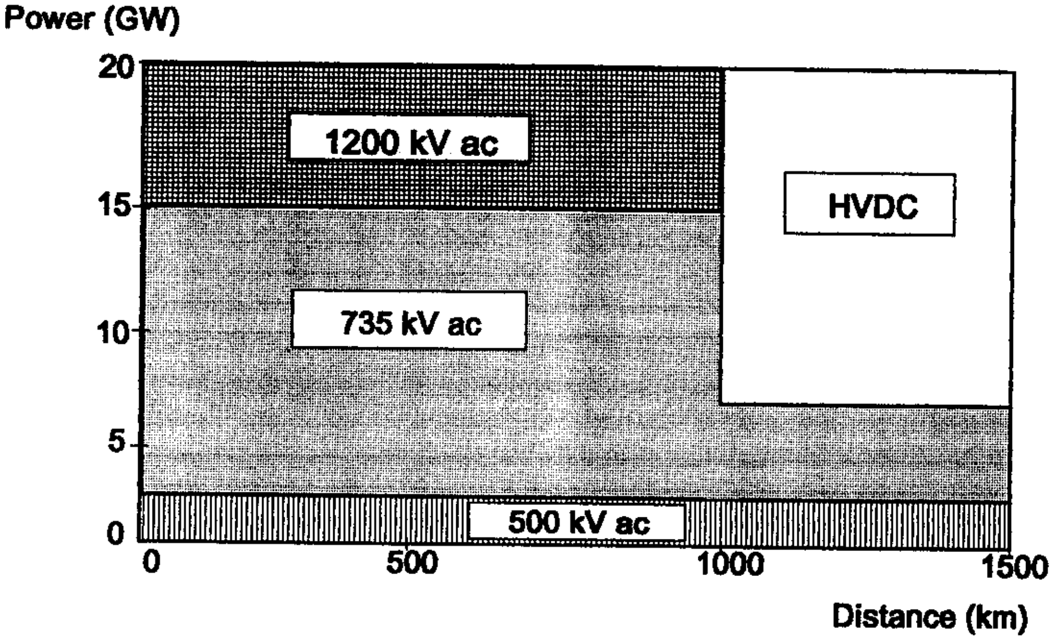


Figure 2. ECONOMIC VOLTAGE LEVEL AS A FUNCTION OF POWER AND DISTANCE

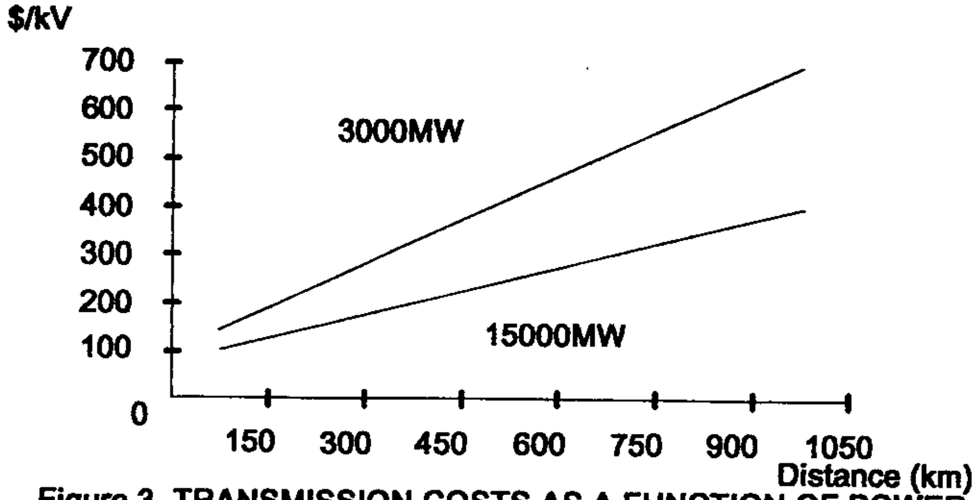


Figure 3. TRANSMISSION COSTS AS A FUNCTION OF POWER AND DISTANCE

3.5. The Influence of Performance Data

The importance of collecting outage data has been recognized for a long time and a system for the recording of component outages of transmission equipment has been in operation in Canada for the last ten years. The principal feature of the Canadian system is that it is component-oriented. Thus one can determine the failure rate and repair rate of the main components of transmission equipment quite independently of their location, function and even their importance in the network.

The abstraction or detachment makes it possible to analyze and design the arrangement of equipment for maximum system performance. It also enables one to carry out the following calculations:

- The calculation of the number of spare units of any type required to meet the design criteria with a given degree of assurance,

- The calculation of the reliability of the transmission system in terms of the LOLE and LOLP for normal and extreme contingencies.

The reliability of the power transmission system is calculated using state enumeration which analyzes normal and extreme contingencies. The probability of occurrence of each degraded state is based on the failure and repair rates of the individual components. For any degraded state, the criteria consist of maintaining stability, voltage profile and acceptable overvoltage for that state as well as topological constraints for any subsequent single-level contingency. If maximum power cannot be transmitted in this degraded state it is therefore reduced to meet the criteria. Once the state's power generation reduction is calculated, the reliability program measures loss of load probability (LOLP) and loss of load expectation (LOLE).

Transmission facilities meeting operational and contingency criteria are traditionally evaluated based on the cost of equipment and losses. Reliability, however, provides an additional tool to enhance the comparability of alternatives by providing minimal reliability standards and additional ranking schemes. Systems with lower total cost and higher reliability are clearly superior, yet assigning a penalty cost to unreliability (LOLE) provides a correcting factor to the overall cost. Due to uncertainty in the cost of unserviced load, a graphical sensitivity analysis can aid in determining superior designs.

Certain designs which are least costly from the point of view of capital investment may be more expensive when the cost of unreliability is included. The cost of unreliability is, of course, a very arbitrary decision and may in fact have no bearing on the choice of transmission system for highly reliable systems which may merely indicate that these systems are overdesigned. The principal point is that there now exist reliability programs that are able to evaluate the effect of unreliability on system design and its cost.[19]

4.0 - UHV TRANSMISSION LINES

In this item the main aspects concerning the electrical / mechanical design and the maintenance of UHV transmission lines will be commented on, as obtained by means of international questionnaires prepared with a view to gathering information about the experience of a number of countries / utilities on these topics - particulary of those that already had UHV AC/DC lines in operation or under construction.
A comparison with the practices adopted for EHV lines will be made whenever possible.
The information obtained will be reported by country; The main technical specifications of the lines surveyed are summarized in table 1 at the end of this item.

4.1. Electrical Design of UHV Transmission Line

4.1.1. Minimum Clearance

Switching overvoltage level and electrical field strength are major factors to decide the minimum clearances of transmission tower or minimum conductor height. These values were already in the previous CIGRÉ report [2], having remained unchanged since then.
In three countries, CIS, Japan and Italy, UHV transmission lines based on the following values are constructed or under construction.

CIS (AC)

The statistical switching overvoltage (2% value), which is the main factor in deciding the clearance of the 1200kV transmission tower, was considered to be 1.8 p.u. (1760kV) phase to ground.
The switching overvoltage control system which has ensured 1.8 p.u. level is comprised of the following:

- Surge arresters
- Shunt reactors with extra-high-speed energizing
- Fast sparkover of shunt reactor arc gaps during extra-high-speed energizing
- Closing resistors on circuit breakers
- Impedance in the shunt reactor neutrals

Minimum clearances of the 1200kV towers against switching overvoltages are,

- conductor to tower : 12m for altitude up to 500m
- phase to phase : 24.2m for altitude up to 500m

The minimum conductor height from ground and the width of right of way are 18m, 140m respectively in unpopulated areas for environmental reasons, so as to keep the maximum electric field intensity under the line within the standard level of 15kV/m at 1.8m height above ground at 32°C, which is observed in the right-of-way area during 1% of time annually.

Japan

For the 1000kV transmission line, the statistical switching overvoltage is 1.5 p.u. phase to ground, 2.6 p.u. phase to phase, resulting in 6-6.7m for the clearance of conductor to ground and 9m for that of phase to phase at an elevation of up to 1800m.

These values have been obtained through switching overvoltage control by the metal oxide arresters connected to the line and through the field tests for obtaining switching impulse flashover characteristics of air clearance in double-circuit line.
Minimum conductor heights from ground are 25m in unpopulated areas, 32m in the areas where possibility of future population remains, and 42m in populated areas for environmental reasons, to observe the limits of electric field strenght of 10kV/m, 5kV/m, 3kV/m under the line.
The width of right of way is decided by taking into account the minimum clearances to be kept during regular patrol and maintenance, electric strength at the edge of ROW, and conductor blow-out distance at mid-span by a 20m/sec wind.

Italy

Statistical switching overvoltage is 1.7 p.u., phase to structure; and 2.7 p.u., phase to phase leading respectively to the minimum air insulation distance of 7 and 12m.

The minimum conductor height from ground is 17.5m to fulfil the limit of electric field strenght of 10kV/m.

The major factors determining the width of right of way are the electric and magnetic field strengths and the conductor blow-out distances at mid-span.

United States (AEP)

Studies at the UHV level indicate the general feasibility of controlling switching overvoltage to 1.6 p.u..

Insulation systems designed on this basis are expected to have acceptable lightning performance and not to experience significant power frequency outages in areas of mild contamination.

Brazil

According to a preliminary design under consideration for the 1050 to 1200kV AC transmission, based on:

- Switching Overvoltage
  - Phase-to-earth = 1.6 p.u.
  - Phase-to-phase = 2.8 p.u.
- Minimum conductor height from ground: 18.0 to 23.0m
- Maximum electric field intensity under the line at 1.0m height above ground: 15kV/m

The minimum clearance ranges determined by analitical studies were:
- Conductor-to-tower: 7.6 to 9.2m
- Phase-to-phase: 10.0 to 18.0m

For the 800kV DC Transmission lines, based on the following criteria:

- Electric field strength - same as AC.
- Radio interference at the edge of right of way must not exceed 42 dB (1Mhz) in heavy rain condition and the signal/noise ratio must be less than 20 dB.
- Audible noise at the edge of right of way: 40 dBA.

The calculated values were:

- Minimum pole to pole clearance: 15.0 to 20.0m.
- Minimum conductor height from ground: 18.0m.

4.1.2. Insulators

CIS (AC)

Disk-type conventional glass insulators with diameters from 300 to 390mm and rated strength from 21 to 40 tons were applied on the first UHV AC lines.

Insulator chains are diferrent in length (from 10 to 14 meters) and in number of insulators in a string (from 45 to 61 pcs.), depending on the level of contamination.

Also, new types of plastic insulators are under development and testing on line.

Japan

As the result of mechanical and dielectrical full-scale tests of various insulator strings, including field-tests for snow-covered insulator strings, 3 or 4 strings of conventional porcelain disk-type insulators with diameter from 330mm to 380mm and rated strength from 33 to 54 tons are revealed to be most appropriate for UHV lines.
The insulator-string length was decided on the basis of dust contamination of 0.011mg/cm^2, taking into account that the applied voltage per disk should be equal to or less than that of existing 500kV lines.

Italy

As regards insulators, following a technical and cost analysis of the different possible solutions, and taking into account IEC requirements, a 400kN cap-and-pin, toughned-glass insulator was designed and a large number of tests were performed. Based in this analysis, the length of the insulator string making catenary configuration is 7.8m phase to structure with 4 strings and 13.5m phase to phase with 3 strings (Diameter of 360mm and rated strength of 40 ton/string).
A series of mechanical and electrical tests were carried out, including cinematic tests, RIV-corona tests, power-arc tests and loading tests.

United States (BPA)

According to the tentative design under consideration, disk-type insulators with diameters of 381mm (rated strenght 60 ustons = 54.4 tons) and insulator chains of 17.8m might be applied.
The length will be decided based on switching surge and flashover experience on existing 500kV lines with contamination.

Brazil

Preliminary studies for the AC alternatives have indicated disk-type conventional 254mm diameter glass insulators strings with lenghts from 7.0 to 8.0 meters, 48 to 55 insulator and 1 to 4 strings in parallel. For the DC alternative, anti-fog glass insulators are indicated in insulator strings 9.3m long and 40 insulators/string. Number of insulator strings in parallel: 1 to 4.

4.1.3. Lightning Protection

Lightning protection performance of UHV, which is mainly associated with clearances to withstand the switching overvoltage, is expected to be better than that of EHV. The operational experience in the CIS, though relatively short, shows that the expected reliability level has been achieved.

CIS (AC)

During the first years of operation, the probability of lightning fault was 0.12 times per 100km a year, which shows good match with the expected value of 0.2.
Despite the lack of experience to evaluate the statistics, the reliability level of the 1200kV lines is fully higher than that of the EHV (500kV) transmission lines, which is 0.5 times per 100km a year in the actual lightning fault level, and fulfils the system reliability criterion that the 1200kV system reliability should be higher than that of the 500 and 750kV systems.

Japan

Along the 1000kV transmission lines the probability of 0.33 times of lighting faults per 100km a year will be envisaged, which is far less that that of existing 500kV transmission lines, even though the route is to be on mountainous area where isokerounic levels are relatively high.

Brazil

As a criterion for the preliminary design a figure of 0.10 outages per 100km a year will be used.

4.1.4. Environmental Considerations

Most of the data shown in this report are the same as those in the previous report.

In summary, in what concerns the comparison between UHV and EHV, the environmental criteria applied for UHV are basically the same as or stricter than those for EHV.

CIS (AC)

Various field tests have been performed under the full-scale test line to confirm electrostatic shocks during agricultural activities, vehicle riding and in connection with live line maintenance.
The tests revealed that the influence on environment caused by a 1200kV line, such as electric field strength, audible and radio interference are not higher than those of 500-750kV lines, and proved that the basic criteria adopted and followed at the planning and design stages are quite adequate.
The measurements on two line sections of 1200kV lines are:

- Radio interference at a distance of 100 meters from the outermost phase; 34-44dB (0.15, 0.5,1MHz), which is below the CIS standard requiring that the intensity of interference from standardized distance do not exceed 43dB during 80% of the year.
- Audible noise at a distance of 300 meters from the outermost phase: 45dBA, which is the exact permissible level.
- Electric field strenght under the outermost phases: 12 - 15kV/meter, which is below the CIS standard level.

As for the electric field strenght, nearly 15 years of experience in 750kV lines (whose conductor height above ground was selected to yield 15kV/m), and the 25 year experience with 500kV lines of over 30000km (with field strength of 12 to 13kV/m) permit to be optimistic about the safety conditions under 1200kV lines.

Japan

Various field tests have been performed under the full-scale test line to confirm electrostatic shocks during agricultural activities, vehicle riding, etc.
The maximum electric field strenght in the area of frequent pedestrian traffic is 3kV/m within the right of way at 1.0 meter height above ground, which is based on Japan national standard for electric field.
The maximum magnetic field of 100-150mG is envisaged at the edge of the ROW.
The design criterion for maximum RI level is less than 20dB at the maximum position under the 1000kV line in heavy rain condition of 4mm/hour.
Also, the design criterion of audible noise level (random noise) is 50dBA at the maximum position under the 1000kV line in the heavy rain condition.
Since hum-noise is less masked by rain noise, it is relatively easily perceived even when the level is low.
Therefore, research has been carried out mainly to establish the evaluating and measuring methods for reduced corona hum noise.

The field tests and corona-cage tests assured that the AN and RI level will be the same as expected and countermeasures will perform well.
Based on these studies, 8x38.4mm bundle conductors were selected.
The environmental indexes shown above are almost the same as those of the existing 500kV line with the 4x28.5 ACSR bundle conductors.

Italy

Various field tests have been carried out or are under way to investigate the effects of both electric and magnetic field on animals and vegetables.
The results show the absence of any remarkable effect on animals through exposure to electric fields of up to 100kV/m for long periods, and no morphological, physiological, or genetic effect in wheat for 3 generations up to 12kV/m.
As regards magnetic field, long-term laboratory investigation on rats is under way. As regards limits for exposure in force in Italy, the maximum electric and magnetic field strenghts in the area where members of the sample will spend a significant part of the day are 5kV/m and 0.1mT respectively. Higher levels (10kV/m and 1mT) are considered where exposure may reasonably be assumed to be limited to a few hours per day.
Corona performance experiments were carried out on the cage and on the experimental line at the Suvereto test site, showing that the levels of RI and AN are acceptable compared with EHV by applying 8x31.5mm bundle conductors with a spacing of 45cm.

United States (BPA)

The design criteria for maximum electric field is 9.0kV/m within ROW and 5.0kV/m at the edge of ROW, based on NESC 5.0mA induced-current safety criteria.
Also, the design criteria for maximum RI level is 40dB (1MHz; at average) at 10 feet from the outermost phase in fair weather conditions, based on IEEE Radio Noise Design Guide.
In the area of BPA, the design criteria for maximum AN is regulated by the State at the level of 50dB (50% value, at average) at the edge of ROW in rain (> 1mm/hour) condition.
As for investigation of corona-noise effect, tests of a quadrature bundle for 500kV arranged in a diamond versus a square configuration, and comparison with trapezoidal conductors versus standard ACSR or ACAR conductors are expected to be conducted.

Environmental studies related to EMF health effects are under study in U.S.A.; some examples from the BPA are as follows;

- Ostrander EMF Environmental Study (1989)

The purpose of this study is to determine if EMF exposure affects hormone (Melatonin) levels in sheep raised under high voltage transmission lines.

- Magnetic Field Characterization Project (1989)

The purpose of this study is to characterize magnetic field environments of all major BPA transmission lines (115, 230, 500kV) using historical current loading statistics for standard line design geometries.

United States (AEP)

Given the absence of any credible health effects due to electric fields, the primary criterion for the ground-level electric fields is to design the EHV and future UHV lines so that electrostatically-induced short-circuit currents are limited to 5mA.

For 60Hz systems, this allows ground-level electric fields of up to 10.5kV/m over farming areas and of approximately 6kV/m at major road crossings.
While UHV may require more specific electrical and structural criteria, the general philosophy will remain the same as for EHV.

In summary, to gain public approval for the UHV designs, it seems probable that the environmental impact in terms of electric fields and corona effects should be no greater than that of the with existing 765kV designs.

Brazil

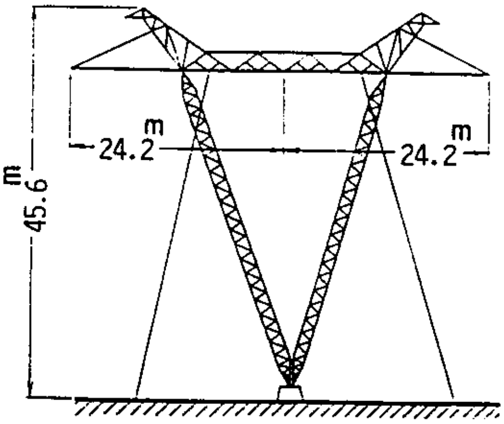
The design criteria for maximum electric field strength at 1.0m height above ground are:

- under the line: 15kV/m
- at the edge of right of way: 5kV/m
- area of frequent pedestrian traffic: 5kV/m
- The radio interference at the edge of right of way must not exceed 42 dB (1Mhz) in heavy rain condition and the signal/noise ratio must be less than 24 dB, and the audible noise at the edge of right of way 58 dBA.

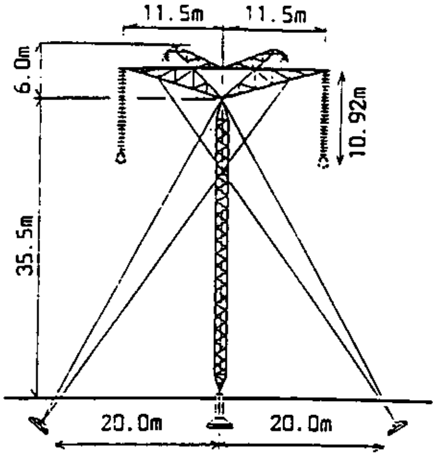
4.1.5. Structure Configuration

Examples of UHV AC and DC towers are shown in figure 4.

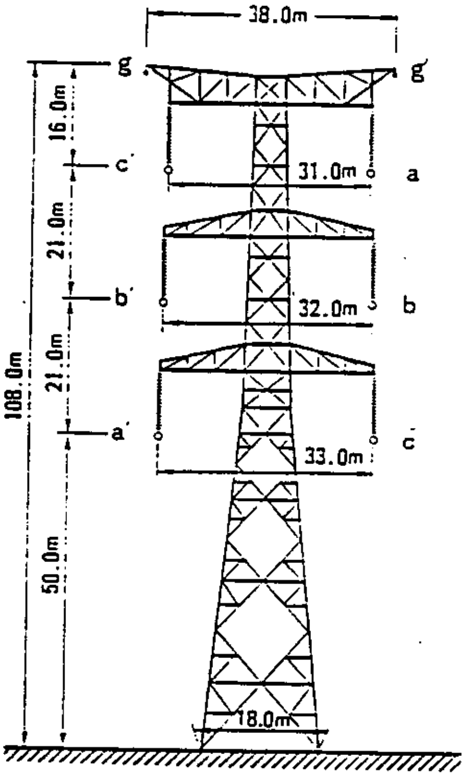
CIS(AC)



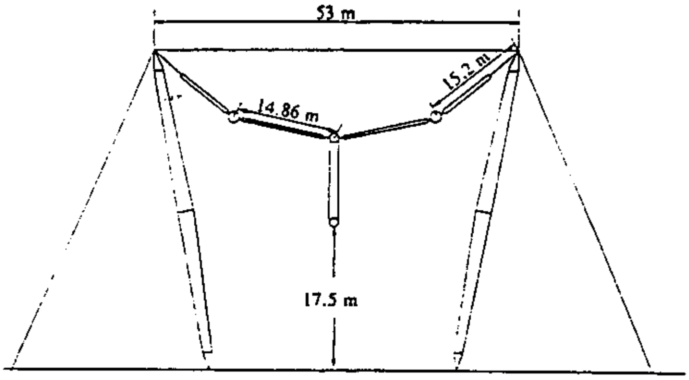
CIS(DC)



Japan



Italy



United States (B.P.A.)

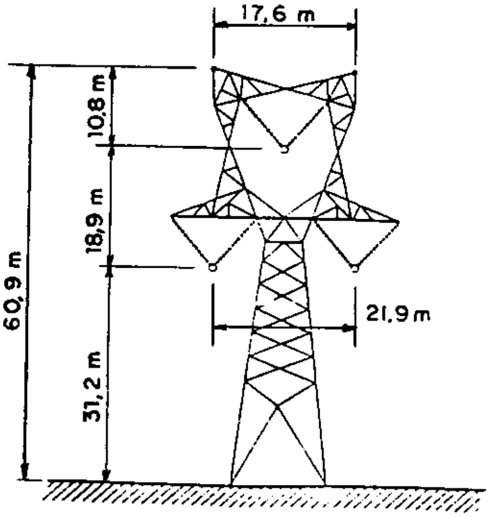


Figure 4 - Structure Configuration

4.2. Mechanical Design

Although the overall structures remain the same as those in the previous report[2], progress has been achieved in collecting data on mechanical test of prototype towers or of the constructed towers.
A rough comparison between EHV and UHV was also attempted.

CIS (AC)

The structural configuration of towers was decided from the result of technical and economical studies.
A single circuit overhead line is hanged on three-leg anchor towers of 23, 28 or 35 meters height, whose weights are 45.9, 57.6 or 75.6 tons respectively.
Intermediate towers are of V-Guyed type, 40 meters high , 45.6 meters wide, 17.8 tons of weight.
Maximum and average span lengths between towers are 460 and 400 meters respectively.
Each phase of transmission line consists of 8 steel-aluminum conductors AC 330/43 with a bundle step of 40 cm.
A comparison of the areas needed for one unit of transmitting power with UHV and EHV overhead lines is shown in the following table.

FACTORS	**Line Voltage (kV)**		
	500	**750**	**1,200**
Distance between side phases	1	1.71	2.19
Transmitting Capacity	1	2.25	6.00
Area Required per unit transmitting power	1	0.76	0.365

These figures prove that in spite of the distance increase between two side phases corresponding to the system voltage increase (2.19 times for 1200kV transmission line), the transmitting capacity of the line is 6 times as large as that of a 500kV line, and the area required per unit transmitting power is 0.365 times.
The transmission tower is attached with two twin bundled overhead ground wires of AC - 70/72 type which are also used for communication between substations.
For vibration and subvibration limitation the combination of 8-beam and coupled spacers was adopted.
Since 1984, when the line was comissioned, the work has been in progress to eliminate the vibration and suboscillation of multi-conductor bundles.
As for mechanical troubles, there has been only one case of conductors galloping on a 1200kV line section, which caused no damage though the conditions were very severe, while the line of lower voltage class could not withstand such load conditions.

Japan

Since the corridor passes through narrow and mountainous area, vertical-arrangement double circuit configuration turned out to be the most advantageous from the technical and economical viewpoints.

The maximum and average span lengths between towers are 1050 and 630 meters respectively which mainly stems from economical reasons and the geographical conditions of the corridors. New structural design of the tower members and new foundation design suitable for the application of the new high tensile strength steel HT 60 (breaking point: 60kg/mm^2), has been adopted, resulting in the reduction of the size of the 1000kV steel towers down to 85% of that of a conventional design.

Also, numerical analysis and full-scale mechanical tests on two suspension pylons and one strain pylon have been carried out.

Based on the result of the full-scale tests concerning stability of structures under seismic loading, static loading conditions corresponding to the condition of a horizontal acceleration of 200gal at ground was chosen for the mechanical design of UHV towers.

It was also confirmed that the structures designed by the conventional two dimentional method have enough dynamic strenght. In order to identify the mechanical properties of UHV conductors and fittings, the behavior of transmission lines has been observed on test lines, the result of which is that there has been practically neither subspan oscillation nor galloping on conductors with galloping control devices.

The comparison of UHV and EHV (500kV) overhead line is shown in the following table.

FACTORS	**Line Voltage (kV)**	
	500	**1,000**
Average tower height	1	1.4
Average tower weight	1	2.5 ~6.2
Average right of way	1	1.6
Average number of towers	1	0.6 ~0.8
Length of Insulator strings	1	1.7
Transmitting power	1	3 ~4

These figures show that, in general, the ratios in terms of mechanical structure between 1000kV and 500kV are smaller that the ratio of transmitting power.

Italy

The single-circuit guyed tower known as "Circus" has been selected to meet the limitation of the land occupation and in general the impact on environment, while ensuring a satisfactory level of electrical and mechanical reliability.

On this tower, the insulator strings supporting the conductors have an important structural function that makes it possible to eliminate steel structures between phases thus allowing a considerable reduction in line corridor width as compared with conventional solutions.

The structure has a high degree of modularity with a small number of standardized parts, making it possible to erect masts of different dimensions and mechanical loading capacities. At the same time, the structure remains flexible and makes it easy to vary the distance between phases, the height of masts etc., depending on the requirements and problems posed by routing.

The tower average height is 50m, and the maximum and average span lengths between towers are 650m and 400m respectively.

As regards the comparison of UHV and EHV (420kV) overhead lines, the interphase distance of UHV is only twice that of EHV, while S.I.L. is seven times greater; consequently the transmitted power per unit space occupied is increased by a factor of 3.5.

United States (BPA)

A single-circuit delta configuration is to be applied for the UHV tower design. The tower average height is 59.9m, and the maximum and average span length between towers are 583.7m and 289.7m respectively.

The phase conductors are under study because the conductors used at the Lyons test line will not meet the AN limit.

Spacer dampers will be used to suppress conductor motion.

United States (AEP)

The basic structural loading criteria that have proven successful on EHV lines will continue to guide UHV line designs.

There are, however, several areas that can be investigated for possible loading reductions.

For multi-subconductor bundles, the possible shielding or "shadow effect" of the leeward subconductors relative to wind pressures should be investigated.

A second area for investigation would evaluate whether the present EHV criterion of a broken phase bundle (all 4 subconductors) should be extended to a complete UHV phase bundle which could consist of 8, 12 or, perhaps, 16 subconductors.

Any reduction in the loading parameters will only be adopted after thorough investigation since various loading conditions often compensate for unusual circumstances as well as the conditions specifically ascribed to the particular load case.

Self-supporting towers and guyed-V towers are good candidates for use at UHV voltage levels.

In addition, various other guyed structures, including Chainette types will be investigated in more detail before a structural system is selected.

It appears that as structure sizes and loads increase, a more extensive dependence on guys may result in more cost-efficient structures.

While overall crossarm lengths (about 39.6m) at 765kV are often roughly equal to the tower height, it is evident that at UHV voltages the overall crossarm width can easily be significantly greater that the overall tower heights when 2.2 to 2.5 structures per km are utilized.

Therefore, the possible cost advantages of increasing UHV span lengths to approximately 1.9 structures per km will be evaluated.

While generally increasing the heights of all structures, an improved overall structure outline and proportion might result.

The standards determined for aircraft safety balanced against cost-effective heights of UHV towers may influence the eventual average-span lengths.

4.3. Maintenance

CIS

The feasibility of live-line work required the solving of several medical and biological problems connected with personnel protection from such unfavourable factors as electric fields, nytroohides and others.

Different types of insulators were used on the 1200kV line so as to give experience to the maintenance personnel.

Live-line maintenance procedure, contrivances, safeguards, and medicobiological regulations applicable to 500-1200kV AC and 1500kV DC lines were developed.

The package of tools and applicances makes possible replacement and repair of insulator units and hardware of insulator strings, and maintenance of conductors and earth-wires.

The protective clothing complies fully with the respective IEC recommendations and satisfies the medical standards as regards electric field intensity, displacement current and impulse current.

In order to test protective clothing models and safeguards and to optimize tools and accessories used in live-line maintenance, self-contained mobile measurement laboratories were manufactured, permitting measuring of electric and magnetic field intensities, ionic currents, high-frequency components of electromagnetic fields on conductors and bundles.

Medical and psychological examination of the personnel with 0.5 to 4-5 years of work under UHV voltage showed no pathological change in their nerves, heart or blood systems.

Japan

The method and procedure of UHV line maintenance are the same as those of EHV in general, that is, all works except for detection of faulted insulators are to be done under de-energized condition.

Some efforts, however, are under way to improve the conventional equipment and systems in order to handle

large facilities effectively such as; vehicles to carry equipment in mountainous area, wagons on conductors, various monitoring system using OPGW.
Also, development of grounding system, voltage-detecting systems for maintenance work and the detector of faulted insulators are in progress.

<u>Italy</u>

No live-line maintenance is scheduled for pilot line.
The most important factors for the maintenance of Circus towers are: climbing equipments along masts and, especially, along insulating catenary, the study of which is under way to allow the bundles to be approached thus unloading the insulator strings. Special equipment to be connected to the external yokes of fittings are under consideration, which will be used together with conventional tools under de-energized conditions.

5.0 - UHV SUBSTATION AND EQUIPMENT

In this item the main characteristics of the UHV substations planned/built in the CIS, Japan and Italy are confronted in table 2, as obtained by means of a questionnaire sent to the companies/agencies concerned.
It is worth noting that whereas in the CIS the substations are of the open air type both Italy and Japan have opted for metal-enclosed substations (GIS).
Other factors may also contribute to make difficult a comparison of the three schemes, not the least the fact that at the CIS the UHV substations are already in commercial operation, whereas in Italy the Suvereto Station has been build mainly for research purposes and in Japan the UHV equipment will be installed only in the next century.
Figure 5 shows the substation scheme for those projects.

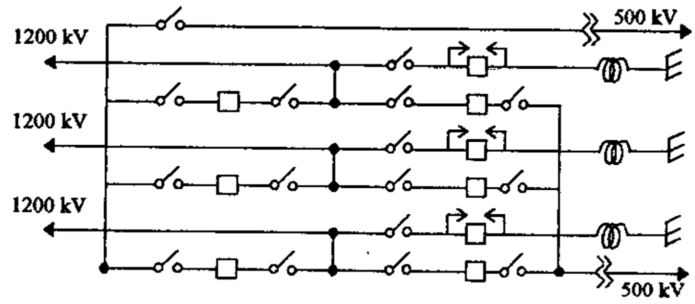


Figure 5a

C.I.S. - 1200 kV open air substation

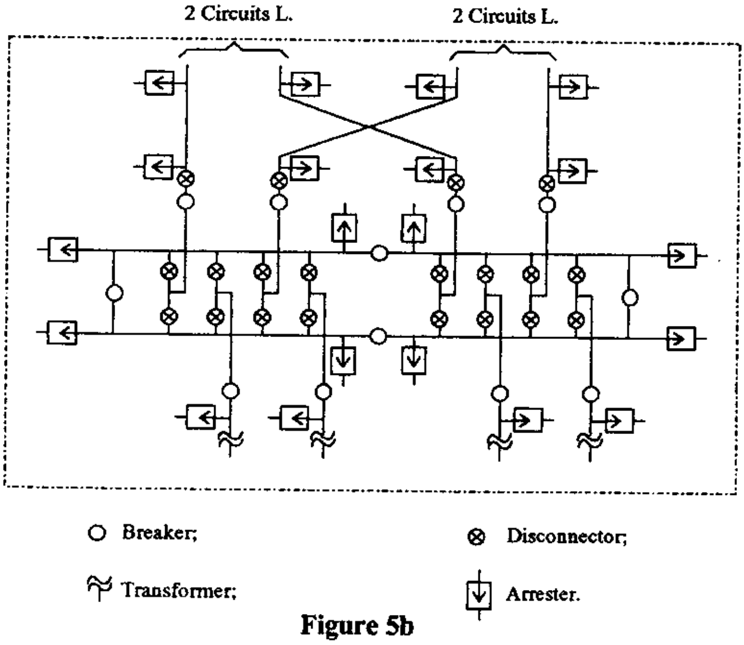


Figure 5b

JAPAN - 100 kV SF_6 substation and connection to transmission line

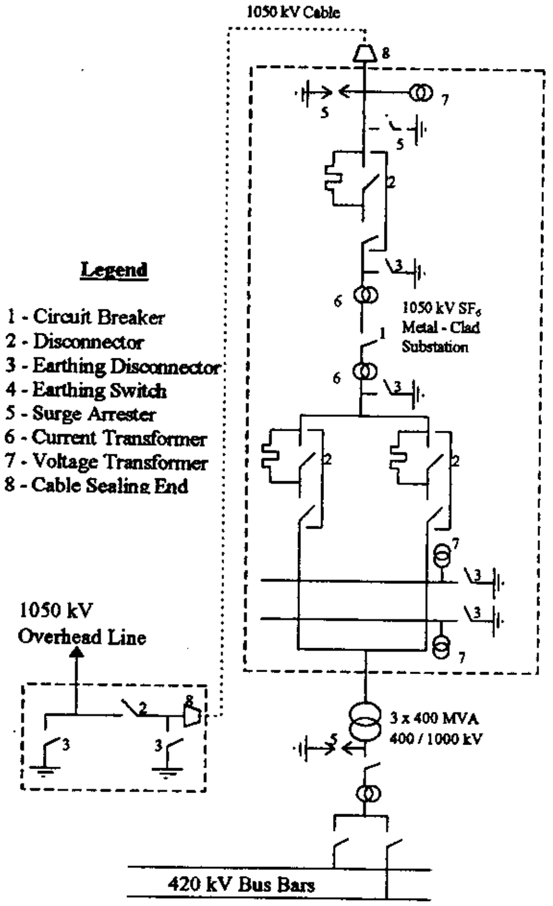


Figure 5c

ITALY - 1050 kV SF_6 substation and connection to experimental overhead line

Figure 5 - Substation scheme

6.0 - UHV TESTING FACILITIES AND NEW TECHNOLOGY

In this item a few details will be given of the main researches under way concerning aspects of the UHV technology, as reported by a number of sources.
Additional information on these investigations can be obtained from the referred literature.
Concerning laboratory facilities, new information on testing instalations in French and India is presented to complement the picture outlined in [2].

6.1. Current research

6.1.1. Performance of Air Insulation

Investigations aimed at optimizing the insulation coordination of the combined phase-to-phase-to-earth have been conducted on a special tower at the 1000kV experimental plant of Suvereto in Italy.
At Les Renardieres in France research has been carried out on the physical behavior of air insulation at UHV spacing [6]. This research deals with simulating lightning in the laboratory, particularly with inception fields, space charge effects, leader propagation as well as attachment mechanisms with grounded or floating electrodes [7,8,9].
Brazil and India also report research in this area but details are not available.

6.1.2. Conductors and Insulators

Brazil reports investigations on the use of all-aluminium and aluminum-alloy conductors as well as on insulator materials other than glass which has exhibited high failure rates on the +/- 600kV Itaipu lines.
Brazil is carrying out a four-year program related to non-ceramic insulators.
Mechanical and long-term corona tests have been performed in Italy on a 4-conductor 56.26 mm (spacing 600mm) ACSR bundle for montainous areas.[10].
A three-year program in Japan investigated insulation design criteria for HVDC line insulators under snowy conditions. The results indicate a dc withstand voltage of about 70kV/m where the specific gravity of the snow is 0.4 and the conductivity of the water melted from the snow is below 30mS/cm. The withstand voltage was found to vary linearly with lenght up to string lenghts of 5.5m. The conclusion was that the withstand voltage of HVDC lines under snowy conditions is 20-35% lower than that of lines in areas of no-salt contamination.
A research and development program is starting in France to study the feasibility of competitive cost long distance transmission lines using burried compressed gas cables, a possible alternative to overhead line.

6.1.3. Corona performance

Corona effects of an asymmetric conductor system, and of an added conductor system, for a 1000kV AC transmission where tested at the corona cage and the Akagi test line in Japan to reduce audible noise from conductors on which spiral wires where wound for a local countermeasure to aeolian noise.
The second harmonic of audible noise is regarded as a significant problem [11].
Italian research in this area has been summarized in the literature [12].
Brazil has been performing test in the corona cage at CEPEL laboratories related to 1000kV AC conductors bundle configurations.

6.1.4. Environmental and Biological Efects

Extensive research is ongoing almost on a worldwide basis on AC electric and magnetic fields.
Major programs in the USA are being sponsored by the Electric Power Research Institute and the US Department of Energy. Large epidemiological studies are in progress on a collaborative basis (Hydro-Quebec, Ontario-Hydro, Eletricité de France).
Biological studies, exposure assessment and computation of induced current densities form the guidelines of the French research[13]. Extensive work is also reported from Italy[20].

Investigations are also known to be under way in Canada, the UK, Germany, and the CIS. An extensive Japanese bibliography documents studies on corona, ion, and electric field effects on HVDC transmission lines.

Brazil is developing an extensive research related to environmental aspects, and social impacts due to the implementation of the transmission system.

6.1.5. Mechanical and Structural Problems

A new method has been devised in Italy to string 8-conductor bundles on line which use "Circus" towers and non-conventional fittings[21].

6.1.6. Overvoltage Control

The advantages of synchronous closing of circuit breakers and the application of surge arresters along the line are under investigation in Brazil.

6.1.7. Equipment Design and Performance

Investigations in India are focused on specific conditions of pollution.

6.1.8. Maintenance

Investigations are ongoing in Brazil but results have not yet been reported. Partial data on the studies in the CIS were reported in 1990 [14,15].

6.1.9. System Verification of Research Results

Field tests on the 1150kV system in the CIS have been partially reported [16].

6.1.10. Equipment Test Procedures

The applicability of existing standards and test procedures is being investigated in Brazil.

6.2. Laboratory Facilities

In addition to the data provided in [2] the following information on laboratory facilities in three countries has been obtained:

France (Les Renardières)

A new hall (43x21x24m) equipped with a 3MV impulse generator and 800/1100kV cascade transformers was added in 1988 to the existing equipment consisting of a 6MV impulse generator and 2.2MV cascade transformers.

India

Voltage Generators:
- 1600kV, 6A, AC cascade transformers
- 5MV, 500KJ, Outdoor impulse generator

Measuring Equipment:
- 600pF, Type CR, Voltage Dividers
- 1200kV, 25pF, Standard Capacitor
- 1200kV, 2nF, Coupling Capacitor

Testing Area

- Fog chamber (24x24x24m) with 800kV entrance bushing

- Corona Test Cage

- Experimental Line, 720m, with provision for two bundle conductors using 4, 6, 8 or 10 subconductors and suitable for of energization up to 1200kV (line to line)

Brazil

- At CEPEL a Corona Cage (100x7x7m) is already installed since 1992.

- A mobile laboratory for electromagnetic field measurements is now in effective operation.

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TABLE - 1 MAIN CHARACTERISTICS OF UHV TRANSMISSION LINES

	CIS (AC)	CIS (DC)	JAPAN (AC)	ITALY (AC)	USA (B.P.A.) (AC)	USA (A.E.P.) (AC)
1. Present Situation	In operation (commissioned year 1985)	Under construction (commissioning year 1993)	Under construction (commissioning year 1992 at 500kV operation) upgraded to 1000kV in the first few years of the 21th century	Under construction (commissioning year 1993)	No concrete plan	No concrete plan
2. Location, lenght (year commissioned)	Ekibastuz - Kokchetav 493km (1982) Kokochetav - Koustana: 397 (1983) *Koustana: - Cheliabirsk 319 (1986) *Ekibastuz - Baenaul 697 (1988) 1906km *Presently in 500kV operation	Ekibastuz - Tambov 2400km (1993)	Nishi-Gumma - HigashiYamanashi 138km (1992) Part of Kashiwazaki - Nishi-Gumma 50km (1993) Kariha	Suvereto 3km (Pilot plant)		
3. Operating Voltage	1150kV (Nominal) 1200kV (Maximum)	+/- 750kV	1000kV (Nominal) 1100kV (Maximum)	1000kV (Nominal) 1050kV (Maximum)		
4. Line Transmission capacity (MW)	5500	6000	5000 (Initial) ~13000 (Final)	5000 (Rated capacity)		
Number of circuits	Single circuit	Bipole	Double circuits on single tower	Single circuit	Single circuit	Single circuit
5. Minimum Clearances						
Maximum temporary overvoltage	1.4 p.u. (971kV)	1.65p.u.	1.5 p.u. (953kV)	1.35 p.u. (818kV)		
Statistical switching overvoltage (2% value)						
. phase-to-ground	1.8 p.u. (1760kV)	-	1.5 - 1.6 p.u.	1.7 p.u. (1453kV)		1.6 p.u.
. phase-to-phase			2.6 - 2.7 p.u.	2.7 p.u. (2308kV)		
Minimum clearances against switching overvoltage						
. conductor-to-tower	12.0m (for altitude up to 500m)		6~6.75m (for altitude up to 1800m)	7m		
. phase-to-phase	24.2m (for altitude up to 500m)		9.0m (for altitude up to 1800m)	12m		
6. Minimum conductor height from ground						
Minimum height	18m	12m	25m 32m 42m	17.5m		
Applied area	Unpopulated	Unpopulated	Unpopulated To be populated in farther future Populated	Area where people are not expected to stay for substantial part of day		
Major factors	Ecological		Ecological Ecological Ecological	Ecological		
7. Width of ROW						
Width of ROW	140m		39m			
Major factors	Ecological		Ecological etc.			
8. Insulator Strings (Suspension insulator strings configuration)	I and V	I	I	Catenary (Circus tower)	Delta	V
Insulator type, material	Disk type, glass		Disk type, porcelain	Disk type, glass	Disk type, ceramic	
Insulator diameter (mm)	300 320 390		320 340 380	360	381	
Ultimate insulator strength(ton)	21 30 40		33 42 54	40	60 uston	
Number of units string	44-55 43-45 49-61	52-62	40 38 32	38(phase to structure) 66(phase to phase)	29	

	CIS (AC)	CIS (DC)	JAPAN (AC)	ITALY (AC)	USA (B.P.A.) (AC)	USA (A.E.P.) (AC)
Number of insulator strings /phase	1-2 1-2 2-4	2	2 2-3 2	4 (phase to structure) 3 (phase to phase)	2	
Length of insulator strings (m)	10 10-14 12-14	9-11	7.8 7.9 7.68	7.8 (phase to structure) 13.5 (phase to phase)	17.8	
Factors to decide insulator strings length	- Dust or salt contamination - Coordination with arcing horn gaps		- Dust or salt contamination (0.011mg/cm^2) - Applied voltage per disk to be equal to or less than that of conventional 500kV lines	- Salt contamination (14kg/m^3) - Required salinity for insulator string (40kgm^3)		
Overvoltges to decide insulator strings length	Switching surge		Temporary overvoltage	Maximum operating voltage	Switching surge with contamination	
(Strain insulator strings Insulator type, material)	Disk type, glass		Disk type, porcelain	Disk type, glass	Disk type, ceramic	
Insulator diameter (mm)	320		320 340 380	320	381	
Ultimate insulator strength (ton)	30		33 42 52	21	60 uston	
Number of units/string	47-57	57-70	40 38 32	48	29	
Number of insulator strings /phase	4	5	4 4 4	8	4	
Length of insulator strings (m)	12-14	13-20	7.8 7.79 7.68	8.16	17.8	
Factors to decide insulator strings length	Dust or salt contamination		- Dust or salt contamination (0.011mg/cm^2) - Coordination with arcing horn gaps - Others Applied voltage per disk to be equal to or less than that of conventional 500kV lines	- Salt contamination (14kg/m^3) - Required salinity for insulator string (40kg/m^3)		
Overvoltages to decide insulator strings length	- Maximum operating voltage - Switching surge		Temporary overvoltage	- Maximum operating voltage	Switching surge	
9. Lightning Protection Location of arcing horn	Between ground wires and any tower		(Suspension tower) At both ends of insulator strings (Strain tower) Between tower arm and jumper assembly	None	None	
Arcing horn gap length (m)	16-20 (Suspension tower) 10 (Strain tower)		6.3 (Suspension tower) 5.9 (Strain tower)	-	-	
10. Grounding wires Type and materials	AC - 70/72		OPGW 500mm^2 Aluminium-clad steel wires	ACSR 29.4mm	Galvanized high strength steel	
Number of ground wires	2 x 2		2	2		
Factors to determine the size of ground wires	- Surface gradient - Induced currenty capacity - Mechanical strength against loading conditions		- Surface gradient (to be less than 16kV/cm) - Induced currenty capacity - Mechanical strenght against loading conditions - Mechanical strength to protect fiber-optics - Short circuit capacity	Mechanical strength against loading conditions	Mechanical strenght against loading conditions	
Shielding angle of overhead ground wires at towers	22 (Suspension tower) 22 (Strain tower)		8.13~8.26 (Suspension tower) 9.37~9.55 (Strain tower)	Negative		

	CIS (AC)	CIS (DC)	JAPAN (AC)	ITALY (AC)	USA (B.P.A.) (AC)	USA (A.E.P.) (AC)
Tower footing resistance	10 or less		10 or less	10 or less	20 or less	
Keraunic level	40~60 days/year		30 days/year	30 days/year	5-40 days/year	
Expected lightning faults (outages/100km/year)	0.2 (actual 0.1)		0.33	negligible		
Expected lightning faults in 500kV system (outages/100km/year)	0.7 (actual 0.5)		0.74 (atual 0.5)			
11. Environmental Consideration						
Design limits for maximum electric field						
Type of limits	Regulation (National Standard)		Regulation (National Standard for Electric Facilites)	Regulation (Decree of Italian Prime Minister)	NESC Safety Criteria	
Measuring points	/ground level /1.8m above ground		1.0m above ground	1.0m above ground	1.0m above ground	ground level
Maximum electric field strength	15kV/m within ROW (Unpopulated area)	25kV/m (Unpopulated) 10kV/m (populated)	3kV/m within ROW (Area with frequent pedestrian traffic)	5kV/m where public may spend significant part of day (a) 10kV/m where exposure will be limited to a few hours per day (b)	9kV/m within ROW 5kV/m at edge o ROW	10.5kV/m over farming area 6kV/m at major road crossing
Design limits for maximum magnetic field						
Type of limits	none		none	Regulation (The same Decree)	Recommendation in company	
Maximum magnetic field strength			100~150mG at maximum loading	1G in the area (a) 10G in the area (b)		
Corona performance						
Conductor surface gradient at maximum operating value (kV/cm)	~29.0		12.9~14.7	15.9 (lateral phase) 17.6 (center phase)		
Radio interference						
Type of limits	- Regulation (National Standard) - Design guide based on CIGRÉ Research Project Report		- Design guide based on GIGRÉ Research Project Report	- Design guide based on CIGRÉ Research Project Report	EEE Radio Noise Design Guide	
Design criteria position	- Maximum position (under the line) - 0.5MHz at the distance of 100m from outer place		- Maximum position (under the line)	15m from lateral phase		
Frequency	0.5-30MHz		1MHz	0.5MHz	1MHz	
Specification of RI meter	CISPR			CISPR	ANSI	
Weather condition for RI limits	All weather		Rain (heavy rain 4mm/hour)	All weather	Fair weather	
RI limit level	43dB		Signal to noise level 20dB	57dB	40dB	
Statistical parameter	A		1% value	80%/80% CISPR Criterion	Average	

	CIS (AC)	CIS (DC)	JAPAN (AC)	ITALY (AC)	USA (B.P.A.) (AC)	USA (A.E.P.) (AC)
Audible Noise						
Type of limits			Design guide based on CRIEPI	ENEL practice	Safety Regulation of the State Standard in Company	
Design criteria position			Maximum position (under the line)	At 15m from lateral phase	At the edge of ROW	At the edge of ROW
Specification of AN meter			IES	IEC		
Weather condition for AN limits			Rain (heavy rain)	Wet rain	Rain (> 1mm)	Foul weather
AN limit level (dB(A))			50	54	50	55
Statistical parameter			50% value	50% value	50% value	50% value
12. Mechanical Design						
Tower						
Span length between towers						
Maximum (m)	460	460	1056	650	583.7	
Average (m)	400	400	630	400	289.7	
Average weight of tower (ton/structure)	Single phase tower V-guyed 45.9 57.6 75.6 107	11	368	20	88	
Average height (m)	23 28 35 45.6	35.5	111	50	59.9	
Materials applied and tensile strength		N.A.	Angle members: Steel (41 & 60 kg/mm^2) Pipe members: Steel (41 & 60 kg/mm^2) Bolts : Steel (41, 50 & 95 kg/mm^2)	Angle-steel (37 & 52 kg/mm^2)	ASTM A36, ASTM A572 Cr 50+60	
Conductors						
Type	AC-330/43	AC-1200/67	ACSR 810mm^2	ACSR 520mm^2		
Stranding condition		Aluminum 76 wires of 4.5mm dia Steel 7 wires of 3.5mm dia.'	Aluminum 45 wires of 4.8mm dia. Steel 7 wires of 3.2mm dia.	Almi 54 wires of 3.5mm dia. Steel 19 wires of 2.1mm dia.		
Diameter of conductor (mm)		46.5	38.4	31.5		
Weight (kg/m)		3.87	2.7	1.95		
Ultimate tensile strength (kg)		27562	18480	16850		
Number of conductors/phase	8	5	8	8		
Subconductor arrangement				Symmetrical bundles (regular octagon) Sub-conductor spacing: 450mm		
Designed thermal capacity		11000 A/phase	11000 A/phase	4000 A/phase (continuous operation)	11600A/phase	
Maximum temperature (°C)		70	100		80	

		CIS (AC)				CIS (DC)
Comparison between AC and DC		A C				D C
		500kV	750kV		1100kV	1500kV
	Number of conductors	3	4	5	8	5
	Bundle Radius (mm)	230	424	340	520	510
	Subconductor spacing (mm)	400	600	400	400	600
	Conductor type	ACSR 300,330 400,500	ACSR 400,500	ACSR 240,300 330,400	ACSR 330	ACSR 1200
	Earth wire	1xACSR 70	2xACSR 70			

TABLE 2 - MAIN CHARACTERISTICS OF UHV EQUIPMENT.

	CIS	JAPAN	ITALY
1. General information on the UHV-AC system			
Present situation			
. under investigation	-	(*)	-
. on construction	-	-	1992 pilot (experimental station)
. in operation	commissioned year 1985	-	-
2. General information on the UHV-AC substation			
Location	Kokchetav	Minami - Iwaki	Suvereto
Nº of UHV lines	2	2	1 (3 km experimental line)
Nº of EHV lines	1	6 - 8	feed through 400 kV
Nº of transformers	1	6	1
Bus bar scheme	poligon	double with 4 tie CBs	double
Type of substation	open air	GIS	GIS
Space occupied by the UHV section (m²)	280 x 600	-	-
Commissioning year	1985	2000 or later	1993
Location	Kustanay	Kita - Tochigi	
Nº of UHV lines	2	4	
Nº of EHV lines	2	4 - 6	
Nº of transformers	2	4	
Bus bar scheme	poligon	double with 4 tie CBs	
Type of substation	open air	GIS	
Space occupied by the UHV section (m²)	300 x 500	-	
Commissioning year	1987	2000 or later	
Location	Ekibustz	Nishi - Gumma	
Nº of UHV lines	2	4 - 6	
Nº of EHV lines	2	6 - 8	
Nº of transformers	2	4	
Bus bar scheme	poligon	double with 4 tie CBs	
Type of substation	open air	GIS	
Space occupied by the UHV section (m²)	-	-	
Commissioning year	1985	2000 or later	
Location	Bazanaul	Higashi - Yamanashi	
Nº of UHV lines	2	2	
Nº of EHV lines	2	4 - 6	
Nº of transformers	1	4	
Bus bar scheme	poligon	double with 4 tie CBs	
Type of substation	open air	GIS	
Space occupied by the UHV section (m²)	-	-	
Commissioning year	-	2000 or later	
3. Main characteristics of UHV-AC substations			
3.1 Substation scheme	Figure 5a	Figure 5b	Figure 5c

		CIS	JAPAN	ITALY
3.2 Reference electrical parameters				
Highest voltage of the system	(kV)	1200	1100	1050
Highest voltage for the equipment	(kV)	1200	1100	1050
Rated frequency	(Hz)	50	50	50
Maximum short circuit current	(kA)	40	50	63
Switching impulse withstand voltage level SIL	(kV)	2100	1550	1675
Ligthing impulse withstand voltage level BIL	(kV)	2900	2250	2250
Power frequency test voltage: value	(p.u.)	1150 kV	$\sqrt{3}$ p.u.	1.50 p.u.
duration	(min)	1	5	1
Pollution severity level		S_e = 18 kg/m^3	ESDD = 0.01 to 0.03	S_e = 20 kg/m^3
Maximum audible noise level	(dBA)	45 (300m from outermost phase)	$\leq$ 50 (transmission line)	58
Maximum radio interference level	(dB)	34-44 (100m from outermost phase)	$\leq$ 20 dB above 1μV	60 (above 1μA)
Maximum electric field at ground	(kV/m)	10-20	3	10 - 15
3.3 Reference environmental parameters				
Extreme ambient temperature: maximum	(°C)	40	40	40
minimum	(°C)	-40	-20	-25
Wind velocity	(m/s)	33	40	36
Ice thickness	(mm)	15	not regulate	5
Ice weight	(kg/m)	-	not regulate	-
Sismic requirements		no	yes	yes
3.4 Substation components and equipment				
Clearances phase-to-ground	(m)	12	11-12 (transmission line)	8
phase-to-phase	(m)	11.4 - 12.4	11.5	12
phase-to-structure	(m)	7.5 - 9.7	7.5	9.5
Acceptable risk of failure		-	-	10^{-3}

		CIS		JAPAN		ITALY	
Insulators: strings (s) and columns (c)		(s)	(c)	(s)	(c)	(s)	(c)
insulator type, material		glass	porcelain	GIS (SF_6gas, Epoxy resin)		GIS (SF_6gas, Epoxy resin)	
insulator diameter	(mm)	300-390	-	-	-	-	-
number of units per string or column		45-63	9	-	-	-	-
single unit creepage distance	(mm)	370	1900	-	-	-	-
specified mechanical failing load	(kN)	210-400	-	-	-	-	-
bending failure load	(kN)	-	12.25	-	-	-	-
torsion failing load	(N)	-	-	-	-	-	-
number of strings or columns per phase		2	3	-	-	-	-
lenght of string, height of post insulator	(mm)	10000-14000	10720	-	-	-	-
disposition: vertical or inclined		-	inclined	-	-	-	-
Factor considered to decide the insulation string lenght and the post insulator height:							
- dust of salt contamination		(*)	(*)	-	-	-	-
- insulation for snow or ice coverage		(*)	(*)	-	-	-	-
- others (specify)		-	-	-	-	-	-
Conductors: bus bar (b) - connections (c)		(b)	(c)	(b)	(c)	(b)	(c)
type (rigid or flexible)		flexible	flexible	-	-	-	-
material		Al	Al	-	-	Cu	Cu
external diameter	(mm)	-	-	-	-	-	-
internal diameter	(mm)	-	-	-	-	-	-
number of conductors/phase		4x640	4x640	-	-	-	-
designed thermal capacity	(A/ph)	4000	4000	-	-	-	-
Decisive factors for conductor design:							
- transmission capacity		-	-	(*)	(*)	-	-
- electric field effect		(*)	(*)	(*)	(*)	-	-
- corona performance		(*)	(*)	(*)	(*)	-	-
- others (specify)		-	-	temperature rise		temperature rise	

		CIS		JAPAN		ITALY	
UHV autotransformers (AT) and reactors (RE)		(AT)	(RE)	(AT)	(RE)	(AT)	(RE)
Rated power	(MVA)	667x3	300x3	1000x3		400x3	-
Number of phases		single phase unit	single phase unit	single phase unit		single phase unit	
Number of windings		3	1	3		3	-
Rated voltage:							
- UHV winding	(kV)	$1150/\sqrt{3}$	$1200/\sqrt{3}$	$1050/\sqrt{3}$		$1000/\sqrt{3}$	-
- HV winding	(kV)	$500/\sqrt{3}$	-	$525/\sqrt{3}$		$400/\sqrt{3}$	-
- other winding (specify)	(kV)	20	-	147		12.6	-
Insulation levels:							
- power frequency withstand voltage	(kV)	1100	1100	$\sqrt{3}$		910	-
- lightning impulse withstand voltage	(kV)	2550	2550	1950		2250-1300-95	-
- switching impulse withstand voltage	(kV)	2100	2100	1425		1800	-
Losses:							
- no load losses (at rated voltage)	(%)	360	900	under examination		220 (measured 193)	
- load losses (at rated voltage)	(%)	1290	900	"		800 (measured 616)	
Exciting current (at rated voltage)	(%)	0.35	-	"		0.5 (measured)	
Impedance voltage	(%)	11.5	-	"		15.06 (measured)	
Weights:							
- total net weight with oil	(ton)	580	245	"		348	
- net weight of core	(ton)	-	-	"		193 (core and windings)	
- net weight of coils	(ton)	-	-	"		73 (oil)	
- net weight of transformer tank	(ton)	-	-	"		82 (with accessories)	
- for transportation	(ton)	-	-	"		245	
Overall dimensions:							
- overall height (including accessories)	(mm)	17000	16400	"		10140	-
- overall width (including accessories)	(mm)	-	8000	"		9940	-
- overall length (including accessories)	(mm)	16000	15100	"		9100	-
Cooling equipment:							
- type of cooling		-	-	forced oil/forced air		forced oil/forced air	
- number of independent cooler groups		-	2	under axamination		5	-
- number of cooling fans (for group)		-	8	"		2	-
Design data:							
- noise level (to IEC specification)	(dBA)	-	90	"		74	-
- flux density at rated voltage	(T)	-	-	"		-	-
- level of partial discharge	(pC)	-	500	"		200	-
- core manufacturing:							
shell or core		-	-	"		core	-
number of limbs		-	2	"		4 (2 wounded)	-
winding location on each limb		-	concentr.	"		3 on 2 limbs	-

		CIS		JAPAN		ITALY	
UHV autotransformers (AT) and reactors (RE) (continued)		(AT)	(RE)	(AT)	(RE)	(AT)	(RE)
Bushings:							
- UHV phase - type		TBT-1150-II	-	gas type			
- total height	(mm)	-	-	11500			
- air length	(mm)	-	-	10620			
- creepage distance	(mm)	-	-	46400			
- neutral - type		-	-				
- total height	(mm)	-	-				
- air length	(mm)	-	-				
- creepage distance	(mm)	-	-				
- HV phase - type		-	-	gas bushing type			
- total height	(mm)	-	-	6700			
- air length	(mm)	-	-	6250			
- creepage distance	(mm)	-	-	20400			
Bushing current transformer:							
- UVH phase - quantity		2	3				
- type		TBT-1150-II	TBT-1200				
- nominal ratio	(kA/A)	4/1	1-2-3-4/1				
- rated output		-	-				
-class		-	-				
- neutral - quantity		2	2				
- type		TBT-110	TBT-1200				
- nominal ratio	(kA/A)	4/1	0.2-0.3-0.4-0.6/1				
- rated output		-	-				
- class		-	-				
- HV phase - quantity		2	-				
- type		TBT-500	-				
- nominal ratio	(kA/A)	3/1	-				
- rated output		-	-				
- class		-	-				
Type tests (Recomendation followed, if any)		-	-				
Circuit breaker							
Rated normal current	(A)	4000		8000		6000	
Rated short circuit breaking capacity (for short line fault and terminal line fault)	(kA)	40		50		63	
Rated short time withstand current:							
- value	(kA)	40		50		63	
- duration	(s)	2		2		1	
Rated short circuit (peak) making capacity	(kA)	102		125		158	
Rated out-of-phase breaking capacity	(kA)	-		25		16	
Rated line charging breaking capacity	(A)	400		1000		900	

		CIS	JAPAN	ITALY
Circuit breaker (continued)				
Rated small inductive breaking capacity	(A)	500	5	64
Rated operating sequence:				
- for rapid three-phase auto-reclosing		0 - 0.3 sec. - CO	0 - 1 sec. - CO - 60 sec. - CO	0 - 0.3 sec. - CO - 60 sec. - CO
- for rapid single-phase auto-reclosing		0 - 0.3 sec. - CO	" " "	0 - 1 sec. - CO - 60 sec. - CO
Rated break time	(ms)	35	40 (main contact)	60
Opening time	(ms)	22	-	< 40
Rated closing time	(ms)	100	-	< 120
Lightning impulse withstand voltage:				
- to ground	(kV)	2900	2250	2250
- between terminals	(kV)	2900	2250 + (635 BIAS)	2250 + (600 BIAS)
Switching impulse withstand voltage:				
- to ground	(kV)	2100	-	1675
- between terminals	(kV)	3100	-	1675 + (600 BIAS)
Closing resistances:				
- value	(ohms)	400	700	500
- inserting time	(ms)	8 - 10	10	10
Max. overvoltages due to switching no loaded lines and transf. magnetizing current	(p.u.)	1.8	1.6 - 1.7	1.78
Opening resistance	(ohms)	-	700	500
Dimensions of the circuit breaker	(mm)	35600 x 23500 x 13650	-	Diameter = 1400 Lenght - 11000
Weight	(kg)	142000	-	10000
Bus-bar disconectors				
Rated voltage	(kV)	1150	1100	1050
Rated normal current	(A)	4000	8000	6000
Short-time withstand current (1 sec)	(kA)	40	50 (2 sec)	63
Peak withstand current	(kA)	102	-	158
Lightning impulse withstand voltage:				
- to ground	(kV)	2900	2250	2250
- between terminals (+)	(kV)	3300	2250 + (635 BIAS)	2250 + (600 BIAS)
Switching impulse withstand voltage:				
- to ground	(kV)	2100	-	1675
- between terminals (+)	(kV)	2400	-	1675 + (600 BIAS)
Auxiliary resistor	(ohms)	-	500	100
Dimensions of the disconector	(mm)	24500 x 2800 x 15100	-	Diameter 1150 Lenght 5200
Weight	(kg)	13370	-	7000

	CIS	JAPAN	ITALY
Earthing switches			
Breaking capacity in respect of inductive loads (cos = 0.2) (kA)	-	3.5	-
Power frequency recovery volotage (kV)	-	600 (peak)	-
Breaking capacity in respect of capacitive load (A)	-	1000	not instaled in the pilot station
Power frequency recovery voltage (kV)	-	900 (peak)	-
Break time (ms)	-	⩽ 100	-
Closing time (ms)	-	⩽ 100	-
Earthing disconnectors			
Rated voltage (kV)	-	1100 (approx.)	1050
L.I. withstand voltage (in open position) (kV)	-	2250	2250
S.I. withstand voltage (in open position) (kV)	-	-	1675
Opening time (ms)	-	-	-
Closing time (ms)	-	-	-
Dimensions (mm)	-	-	-
Weight (kg)	-	-	-
Surge arresters			
Rated voltage (kV)	800	826 (approx.)	749
Rated current (kA)	14	20 kA	20
L.I. protection level (kV)	1850	1620 (20 kA)	1800
S.I. protection level (kV)	1800	-	1450
Power frequency sparkover voltage (kV)	1100 - 1250	(metal oxide type)	(metal oxide type)
Line discharge class (kJ)	-	-	-
Pressure relief test current (kA)	-	-	63
Creepage distance (for open air solution) (mm)	> 21600	(tank type)	(tank type)
Dimensions (mm)	12500	(4300 - 4800) x (1800 - 2200)	4600 x 1500
Weight (kg)	11700	12000 - 12500	1500

		CIS	JAPAN	ITALY
Current transformer				
Internal insulation		oil	under examination	SF_6 gas
Nominal ratio	(A)	2000 - 4000 / 1	" "	6000 / 1
Type		T90PM - 1150	" "	TPY (for relay protection)
Energization cycle		-	" "	0 - 0.3 sec. - CO
Error in transient conditions	(%)	-	" "	7.5% first energ. - 12% second energ.
Error in steady state conditions (class)		10P, 0.5	" "	5P
Rated output	(W)	40, 30	" "	5
Primary time constant	(ms)	-	" "	150
Creepage distance (for CT with air insulation)	(mm)	18000	" "	-
Dimensions	(mm)	4200 x 4200 x 14500	" "	-
Weight	(kg)	21560	" "	-
Voltage transformer				
Internal insulation		oil	" "	SF_6 gas
Nominal ratio	(kV)	$1150/\sqrt{3} : 0.1/\sqrt{3}, 0.1$	" "	$1050/\sqrt{3} : 0.1/\sqrt{3}, 0.1/\sqrt{3}$
Type		HAE - 1150	" "	Capacitive with amplifying unit
Error in stady state conditions (class)		1.0, 3P	" "	0.2, 3P
Rated output	(VA)	300, 600	" "	30 (for static relay protection)
Creepage distance (for VT with air insulation)	(mm)	18000	" "	-
Dimensions	(mm)	1500 x 1500 x 11300	" "	-
Weight	(kg)	6400	" "	-
Bushings (SF_6 - Air / SF_6 - oil)				
Type		-	SF_6 oil (condenser core)	SF_6 / oil
Rated current	(kA)	-	8000 / 4000	1600
Total height	(mm)	-	11500	4928
Air or oil length	(mm)	-	10620	2538
SF_6 length	(mm)	-	10620	2310
Creepage distance (for air insulation)	(mm)	-	under examination	-
Diameter	(mm)	-	under examination	800
Weight	(kg)	-	under examination	2600

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