IMPORTANT ACHIEVEMENTS

OF CIGRE

The following papers present the contributions
of the 15 Study Committees
to the important achievements of CIGRE, namely :

Rotating Machines	*SC 11*
Transformers	*SC 12*
Switching Equipment	*SC 13*
HVDC Links and AC Power Electronic Equipment	*SC 14*
Materials for Electrotechnology	*SC 15*
HV Insulated Cables	*SC 21*
Overhead Lines	*SC 22*
Substations	*SC 23*
Power System Insulation Coordination	*SC 33*
Power System Protection and Local Control	*SC 34*
Power System Communication and Telecontrol	*SC 35*
Power System Electromagnetic Compatibility	*SC 36*
Power System Planning and Development	*SC 37*
Power System Analysis and Techniques	*SC 38*
Power System Operation and Control	*SC 39*

December 1998

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STUDY COMMITTEE 11 : « ROTATING MACHINES »

INTRODUCTION

SC11 is responsible for the field of Rotating Electrical Machines and includes in its scope all such machines for power generation and large motors for mover stations. It also includes a brief to cover materials technology relevant to machines and superconducting technology relevant to CIGRE activities.

The review of trends on national perspectives regarding electrical machines shows the wide variety of situations and problems, on political, economic and technical aspects. Hydro, thermal and nuclear sources of energy are quite diversely balanced in the world, thus confirming the need for a wide technical scope within the SC. The impact of economic crisis is evident in many countries in the 90s, with a noticeable exception for Asia where generation equipement is being developped at a sustained level.

The race for higher unit ratings for very large generators has been stopped and life management of machinery has been the prior concern for more than a decade now. SC11 has clearly oriented its studies to contribute to this issue. The emphasis has been put for some years in the field of conventional machines on the improvement of the service supplied by units in operation for increase in performance, better reliability, and life extension.This trend is well confirmed now and will keep on in the future ; the development will continue on diagnostics, monitoring, maintenance and life management / extension.

A second key issue which has been of growing importance for the recent years is the question of relation between the electrical system and the generating units. With the unbundling of generation and transmission becoming more prevalent, the importance of the effect and costs of trade-offs in power plant capital and operational costs has to be scrutinised to enable generators and system operators to minimize and to agree on costs. Jointly with SC39, SC11 has contributed to develop the concept of interface between the system and the generating plants as an exchange of services, useful in integrated systems as an aid for decision making at decentralized level. Another key problem on which SC11 has contributed lies with the ancillary services normally associated with generation, such as : VAR control, voltage control, frequency response, time required to accept load, black start capability...A systemic and multidisciplinary approach has been developped, involving the System Committees with SC11, acting as a Generation Committee.

SC 11 is also well involved in new developments, including non conventional rotating machines, variable speed drives, new cooling techniques such as higher rated air cooled generators...

There are 5 major technology areas for long term strategy consideration viz :

1 - Superconducting technology

2 - Power electronics

3 - Machine monitoring and diagnosis

4 - Machine/system interaction

5 - Machine evolution

This background will be explained with reference to chosen specific technical examples, detailed hereafter to demonstrate the main contribution of the Study Committee to this field during the last two decades.

As regards the future trends, while keeping and developing its "core competence" in electrical machines, particularly in the field of life management, SC 11 has widened its scope of activities to cover generation and not only the generators. The trend towards more system based approaches and joint studies with other committees will become increasingly prevalent in future years. Machine expertise and system knowledge are the qualities required of members and experts of SC 11 both now and in the future. It will be necessary to respond to questions such as:

- reciprocal impact of generation characteristics and power systems evolution,

- ancillary services in a more competitive environment, and impact on machines.

1 - LIFE MANAGEMENT AND GENERATOR CONDITION MONITORING

As regards turbogenerators, works have been conducted and the results recently published in ELECTRA on ageing caused by field current cycling [7], on rotor and stator windings integrity [10] [11], and last but not the least on a Guideline for Operators on the data required for generator life management.

On hydrogenerators a 1987 survey of the experience with condition monitoring [1] was recently updated including :

a) conventional monitoring tools used in well established ways

b) novel applications of conventional tools

c) new monitoring tools

for the five main components of stator core, stator winding, rotor winding, air gap normality, together with stator and rotor eccentricity, bearing loading, vibration level and temperature monitoring.

For all types of machines monitoring and diagnosis are key topics in the optimisation of operation, protection and maintenance of generators and motors as well as for the Life Management, and are regularly discussed at Paris conferences to provide designers and operators with essential feedback and information. A CIGRE / EPRI colloquium devoted to life management was held in Florence (Italy) in April 1997.

2 - TORSIONAL STRESSES AND FATIGUE IN TURBINE GENERATOR SHAFT LINES

The shafts of turbine generators are subject to the risk of deformation and cyclic fatigue from fault conditions and system operation. Studies of the problem involve modelling of the electrical and mechanical torsional behaviour of the shaft line under applied faults, such as mal-synchronising, and system operation, for example rapid reclosing of breakers for fault clearance. Fatigue risk evaluation involves calculation of the transient torques, the number of cycles and the cumulative fatigue damage at critical features, such as stress concentrating fillets at the LP Turbine/Generator coupling. Direct measurement of shaft torques are possible for trial purposes but on-line monitoring requires a complete model of machine behaviour fed from inferred shaft torques by optical measurement of shaft displacements. Development of the analytical techniques and on-line monitors was accomplished in the 1979/89 decade. The CIGRE studies involved comparison of the results of fatigue evaluation for defined benchmark studies by different countries.

Good agreement on calculated shaft was accompanied by divergence on the fatigue evaluation due to different assumptions of the cumulating damage at shaft strain concentrations. However the relative severity of different types of faults could be classified and support provided to proposals that a large turbine generator should be capable of sustaining a specified number of mal-synchronisations, out of phase operation and close-up three phase faults without absorbing more than 30 % of the shaft fatigue life, thus allowing margin for less severe operational incidents during the unit lifetime. The damaging effect of rapid reclosure has been fed to system operators and is avoided whenever possible. Monitors are available for cumulative life evaluation on-line. Though not essential with well regulated operation such monitors have already detected unforeseen sub-synchronous resonance and are available for critical locations. Ref. [4] reports the CIGRE studies and the recommendations for generator shaft capability.

3 - NEW AND NON-CONVENTIONAL MACHINES AND SUPERCONDUCTING APPLICATIONS

This Group was initially concerned with the development of superconducting (SC) generators utilising low temperature superconductors [3] and has continued with studies of technical problems on :

- Quench protection

- Dynamic performance of SC generators and rotors

- Application of SC wires

- Liquid helium management and SC winding cooling

- Maintaining high vacuum in the rotor

- Operational measurements on SC rotors

- Structural materials of SC rotors

- Air gap winding

- Reliability and availability of cryogenic equipment

A report was published in Electra in 1996, with guidelines on the specification of parameters for SC generators [8].

To take advantage of the expertise in this Group, composed of the world authorities in S.C. development they have also produced a perspective on high temperature superconductor application. Low temperature SC applications are already in place for turbine generators and are envisaged for current limiters FCL and SMES (SC magnetic energy storage). High temperature SC's applications depend on the long timescales for conductor development.

4 - LARGE MOTORS AND DRIVES

Power Electronics have greatly extended the capability of both synchronous and squirrel cage induction motors for application as adjustable speed drives for fluid flow regulation in power plants with resulting reductions in energy consumption and pollution.

Studies of the merits and economics of different types of Adjustable Speed Drive (ASD) have already been published [2].

Now that the application of ASD's for boiler feed pumps and fans are well established a comprehensive survey of experience is being undertaken on their specification, power supply/drive interaction, design features, testing, economics, control response, environmental improvements.

5 - GENERATION AND THE SYSTEM

There is a marked trend within CIGRE to encourage joint works involving different SCs, regarding in particular the interelation between Generation and Electrical System. Three significant examples are detailed below.

5.1 DIRECTLY CONNECTED GENERATORS TO HVDC CONVERTERS

Several technical and economic advantages are offerred by direct connection of generators to a separate AC/DC converter for connection to a DC transmission system. The results of studies of the main characteristics and comparative advantages have already been published in Electra [5] including the relevant generator considerations of harmonics, variable frequency and extended power factor operation. This has involved the latest analysis tools for generator electromagnetic and dynamic behaviour. Work has been extended on the generator reactive power and reactance requirements over the speed range for system/machine modelling, leading to a publication in ELECTRA in 1996 [9].

5.2 SYSTEM AND GENERATOR INTERACTION : TECHNICAL AND ECONOMIC IMPLICATIONS OF REQUIREMENTS AT THE INTERFACE

There is a complex interaction between the system and the generating plant at their interface. A joint study involving SCs 11 and 39 has been conducted to review the technical and economic aspects of present and future needs. Everything is to be considered but concentration is on the generators contribution to reactive power and voltage control, generation power reserve and generator performance required to cope with credible system disturbance. A paper has been produced by a 39-11 joint WG [6], and a joint plenary session was organised on this topic during the 1994 conference in PARIS.

5.3 GENERATION DEVELOPMENT AND IMPACT ON POWER SYSTEM

There are a number of new generation technologies, which may have an impact on operation and planning of the System. To address the question of identification and characteristics of generation, and particularly distributed generation, SC11 formed a Joint Task Force with participation by System Committees 37, 38 and 39.

An « Update on distributed generation systems » was presented at the Symposium of Tours on behalf of the Joint Task Force [12].

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[5]	**Direct Connection of Generators to HVDC Converters : Main Characteristics and Comparative Advantages**	Electra N° 149, August 1993
[6]	**System and Generation interaction : technical and economic implications of requirements at the interface**	Paris 1994 Session - Paper 39/11-07
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[8]	**Technical problems involved in the development of superconducting machines**	Electra N° 165, 1996
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[11]	**Report on stator winding integrity**	Electra N° 169, 1996
[12]	**Update on Distributed Generation Systems**	Symposium Tours 1997 - Paper 500-07

STUDY COMMITTEE 12 : « TRANSFORMERS »

INTRODUCTION

When CIGRE started in 1921 the transformer already celebrated his 36th birthday.

The fundamental theories were fully developed and the basic design features and materials seem to have remained unchanged since those days. But with the increasing demand of electrical energy and the growth of grid systems it turned out that also the transformer technology faced new problems to be solved.

Whereas in the past the activities of Study Committee 12 Transformers were concentrating on design problems related to the rapid increase of rated voltage and power and the application of new materials, service conditions and their impact on the transformer performance have governed the discussions of the last two decades.

1 - VOLTAGE RELATED PROBLEMS

Until the mid of the century the highest sytem voltage had been increased step by step to a level of roughly 300 kV.But from then within no more than 15 years rated voltage climbed up to a level of 800 kV and more.The development of transformers and reactors for extra and ultra high rated voltage and design and test problems of this new generation of transformers was a main topic of the SC 12 activities in the late 60th and early 70th (Fig.1).

Intensive and extended work was dedicated to the aspects of impulse stress phenomena in HV-windings and to the development of appropriate impulse test procedures.In those days the risk of failure in service caused by lightning stroke or under impulse test was high.Research and development work was concentrated on the design of windings which were able to withstand impulse stress and on related test procedures.

Another field of activity was to develop non-destructive test methods in order to confirm reliable dielectric performance of large HV transformers.Ionisation problems and Partial Discharge measurement became an important item in the work of the Study Committee [1].The results of these actvities were of major influence on the elaboration of the related IEC standards for dielectric tests including PD measurement and on the development of adequate measuring device [5].

2 - CURRENT RELATED PROBLEMS

The increase of rated voltage was accompanied by a steep increase of the power rating of transformers.It culminated in 1 300 MVA rating of a GSU transformer in 1972 and 2 000 MVA bank rating of single phase autotransformers in 1980.As a consequence of the rapid increase in power manufacturers and users were faced with a couple of new problems concerning losses, short circuit strength and thermal performance which all entered the discussion platform of Study Committee 12.

Though the efficiency of large transformers is extremly high - 99.5 % or more - the amount of load loss exceeded the hallmark of 1 000kW with considerable impact on the performance of the internal cooling.The development and application of OD (oil directed) cooling was only one consequence. Methods for loss measurement and heat-run tests had to be revised and adapted to the new demands.

Stray flux problems and the application of proper protection against local hot-spots became more essential and initiated the development of calculation tools based on the application of advanced computer programs [2,3].

Another main concern was the short circuit withstand capability of very large transformers reflecting that the short circuit forces were increasing dramatically by the increase of rated current and additionally by the increase of the short circuit power of the systems.These problems were extensively discussed in a Working Group and several times addressed as preferential subjects at the Paris Sessions.

Looking into the list of preferential subjects from 1972 to 1996 and reviewing the relevant publications and Working Group reports it can be stated that Study Committee 12 played an active part in the related discusssions and in the development of standards.

3 - NEW CHALLENGES TO THE TRANSFORMER INSULATION SYSTEM

In the late 70th unexplained failures in large power transformers under transient voltage conditions initated extensive studies of resonance phenomena in windings.The first investigations covered the frequency range up to several hundreds of kHz typical for conventional transmission systems and stations. As a result of Working Group 12.07 „ Fast Transients“ recommendations for adequate design and testing were issued [4].

When gas insulated systems (GIS) for EHV application with direct SF6-connection to the transformer were introduced, a new kind of overvoltage impact on the transformer appeared: very fast transients (VFT), which are raised by switching operations in the GIS. It is the rise time of nano seconds and the high frequencies in the MHz range, which impose a new kind of stress on the transformer windings. SC 12 is still involved in these matters in cooperation with other Study Committees.

About 20 years ago at the Brughes Colloquium Japanese experts for the first time reported on phenomena of static electrification in HV-transformers with only low response by other experts.But in the early 80th an increasing number of faults were reported, which were clearly related to static charging in large oil filled transformers.In collaboration with EPRI and other scientific institutions SC 12 started a Joint Working Group with SC 15 to investigate into the basic physics of the phenomenon and to determine the influencing parameters and counter-measures.The preliminary results were presented at colloquia and workshops but there are still some open questions remaining.

4 - SERVICEABILITY OF POWER TRANSFORMERS

In 1973 the „oil crisis“ terminated the trend towards steady increase of energy consumption and further increase of power and voltage ratings of the related equipment.Servicebility, safe operation and environmental and economical aspects became predominant.

As a key issue of loadability all aspects of the thermal performance including determination and direct measurement of tolerable hot-spot temperature, heat run test procedure, the application of Dissolved Gas Analysis to evaluate the test results, overload practice and its impact on remanent life exspectation have been investigated by a very effective Working Group on thermal aspects [9].

Regarding the environmental impact of transformers noise reduction is of increasing importance.WG 12.12 has elaborated the new IEC-standard on noise intensity measurement based on extensive measurements performed by the members of the group [7].

Provisions against fire hazard and pollution by oil spill in case of catastrophic faults on large transformers and new concepts with nonflammable insulation systems and rupture proof tank design have been discusssed.

In recent years and in the near future life management and reliability are the main domains of actvity in Study Committee 12.The principal reasons are that in the industrialised countries the bulk of power transformers has come to age and that deregulation of the energy supply market

has forced economical considerations on the user side.Both aspects raise the question of more precise assessment of the remanent life and improved reliability of the transformer in service.

Study Committee 12 contributes to these considerations by intensive work in a Working Group on life management.The work is grouped in three Task Forces with the objective to provide practical tools which may be used by all who are charged with managing transformer assets.The scope covers general knowledge and theoretical issues [6], diagnostics and monitoring techniques and operations to be used after a problem has been diagnosed.

5 - HVDC CONVERTER TRANSFORMERS AND REACTORS

The development and introduction of HVDC transmission systems was a new challenge for both transformer users and supplieres.Traditionally the transformer technology has to deal with AC phenomena and the design principles are related only to AC conditiones.The designers had to learn how to match different dielectric requirements under transient and steady state DC conditiones and to design adequate insulation structures which are able to withstand DC voltage and superimposed AC voltage stresses under test and service conditiones.Furthermore they had to take into consideration harmonics in the load current and DC excitation of the core and their impact on noise and losses.Pollution of bushings and airside insulators required much more attention than under AC conditiones.To respond to the particular service conditions extensive development work had to be performed.New and adequate test procedures had to be introduced in the standards.A Joint Working Group of SC 12 and SC14 worked very hard to prepare standards for the specification and testing of HVDC transformers and reactors.The results have been published in Electra [8].

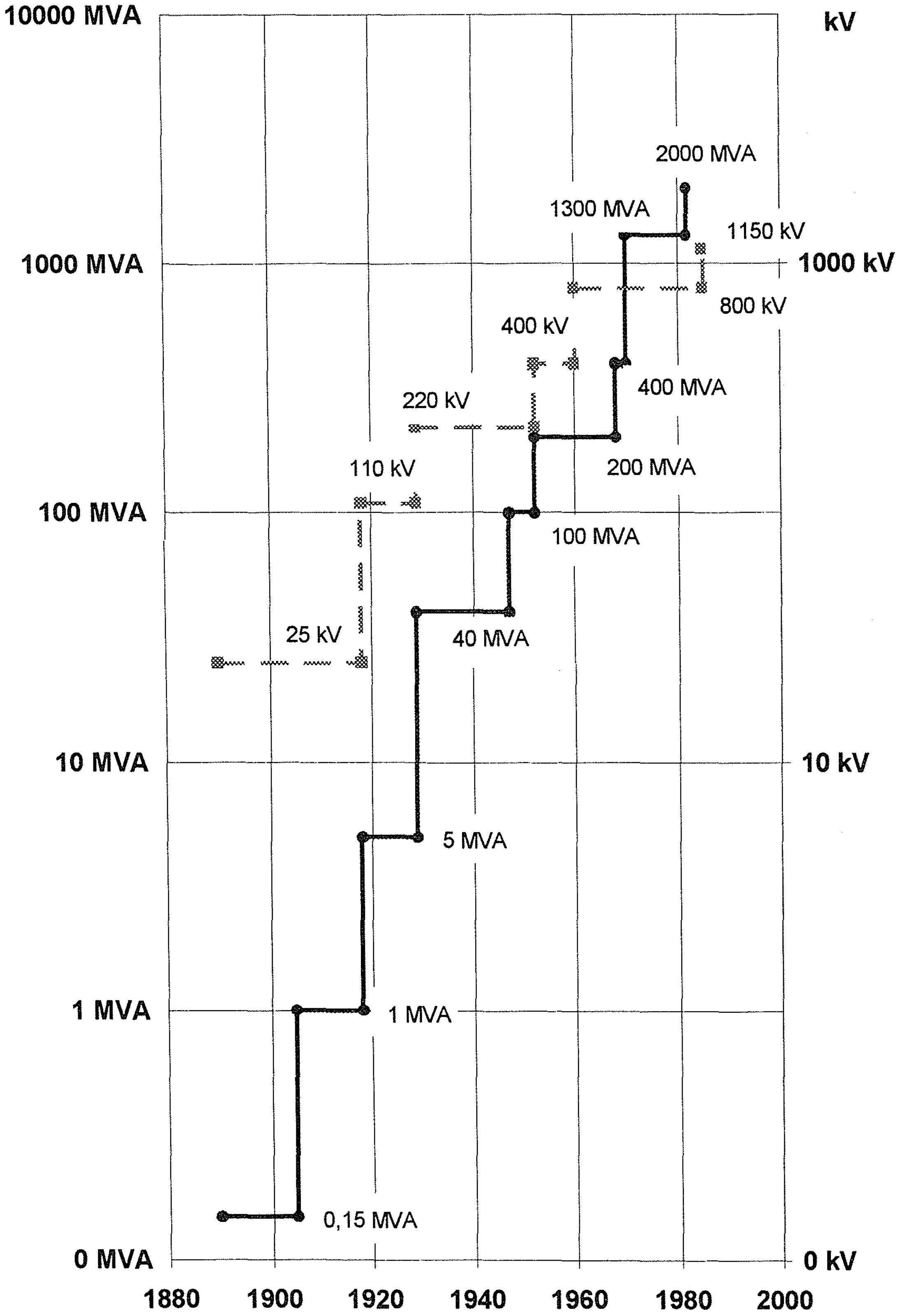
6 - INSTRUMENT TRANSFORMERS

On the decision of the Technical Committee in 1993 instrument transformers were included in the scope of Study Committee 12. Since that time a Working Group has started to review the failure statistics of instrument transformers and to study the service experience with new and non-conventional current and voltage measuring devices for the application in HV and EHV systems.

7 - ON-GOING AND FUTURE DOMAINS OF ACTIVITIES

The main directions in the future will be :

- life management
- reliability including accessories
- service conditiones and interactions in the electrical environment of transformers
- environmental and economical impacts
- new/non-conventional design concepts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	• Review DGA during heat-run test	Electra 156, 1994
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STUDY COMMITTEE 13 : « SWITCHING EQUIPMENT »

INTRODUCTION

Study Committee 13 focuses its interests and efforts in the area of switchgear and switching equipment for high and medium voltage applications. This includes theory, design, and construction of switching equipment and the behavior of switching equipment in, interaction with, and duties imposed by the system under normal, emergency and fault conditions. The scope of the work of the Study Committee covers a broad range of elements including arc physics, transient behavior of networks, switching phenomena, reliability, maintenance, and diagnostics, life expectancy, and testing.

SC 13, by providing a forum for the exchange of knowledge and experience, responds to the opportunities created by new technologies and challenges of evolving system requirements to support the availability of reliable and cost effective switching equipment to meet present and future industry requirements worldwide.

1 - CIRCUIT BREAKER TECHNOLOGY DEVELOPMENTS

High-voltage circuit-breaker technology has evolved significantly over the past 30 years. Initially, high-voltage circuit-breaker interrupters were commonly of the minimum-oil, bulk-oil, air-blast, or SF6 two-pressure types. These breakers were often mechanically complex, with many series interrupting chambers, large compressor systems, and auxiliary interrupting chambers for opening resistors.

Today's high-voltage breakers employ, almost exclusively, SF6 single-pressure interrupters, with both "pure" and "thermally assisted" puffers. The new SF6 single-pressure interrupter technology offers many advantages over the older technologies, including a reduction in the number of interrupting chambers and reduced mechanical complexity. The use of fewer chambers, however, has increased chamber stresses and has presented many new challenges in achieving reliable electrical performance. A more detailed understanding of the complex arc physics phenomena and of the switching stresses circuit-breakers experience has become necessary.

The use of thermally assisted puffer technology has reduced the operating mechanism requirements for circuit breakers. Lower mechanism energy requirements allow the use of potentially more reliable and less expensive mechanisms. Again, a better knowledge of the interrupter characteristics is required as the interrupter characteristics are dependent on the current being interrupted.

In medium voltage, specifically for rated voltages 3 to 40 kV, the vacuum circuit-breaker has become the dominating technology. It offers significant advantages because of its low contact erosion and, again, small operating energy. However, new interaction phenomena during switching on and off, particularly of inductive loads, had to be studied and taken into account to ensure reliable operation.

2 - APPLICATION OF ARC PHYSICS TO CIRCUIT-BREAKERS

The electric arc is the heart and soul of the circuit breaker. The arc interruption process is extremely complex. There are strong interactions between the arc and the connected power system. A solid understanding of the physics of the arc is necessary to develop and correctly apply circuit breakers.

Important contributions to the understanding of arc physics, especially in calculation methods, black box modeling, and analytical tools, have been made by SC 13. Of special importance is the survey of theoretical and practical methods to predict interrupter performance and black box modeling. Black box models are applied to gas breakers and describe the variation of arc conductance in the thermal phase of interruption which is critical for modern highly stressed SF6-interrupters . This work has greatly enhanced the understanding of circuit-breaker performance and capabilities, and has reduced costly developmental testing requirements.

The continuing development of high-voltage circuit-breaker towards less complex designs, higher voltage withstand and lower probability of restrikes requires a further insight into the interactions between the electric arc, the flow of the extinguishing medium and the electric field distribution within the interrupter. SC 13 will continue to study these phenomena and to elaborate methods to optimize the interrupter design.

While the modeling and calculation methods for high pressure arcs have been developed to a stage that they permit the calculation of the interaction between the circuit-breaker and the network or the load, such procedures are not yet available for vacuum arc circuit-breakers. SC 13 will closely follow the improvements in the physical understanding of vacuum arcs until they have reached a stage that can be used as a basis for mathematical models for arcing behavior and electric withstand recovery.

3 - FIRST AND SECOND INTERNATIONAL SURVEYS ON THE RELIABILITY OF CIRCUIT-BREAKERS IN SERVICE

Circuit-breakers are the primary high-voltage protective elements, as well as the principle dynamic control elements for power systems. The effectiveness of these devices is critical to the safe and reliable operation of a power system. Two international surveys were conducted by Study Committee 13. Each survey incorporated more than 70,000 circuit-breaker-years of data. The first, covering all technologies in service, was completed in 1981. The second, which covered SF6 single-pressure breakers only, was completed in 1994. These studies demonstrated the improved reliability of the newer technologies by quantifying the decreased major-failure rate, but showed an increase in minor failures. The results of these studies have influenced circuit-breaker design and testing, power system reliability planning, and maintenance practices on circuit-breakers, and continue to do so.

Due to its role as the decisive safety device in transmission and distribution networks circuit-breaker reliability remains a critical issue for all circuit-breaker technologies. Therefore, it will continue to play a major role in the work of SC 13.

4 - CIRCUIT-BREAKER STRESSES AND TEST METHODS

In past decades, the short-circuit currents and stresses in transmission and distribution networks have become higher and it was therefore necessary to have a more profound understanding of these circuit-breaker stresses, to test them in a realistic manner, and to cover all possible switching conditions. Moreover, new measurement equipment with a higher sensitivity made it possible to more closely study the response of the systems during and after short-circuit interruption.

Transient recovery voltage wave-shapes and amplitudes under terminal fault conditions were studied for all voltage levels from medium up through extra high voltage. These studies included various system configurations and different fault circumstances. Studies also addressed power system time constraints and breaking conditions in case of extremely high direct current components.

For SF6 circuit-breakers with high short-circuit current breaking capacity, the short-line fault was found to produce the highest stress. Studies of SC 13 were the basis to determine the critical stresses, to explore the physical phenomena associated with this type of fault, and to investigate the limits of the circuit-breaker's interrupting capabilities.

Similar studies were carried out on the process of closing and reclosing of transmission lines in extra high-voltage networks, both through field tests in actual networks and by calculations. They showed which system and circuit-breaker parameters affect the overvoltages associated with closing operations, and how these overvoltages may be controlled.

Standards and tests were developed to address the system requirements. The ratings, test requirements, and testing procedures established by IEC SC 17A continues to be beneficial for both sides.

Synthetic test circuits were designed to test high-voltage circuit-breakers full scale up to the highest ratings under any fault and load condition in a realistic manner. For many years, up to present time, SC 13 has examined the interactions between the circuit-breaker and the test circuits to verify that the tests resemble the actual system response. The establishment of such realistic testing procedures play a major role to ensure the reliability of circuit-breakers and their capability to control all possible faults in any network configuration.

5 - INTERRUPTION OF SMALL INDUCTIVE CURRENTS

There have been an imposing number of failures of equipment and circuit-breakers associated with switching reactive currents. Switching of small inductive currents such as stalled motors, shunt reactor current, and unloaded or reactor-loaded transformers pose special problems for circuit-breaker technology. High rates of rise of recovery voltage and complex current chopping and transient phenomena may force the circuit-breaker to restrike at short contact spacings and thus produce steep-fronted voltage surges and overvoltages that possibly over stress the external and internal insulation of the reactive load.

As neither detailed nor comprehensive literature existed which explained the physical phenomena associated with such reignition behavior, SC 13 carried out fundamental research based on field and laboratory tests and extensive theoretical work. These studies dealt with SF6 and air blast as well as with vacuum circuit-breakers. It could be shown that a complex interaction exists between the electric arc, which tends to be unstable under these conditions, the short contact spacing during opening or closing operation, the reactive load, the capacitance in the immediate vicinity of the circuit-breaker, and the power system elements on the source and the load side. The results enable the system engineers and the designers of circuit-breakers, reactors, transformers, and motors to take measures to reduce the failure rates and ensure reliable operation.

The publications of SC 13 were adapted by IEC and IEEE to issue application guides for these switching cases.

6 - CAPACITIVE-CURRENT SWITCHING

Circuit-breakers typically switch Capacitive currents much more often than they switch fault currents. Investigations performed within the Study Committee determined that modern breakers, with their more highly stressed interrupting chambers and statistical performance behavior, required new capacitive-current testing methods to assure that performance met application requirements. In close cooperation with SC 13, an IEC/IEEE Working Group was formed to develop a common approach for incorporation into both IEEE/ANSI and IEC standards.

Although the work has not been concluded yet, the first results are being introduced into the IEC standard for high-voltage circuit-breakers, which is presently under revision. They take into account that during capacitive current switching, the circuit-breaker interrupter is stressed not only by the electric arc, but by local surface charges also, which rest on the insulating parts within the interrupter. Furthermore, as the life time of circuit-breakers and the time intervals between maintenance are now in the order of decades, pre-stress conditions have to be recognized during capacitive current switching tests.

7 - SWITCHING EQUIPMENT FOR HIGH-VOLTAGE DIRECT CURRENT SYSTEMS

As the number of direct current systems in service has increased, so has the opportunities to apply switching equipment in high-voltage direct current systems. Future multi-terminal and interconnected DC systems will undoubtedly have application requirements for switchgear. These applications include metallic return transfer breakers, current-commutation switches, disconnects and earthing switches and direct current circuit-breakers. A joint working group with Study Committee 14 focused on system stresses and other issues associated with the application of switchgear on direct current systems, and thereby developed preliminary specifications for devices for these various functions.

8. SUMMARY AND FUTURE WORK

Over the past two decades, high and medium-voltage circuit-breaker technology has evolved from oil and air-blast technologies to SF6 single-pressure and vacuum technologies. This evolution has resulted in the development of breakers of higher reliability than most of the older technologies primarily because of their reduced mechanical complexity. Although two or three chambers are most commonly employed at 550 kV, the new SF6 circuit-breaker technology allows for only a single interrupter chamber design to be used at these voltages. The reduced number of interrupters is made possible by an increased knowledge of system stresses, circuit-breaker performance and circuit-breaker/system interactions.

Over the same 20 years, microcomputer technology has made radical advances. This technology has and will continue to significantly affect every aspect of our lives, including high-voltage switchgear. The future will see new-age electronics incorporated into control, operation, and monitoring of breaker performance.

Thus, technical challenges involving system operations and financial pressures on the utility industry are met to reduce life-cycle costs and extend equipment life. New possibilities for diagnostics will further improve reliability and performance of circuit-breakers.

Controlled switching investigations are exploring the capabilities of new circuit-breaker technologies. Microprocessors are being employed to improve performance of switchgear by controlling circuit-breaker opening and closing times.

Finally, work on fault-current limiter specifications is underway. Such specifications will prepare the design of fault-current limiters using superconducting technologies.

Study Committee 13 continues to work closely with IEC TC 17 and has a task force specifically looking at revisions of IEC standards. A close relationship exists between IEEE, IEC and CIGRE concerning switchgear, and many activities are done cooperatively. The Study Committee continues to be a resource for the development of IEC standards and has been involved with several issues in the revision of IEC 56 (high voltage alternating-current circuit-breakers).

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STUDY COMMITTEE 14 : « HVDC LINKS AND AC POWER ELECTRONIC EQUIPMENT »

INTRODUCTION

Study Committee 14 started its work as an Equipment Committee. The main subject was the discussion of new mercury arc and later thyristor technology for the converters as the essential part of the HVDC schemes. During the development, however, the system aspects became more and more important as the interaction between the HVDC and the system is the crucial question technically and commercially. The work of SC 14 is developing more and more in this direction, especially as new items as FACTS and Custom Power have been added to the scope. In this technologies the system aspects play even a more important role. This can be seen from the most important milestones in the work of SC 14, listed below.

1 - MERCURY ARC CONVERTERS FOR HVDC

Mercury arc converters have been used for industrial applications during the 1920s and 1930s, with maximum voltages of 3.000 V for railway substations (a few radio transmitters at 15.000 V). But it was only in 1954 that they were developed sufficiently for HVDC, and then in the beginning only for 100 kV, 20 MW in the original Gotland (Sweden) scheme.

Over the whole period of CIGRE SC 10 (predecessor of SC 14) from its inception in 1945 up to late 60s the mercury arc valve was the most important topic in the work of the Committee /1, 2, 3/. During this time the number of HVDC schemes have been built culminated to large long distance transmission projects in this technology as Pacific Intertie and Nelson River I.

2 - TRANSITION FROM MERCURY ARC TO SOLID STATE VALVES

The first solid state project (back-to-back) to enter commercial service was Eel River (Canada) 80 kV, 320 MW in 1972. The period 1954 to 1972 can be considered as that during which the mercury arc valve reigned supreme, with the last stage of Nelson River Bipole 1 (Canada) in 1976 achieving a power of 1.620 MW at +/- 450 kV as the end of the overlap period, following which all future HVDC schemes were to be solid state.

The change to solid state valves brought with it the freedom from troublesome characteristics such as arc back and associated transient effects. The initially held view, that thyristors were so sensitive to over-currents and over-voltages, that their use would be limited to back-to-back, was soon seen to be false as special protective circuits were developed. The period 1976 right up to today is that during which solid state valves have reigned supreme /4/.

The Study Committee 14 contributed essentially to this development through intensive work and discussions in Working Groups and at Committee meetings.

3 - DEVELOPMENT OF VALVE CONTROLS, FIBRE OPTICS AND ARRESTORS

The thyristor valve would not have been possible for application in HVDC without additional developments as fibre optics and lightning arrestors, in particular the more recent zinc oxide arrestors, which made it possible to provide the necessary current and voltage protection of the valves and to transmit control and protection signals to a myriad of voltage levels /5, 6/.

4 - CONVERTER STATION AND SYSTEM CONTROL

The new basic controls for HVDC with new ideas as current control, angle control, equidistant firing, dc busbar voltage control and voltage dependent current limit have been developed. Reason for this was the increasing importance of the interactions between HVDC and AC system /7/.

In addition supplementary control options as power modulation, reactive power modulation, flicker control during switching of filters and capacitors and subsynchronous damping control have been developed. In the 70s and 80s the Study Committee 14 extended its work to the important subject of interaction between the HVDC and the system producing important expertises in this field. This has also been reflected in the extended scope of the Committee /8, 9, 10/.

5 - CONVERTER STATIONS CONNECTED TO WEAK AC SYSTEMS

As HVDC developed and the rating of the schemes became large it was required to operate into an ac system with low short circuit capacity. In 1986 it became apparent that the subject requires much more studies if the SC 14 was to fulfil an objective to produce some guidelines to utility system planners, in particular those with little HVDC experience.

An important Working Group has been built on this subject in cooperation with IEEE. The final document, in 2 parts, has been published by CIGRE covering explanation of basic phenomena and giving guidelines how to design systems with infeed into an ac system with low short-circuit capacity /10, 11/.

6 - MULTITERMINAL HVDC

Most of HVDC projects are two terminals or back-to-back schemes. However, to enable the interconnection of a larger number of loads or power plants the technology for multiterminal HVDC schemes has been developed. First such three terminal projects have been put in operation in 80s /12/.

The HVDC Substation technology remains almost the same as for two terminal schemes, however, major improvements have to be done in the field of control. The HVDC system became more complex as the number of possible operating conditions became large. Nevertheless studies demonstrated that 5 terminal systems /13/ and even systems up to 10 terminals became feasible.

7 - EQUIPMENT FOR REACTIVE POWER CONTROL IN AC AND DC SYSTEMS

Early HVDC schemes and many ac systems utilised synchronous condensers to provide reactive power, but static equipment now fulfils this requirement, known as Static Var Compensator (SVC), to achieve an overall supply or demand of reactive power /14/. Much of the HVDC valve technology contributed to the design of SVC equipment.

Their success has lead to investigations on whether other equipment used in AC systems, such as series compensation, could benefit from the use of Power Electronics, leading to a new concept dubbed FACTS.

8 - POWER ELECTRONIC EQUIPMENT FOR AC SYSTEMS

The new technology of Power Electronic for AC systems known also as Flexible AC Transmission (FACTS) was added into the scope of SC 14 in 1992. This technology offers great potential for value-added utilization of transmission lines and power systems by overcoming limitations of stability, active and reactive power control, voltage control, and phase angle control, through the use of a variety of power electronic Controllers on a case by case basis.

This extends the application of power electronics where HVDC transmission is not economically viable, and frequency is the same. FACTS became an important part of the activities of the SC 14 /15, 16/.

9 - CUSTOM POWER

More recently, another new technology, Custom Power, has been introduced into the SC 14 activities. This power electronics technology, involving controllers applied in the subtransmission and distribution systems, offers the possibility for utilities to supply value-added service of high quality and reliability to its industrial and commercial customers and industrial areas /17, 18/.

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STUDY COMMITTEE 15 : « MATERIALS FOR ELECTROTECHNOLOGY»

INTRODUCTION

Study Committee 15, "Materials for Electrotechnology", addresses the performance of material structures and associated aging processes, of relevance to equipment used for electrical energy generation and transmission. Formerly, SC 15 placed its emphasis on insulation materials. However, recently, the scope of SC15 was significantly expanded to include all kinds of material structures and interfacial processes; diagnostic techniques and tests for evaluating the performance of material systems under multi-factor stresses at normal or abnormal operating conditions; and condition monitoring of the insulation system for life management of installed equipment. Additionally, SC15 will address the optimized and integrated component designs of the future, requiring material structures with improved endurance at higher stress densities and other advanced abilities, such as self-restoring and sensoring. SC 15 has the horizontal advisory mission to provide the equipment committees of CIGRE with a materials scientific basis in engineering terms for an overall understanding of the future system performance.

At the 1996 Paris session, SC 15 completed implementation of the Strategic and Action plans recently prepared by all study committees. Thus the new title for the study committee, "Materials for Electrotechnology", now gives a fully appropriate description of the new, expanded scope of the committee. A new working group, joint with SC 33 (JWG 15/33-08), covering insulation monitoring and life estimation, formed in response to SC15's new mission, presented its initial results and perspectives in a formal paper at a joint General Session with SC21 and SC33 (1). The activities of this group can now be accessed via the Internet (potent@mit.edu). Also, the work carried out by the former working group on solid insulating materials has been restructured into that of three new working groups and three new task forces, whose activities will initially be guided by an ad-hoc advisory group of the study committee. Under the strategic plan the activities of the present nine working groups are organized under five broad technical directions:

- Liquid, solid and gas insulation, and capacitors.
- Breakdown and aging mechanisms.
- Insulation monitoring; life estimation and management.
- Advanced insulating materials.
- Standardization.

The new expanded scope of SC15 is as follows:

"Material science of relevance to the field of electric energy generation and transmission: Internal insulation in solid, liquid, and gaseous form; composite insulation; insulation for superconductive equipment; non-linear materials; fire retardant materials; conducting polymers; and advanced insulating materials. Other material science topics of relevance to CIGRE's apparatus (such as superconducting materials, metals and alloys, semiconducting materials for power devices, etc.) will be dealt with in cooperation with the relevant study committee.

Basic and applied studies of the dielectric, electrical, mechanical, physical, and chemical properties of the above materials. Testing methods, behavior in operation, ageing under stress, and breakdown mechanisms. Capacitors: materials, construction, and performance. New capacitor developments of relevance to the electric power industry".

The new scope adopted for SC15 will help in charting the future course of materials information and understanding that will be needed by the electric power industry as it rapidly approaches the Twentieth Century, including such information as will be needed by CIGRE's apparatus committees. It attempts also to offer some visionary assessment of areas such as electric vehicles which could significantly impact electric power usage in the future.

The major milestones of the work in SC 15 over the past twenty years are summarized below.

1 - OIL-PAPER INSULATION

The oil-paper of interest in SC 15 has been primarily the mineral oil-Kraft cellulosic paper used in large oil-filled transformers, where the mechanisms of ac and dc (converter transformers) breakdown, thermal aging and diagnostics have been studied extensively over the past twenty years. The use of gas-in-oil analysis and the use of gas ratios as a diagnostic tool were pioneered in WG 15-01. Guidelines prepared for IEC are now widely adapted by many professional societies world-wide. A revised set of guidelines, based on international service experience, has recently been prepared and will appear in Electra in condensed form. Another area where significant progress has been made is in chemical analysis methods for assessing the degradation of oil-paper insulation and other insulating materials within an oil-filled transformer (2). The statistical aspects of electrical testing of oil-paper insulation, especially breakdown, has long been of interest from both an academic and practical standpoint (3).

2 - LIQUID DIELECTRICS

In capacitors, the demise of PCBs in the 1970s, because of environmental reasons was followed by the development of high performance, highly-gas-absorbing aromatic-rich synthetic fluids. In transformers, some modification of mineral oils by synthetics such dodecyl-benzene was found to improve performance, but mineral oil remains the material of choice. WG 15-02 has been engaged in understanding these evolutions, including such properties as internal discharges and gassing, and their specific dependence on chemical composition. It also examined the interactions of different impregnant fluids with the biaxially-oriented polypropylene film used in capacitors (4). Recently, the current status of insulating liquids, including electrical and physical properties, technology trends, and environmental, health, and safety issues was summarized (5).

3 - INSULATING GASES

One of the most popular Technical Monograms issued by CIGRE is that prepared on the Paschen curves for SF6 and other gases, which provide breakdown data as a function of gap and pressure (6). Of more practical interest was the work on the voltage-time characteristics of SF6 gas (7). This has since been extended to the fundamentals of V-t behavior in SF6 gas for Very Fast Transients and for dc stresses, which is being used by the GIS industry for design and diagnostic purposes. The present focus of attention is on the effect of particles, plus the standardization and calibration of GIS diagnostic methods.

4 - CAPACITORS

Significant improvements in the efficiency of power capacitors have taken place over the past twenty years as a result of changes in the solid dielectric materials that the capacitor uses, plus the dielectric fluid used for impregnating the solid. Paper was first replaced by polypropylene film-paper designs, then by all-film designs. PCBs were replaced by a succession of highly-gas-absorbing liquids. WG 15-05 has been at the forefront of these changes, helping the industry understand their fundamental and practical significance.

5 - SOLID INSULATING MATERIAL: INTERNAL DISCHARGES, TREEING AND WATER TREEING

In the polymeric insulation used for extruded cables, internal discharges, treeing and water treeing are fundamental electrical degradation modes which depend on a wide ange of variables. The understanding of these and the evaluation of a variety of different test methods was extensively addressed by WG 15-6 (8, 9). Chemical(bulk and trace), physical, and mechanical properties were important characterization qualities addressed in this work.

6 - SOLID INSULATING MATERIALS: COMPOSITE INSULATION

The viability of using polymers such as silicone and EPDM rubbers, suitably reinforced and filled, to replace ceramic insulators for transmission lines and similar applications, is reasonably well -- though not completely-- accepted world wide. The testing of such insulators both at the screening and the performance stage, is a highly controversial topic being discussed by professional societies world-wide. This topic was formerly addressed in WG 15-06, in trying to understand the role of anti-tracking and anti-erosion fillers and hydrophobicity recovery and measurements such as leakage current. A new test method, the so-called CIGRE "Merry-go-Round" test was developed for IEC during this work. Outdoor insulation is now being addressed by a new working group, WG 15-04.

7 - SOLID INSULATING MATERIALS : INSULATION FOR CRYOGENIC EQUIPMENT

This topic is of interest to those involved in long term development of cryogenic machinery. A SC15 task force reviewed the status of insulating materials for such applications in a recent IEEE publication. A new task force, reporting to the study committee, will be looking into the future to examine the future directions of such developments.

8 - MICA BASED INSULATION

The validity of using high frequency for accelerating the aging of generator insulation models was an early focus of work on mica tape insulation (10). More recently the emphasis has shifted to understanding the effect of inverter transients (dV/dt, voltage peak, frequency, and other factors) on insulation life.

9 - DIAGNOSTICS AND MONITORING

These topics are of major interest world-wide, as users shift from scheduled to condition-based maintenance and as extending the life of equipment shifts upwards in priority. Many of CIGRE's study committees are involved with the topic. The degradation of insulation is often a major factor in the equation. Several of SC15s working groups have been involved in monitoring, diagnostics and life estimation for many years and the study committee has organized a number of Symposia, Colloquia and workshops, starting in 1979. A joint working group with SC33 is now trying to find the common themes governing aging and monitoring (1). The work will link with similar working in the apparatus committees over the next few years.

10 - ADVANCED MATERIALS AND INTERNAL INSULATION AND INTERFACES

These are two new areas of study in SC15, emerging from prior work on solid insulating materials. The first was the subject of a Colloquium at the 1997 meeting of SC 15, held in the USA (11). The second area is of relevance to many areas of insulation; initially it is strongly linked to SC21 interests in extruded polymer insulation such as at splices and terminations.

11 - ENVIRONMENTAL ISSUES

Many environmental issues affect the activities of CIGRE's working groups, though usually, as in SC15, these are secondary to the main technical work. One SC15 example is in the field of insulating liquids where health, safety, disposal, and regulation are factors which must each be taken into account in addition to technical performance and cost. At the 1996 CIGRE, a joint Panel Session between SC 15 and study committees 11, 12, 13, 21, 23, 36, and 37 was held on "Environmental Issues" affecting the power industry, including those related to insulating materials, rotating machinery, transformers, HV insulated cables, overhead lines, substations, and electromagnetic compatability (12). The discussion demonstrated the increased awareness of CIGRE with respect to environmental issues. It covered environmental issues from the perspective of electrical systems, electrical equipment, and insulating and non-insulating materials; and was designed to provide a broad, unbiased perspective of these issues and their coupling to associated issues such as safety, health, regulatory and technical performance.

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STUDY COMMITTEE 21 : « HV INSULATED CABLES »

INTRODUCTION

The field of activity of the Study Committee 21 covers HV cable systems for AC and DC transmission and distribution :

- at voltages > 60 kV
- with solid/liquid, solid, and gaseous insulation
- for laying in air, underground and in water.

In the following major activities of the Committee during the past 20 years are presented.

1 - UNDERGROUND POWER CABLES

The Committee has been in service since 1927 and has during these years represented an important international forum regarding HV cables technology from the introduction of the oil-pressure paper insulated cable in the twenties to the present competing systems designed with a dielectrics of extruded synthetic materials or gas under pressure (GIS).

The work of the committee has covered all aspects of cable technology from cable system design, manufacture, installation and service, quality assurance, tests and testing technology.

The Committee has closely followed the evolution of cable technology and has heavily contributed to the definition of pratical solutions which are the basis for modern cable technology :

Important work has been :

- current rating for stationary, cyclic and emergency load (1),
- cable dielectrics (2),
- electrical field stresses in cable dielectrics,
- water treeing in cables with extruded dielectrics,
- cross-bonding of cables (3), (10),
- forced cooling of cable systems (4)
- weibull statistics as a toll for design of cable dielectrics (2),
- service experience of cable systems (11),

- test recommendations for HV cable systems with extruded dielectrics (12), (13),
- laying and installation methods (14),
- HV cable accessories (17),
- comparison between HV overhead lines and underground cables (18),
- compressed gas insulated cables (7), (9).

Through a number of publications in Electra has defined the technical basis for international technical standards regarding able technology (IEC, CENELEC, etc...).

2 - SUBMARINE POWER CABLES

Submarine power cables has be on the agenda for Study Committee 21 over all these years and there is no doubt that the Committee and the biannual Paris sessions have influenced the technical evolution of submarine cable technology to a large extent. A number of technical reports/papers both for HVAC and HVDC have been published which are used as international reference documents for technical project specifications (8).

Specifically regarding test recommendations CIGRE reports (5), (6), (21) have a dominant position because submarine cables are not included in the IEC scope of work.

At present a Working Group (WG) has been asked to revise the existing test recommendations for mechanical tests (6) and the test recommendation for electrical tests on HVDC cables (5). Further, due to the fact that submarine cables with extruded dielectrics are being used more and more, the WG will also work out a test recommendation for such cable types. The revised test recommendation for mechanical tests was presented in Electra in April 1997 (21).

3 - TESTS ON INSTALLED CABLE SYSTEMS

A long period of work in the Committee has been devoted to the definition of efficient test methods applicable to cable systems with extruded dielectrics either after new installation or after repair. Several methods were analysed : DC voltage already used for paper insulated cables and easily applicable, oscillating wave derived from the commissioning tests applied on GIS and at last AC High Voltage tests. The challenge was to recommend an efficient test that was easily applicable and cos-efficient.

It appeared that DC was not technically efficient and that it could be harmful. The oscillating wave method had also a limited application ; only feasible for detection of irregularities caused by improper mounting of prefabricated accessories. The HVAC test was the most attractive one but until recently, HVAC test equipment was not available for testing of installed cable systems due to size and weight limitations.

Today, mobile HVAC test equipment based on series resonant systems have been developed and positive operational experience have been gained by some utilities.

Another possibility is to combine DC testing of the over-sheath of the cable after installation with the introduction of quality assurance procedures at the various project stages (manufacturing, installation,...).

A WG report on after laying tests will be presented in Electra in 1997. This report will be used as a reference document for IEC in connection with revision of future standards.

4 - PARTIAL DISCHARGE MEASUREMENTS ON SITE

New developments such as partial discharge measurements on installed cable systems are being developed and could be attractive in a near future. A WG has been installed for studies of the application of partial discharge measurements for both after laying test and diagnotics. If the conclusions of this work is positive, partial discharge measurements will be included in future test recommendations.

5 - DIAGNOSTIC METHODS

The cable systems are designed for a long service life. Consequently a method for evaluation of the actual status of a cable system is of a great interest for the network operators. An diagnostic analyses can be attractive for various reasons : definition of necessary actions in case of failures, prevention of failures which could lead to outages, assessment of remaining life of a cable system in order to define maintenance actions or if necessary eventual replacement, etc. The diagnostic methods could be destructive (examination in laboratories,...) or even better non destructive (sampling of oil, partial discharge measurement in situ, temperature measurement along the line in order to point out possible hot spots,...). However, it is mandatory that they are based upon a good knowledge of the basic ageing phenomena.

A WG has studied applicable diagnostic methods for cable systems and a recommendation for diagnostic methods for paper insulated cable systems for which the ageing phenomenon are particulary well known due to the wide field records were presented during the CIGRE Session in 1996 and will soon be published in Electra (20). For extruded cable systems, however, knowledge of ageing phenomenona are at present not considered sufficient for definition of diagnostics. Further studies will be initiated in this field in close cocperation with Study Committee 15.

6 - ENVIRONMENTAL ISSUES

A work was conducted on the prevention of termite attack on HV power cables by a WG installed in 1991 for a 3 year period. This question was crucial in some areas (Austrialia, Africa, ...) where termite activity could lead to cable degradation. Due to recent environmental regulations, the chemical products usually incorporated into the oversheaths of the cable are more and more prohibited. Installation techniques which create obstacle to the termite penetration can be also used. Recommendations have been published in Electra 157 (15).

Environmental issues are considered as a challenge today and for the future. The Life Cycle Analysis (LCA) methods are more and more used as tool for evaluating the environmental impact of electrical equipment from "cradle to grave". A Task Force has worked out a report regarding the applicability of LCA methods for cables systems. It was concluded that LCA could be a valuable tool, however, they were complex to use and the results very sensitive to imput data. Further studies are necessary in cooperation with the other apparatus committees. A panel session will be dedicated to this issue in the Paris 1998.

Another environmental issue which has been studied by the Committee is electromagnetic fields generated by cable systems. A Joint Working Group (JWG) 36/21 has worked out digital methods for evaluating field levels in various pratical cable configurations. Two cable families were studied : those without ferromagnetic components (single core cables with lead sheath or Cu/Al screen) and those including ferromagnetic components, e.g. HPOF calbes (pipe type). The JWG has worked out two reports which will be published as CIGRE brochures describing digital methods which also have been verified through measurements. The first brochure was published in 1996 (19). These two documents represent a practical tool for engineers in charge of installation design of HV cable systems.

7 - NEW INNOVATIVE TECHNOLOGIES

The recent scientific and technical developments such as the discovery of high temperature superconductors, polymeric conductors etc.., will definitely influence energy transmission technologies in the future. Since 1993, a Task Force has been installed in order to keep the Committee informed about evolving techniques by regular reports so that the Committee can make plans for future activities in due time.

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STUDY COMMITTEE 22 : «OVERHEAD LINES»

INTRODUCTION

The field of the present activities of Study Committee 22 "Overhead Lines" covers all the subjects related with design, construction and operation of overhead lines including the mechanical and electrical design of line components (conductors, ground wires, insulators, accessories, structures and their foundations), validation tests, the study of in service performance, the maintenance and the assessment of the component state, as well as upgrading of overhead lines.

The Committee gathers about one hundred and fifty international experts from about twenty-four countries. During the last twenty years, SC22 activities were directed to reduce line impact on the environment, to increase line reliability, to optimize line cost and to study refurbishment methods to increase their transmission capability.

A summary of the significant milestones in the work of the ten working groups which were active during that time period are highlighted in the following.

1 - ENVIRONMENTAL CONCERNS AND REGULATORY CONTROLS

The environmental impact of overhead lines has been of concern to SC22 for many years and has been under study since the early 80's. A symposium on "Transmission Lines and the Environment" held in Stockholm in 1981 covered in its second part the "Effect of Lines on the Environment" concerning the impact on landscape (routing, tower design etc.), the use of space (phase, configuration, operation and safety clearance, polyphase lines) and interferences (RI, TVI, AN, induction effects, the electrical field at ground level, ecological effect). A working group set up about that time issued an internal report in 1986 concerning the state of the art in relation to the topics mentioned above with particular emphasis on routing to minimize impact, new structures and configurations for minimal impact and developments in the debate on the alleged health effects of electromagnetic fields.

Severe constraints are imposed to line designers by the environmental compatibility which are, in many cases, largely prevailing on the economic optimization requirement and can become limiting factors for the feasibility of the line itself. Alternative to overhead lines are very expensive and in many cases extra cost for increasing line compatibility became acceptable. Overhead line can be considered today like a species undergoing mutation under the environment pressure. Therefore a symposium was planned in 1991 on the subject of: "Compacting overhead transmission lines". About fifty reports were presented covering :

- new tower geometries and conductor arrangements;
- method for increasing the power capacity of overhead lines;
- quantitative evaluation of environmental merits of compact lines for a cost benefit analysis.

In 1994 following the request of the CIGRE Technical Committee Chairman, a new working group was set up to monitor and report on developments and identify issues concerning regulatory controls and environmental concerns internationally. This working group is analyzing the effects of these developments and issues on transmission line design, planning, routing, construction and operation and on the process and the procedures to obtain permits for transmission lines or to develop and maintain the transmission network.

Integration of overhead lines in the environment was a preferential subject at the Paris 1996 session and designs for environmental constraints and mitigation of visual impact is a preferential subject for 1998 session. The papers submitted in 1996 and the resultant discussions indicated that many countries had carried out overall reviews of their procedures for obtaining overhead line permits in order to assist in achieving permits from the relevant authorities and greater public acceptance of the need for overhead transmission lines. Amongst the measures adopted were the introduction of general protocols, broader consultation with the communities involved, removal or reduction of the impact of lower voltage networks and the use of lower visual impact structures and designs to minimize field effects. Sophisticated techniques has been developed to simulate overhead lines in the environment and to evaluate the impact of overhead lines with a view to minimizing or mitigating these impacts. It was planned to bring these techniques into increasing use in an interactive mode in discussions with communities and authorities.

2 - COMPARISON OF HIGH VOLTAGE OVERHEAD LINES AND UNDERGROUND CABLES

In recent years opposition to overhead lines has become one of the many focal points in the public's demand that the natural environment be preserved. Utilities were on one hand required to provide a quality electricity supply at minimum cost and on the other were faced with increasing delays in obtaining planning permission to construct new overhead lines and requests that existing lines be undergrounded on considerable lengths of their low and medium voltage networks where the cost implications were not so severe as for high voltage networks.

CIGRE conscious of these developments and of their significant cost, technical and operating implications set up a Joint Working Group (JWG21/22-01) to undertake an objective comparison, with particular reference to environmental effects, of overhead lines and underground cables. The JWG, titled "Comparison of Overhead Lines and HV Cables" issued a questionnaire and ultimately analyzed the responses from 64 utilities covering over 860 000 km of existing HV alternating current transmission circuits in its member countries. The "Guidelines for the comparison of High Voltage Overhead Lines and Underground Cables" « 1 » prepared by the JWG found overall less than 2% of transmission circuits were undergrounded and less than 0.3% in the higher voltage range.

3. PRINCIPLE OF OVERHEAD LINE DESIGN

During the 1960 overhead transmission lines design and construction were booming in industrialized countries and tens of thousands of km of lines were commissioned every year at increasingly higher voltages. SC22 was actively involved in improving design criteria « 2 » that were based on deterministic approaches and introduced more rational design based on reliability concepts. This involvement led to the publication by IEC in 1990 of document IEC 826 "Loading and strength of overhead lines".

Compared to designs based on safety factors, the approaches developed by SC22 allow to either reduce the cost of lines or to improve their reliability for the same cost. SC22 was also involved in analyzing line failures and introducing design requirements to prevent them. This work significantly contributed in reducing the occurrence of cascading failures quite common during the last 40 years.

It is quite rewarding to see that the results of the work done by SC22 has now been incorporated in many design standards throughout the world and are now being implemented as an IEC standard on line design.

In compliance with CIGRE's mandate, SC22 has played a key role as the technical counterpart of IEC/TC11 for issues related to line design and completed various tasks at the specific request of IEC/TC11.

4 - ELECTRICAL ASPECTS OF OVERHEAD LINES

A steady and dynamic state mathematical model using empirical data has been developed to enable the temperature of a conductor to be determined in the steady and unsteady (dynamic) state. This enabled the conductor current rating (ampacity) to be evaluated for design purposes as well as in real time. The empirical data was used in order to simplify otherwise very complex algorithms to make the model practical « 3 ».

The thermal rating of a conductor is a function of safety to the public and clearances affecting the thermal rating are clearly stated in statutory regulations. The ampacity of a conductor varies continuously in real time due to different ambient conditions to which the conductor is exposed. A number of probabilistic methods using simulation techniques was developed and documented for use. This enables the planners to decide on the level of risk they wish to put into designs. The previously used deterministic method had an implicit risk that was never quantified and was unknown to the planner. Similarly system operators can use the model to optimize the power flow down corridors by performing a similar risk assessment « 4 ».

The benefit of the method is that the ampacity is generally increased since the deterministic approach is generally conservative.

5 - OVERALL DESIGN OF OVERHEAD LINES

In order to make an optimized design of an overhead line, in 1985 a working group was set up to study the sensitivity on the line cost of the different parameters characterizing the line, using worldwide available information and software tools.

Four reports were published in Electra covering the following subjects:

- Parametric studies of overhead transmission costs « 5 »
- International survey of component costs of overhead transmission lines « 6 »
- Foundations costs « 7 »
- Cost effect of designing for different insulation pollution levels « 8 ».

6 - INSULATORS

During the last twenty years, SC 22 has focused its work on the electrical and mechanical aspects of conventional and composite insulators. To date this has lead to twelve publications which may be found in ELECTRA. They cover the following subjects :

• Study and conclusions form the results of the inquiry on insulators

- Report on conditions of the use (1979),

- Information on damages (1981),

• Technical basis for minimal requirement for composite insulators (1983),

• Worldwide experience with HV composite insulators « 9 »

• Protective devices for insulator sets « 10 »

• Comparative electric field calculations and measurements « 11 »

• Guide for the Identification of Brittle Fracture of Composite FRP Rod « 12 »

• Use of Stress Control Rings on Composite Insulators « 13 »

• Analysis of the Replies to the Questionnaire Concerning the Use of High Mechanical Performance Insulators « 14 »

• Service Performance of Composite Insulators used on HVDC lines « 15 »

• Review of "In Service Diagnostic Testing" of Composite Insulators « 16 »

• Cantilever Load Performance of Composite Line Post Insulators « 17 »

Presently, the main effort of the WG is devoted to the gathering and the analysis of information on the performance that utilities around the world have with composite insulators installed in their systems. Work is also being done to establish the characteristics of line post insulators when they are subjected to dynamic mechanical loads. The brittle fracture of composite insulators is still the subject of ongoing studies. The study of the change in insulator characteristics as a function of time is also considered.

7 - FOUNDATIONS

The SC22 has allowed overhead lines foundation engineers to meet to discuss their problems, to compare the results of their tests and because of the interactive nature of the group, to improve their analyses, theories, formulae and conclusions. Topics have included theory and practice, design and construction, and have advanced to take account of new concerns in the overhead lines industry.

During this period discussion and studies have covered all types of foundations used at any time for overhead lines and have included :

- the design of uplift resistance, for compression and lateral resistance,
- the differing behavior of foundations either when tested at different speeds or when subjected to different types of static and dynamic loads from the structure,
- the effects of seasonal variations on foundation strength,
- the variability of foundation strength and the accuracy with which strength can be assessed,
- consideration of ground investigation techniques and requirements for overhead line foundation design and construction,
- design principles to be used for the connection between the structure and the foundation,
- methods which it is recommended should be used for foundation testing in order that there should be uniformity of method and thus the possibility of comparing and analyzing results « 18 »,
- durability of foundations, methods of repair and of upgrading.

8 - TRANSMISSION LINE STRUCTURES

SC22 activities are focused nowadays in particular on new designs of overhead lines structures and means of assessing existing structures. Many studies have been conducted on probabilistic methods, on modeling and on testing methodology.

New shapes in terms of transmission line tower design were reported from many countries lately. It seems that a compact line with an improvement on the aesthetic appearance of the towers, is an efficient way to promote an easier public acceptance of new transmission lines, to face the restrictions in the rights of way as well as the environmental concerns from a global point of view.

Assessment of existing structures: Due to the ageing of the great number of lines in operation and due to the increasing public opposition to the construction of new overhead lines, the assessment studies of the existing lines have become more and more significant and fundamental for refurbishment, upgrading and/ or uprating purpose.

The development of a methodology for assessing the structures, establishing recommendations for the collection of field data, discussing criteria for the structural analysis and suggesting tests to be performed is under way by SC22.

The probability based analysis was accepted as principle for new transmission line designs. Two reports were published at the end of 80's (1988-1990) covering the application of IEC 826 « Loading and strength of overhead Transmission lines ».

A need for a better and more comprehensive understanding of the variation of tower strength has been recognized to support the evolution from the deterministic approach to the probabilistic based design. The impact of designer assumption has been published in 1991 « 19 ». The main conclusions brought up were :

- predicting the forces in main members under load is generally good, typical COV of 3.6%,
- predicting the forces in lightly loaded members has presented great dispersions and additional testing and modeling would be needed to improve the accuracy of the available techniques,
- as a result of the experiment, it was concluded that the strength dispersion of 7.5% assumed by IEC in document 826 is acceptable and appropriate.

A revision of the present methodology for tower testing (IEC 652 Standard /1979) has been performed by SC22 trying to evaluate the impact of some probabilistic concepts such as statistical distribution of the material properties, exclusion limits, risk of failures, etc. on the test results.

9 - MECHANICAL BEHAVIOR OF CONDUCTORS AND FITTINGS

Vibration, fatigue, measurement, design tension and damping of Single Conductors :

During the first third of the century, with overhead lines in their relative infancy, conductors experienced occasional damage and breakage, which was properly attributed to fatigue resulting from wind driven aeolian, or vortex shedding, vibration. This vibration is generally in the 3-150 Hz frequency range with amplitudes up to one conductor diameter. The mechanisms contributing to this damage, the means of reducing the damage, and techniques for design to minimize this damage, have been studied and reported through SC22 and its working groups in 1988 and 1989.

The resistance of conductors to fatigue damage depends on their materials, construction, and the type of clamps used to suspend the conductors. Methods of testing and representative properties for several, but not all, common types of conductor have been summarized and estimates of conductor fatigue life have been developed and published in 1985 and 1995 « 20 ».

It was recognized that damage severity increased as the design tension of the conductor was raised. Utility surveys on failure events and design practices led to publication of guidelines on safe tension levels. Damage to conductors is generally related to amplitude of vibration, which can be limited by the damping of the conductors themselves and by added dampers. Techniques for measuring the conductor self-damping have been presented in 1979, and methods for determining the damping of stockbridge dampers, which is typically an order of magnitude greater, have been standardized and published in 1981.

Bundle Conductor Vibration

Bundle conductors are subject to aeolian vibration, and also to wake induced oscillation. Efforts have been made towards defining optimized properties and placement of spacers or spacer-dampers to ameliorate the wake-induced motions. A state of the art report on spacer-damper use for bundle conductor vibration control is in progress.

Galloping of Conductors

Galloping frequently causes major disturbances to power systems with costly repairs to conductors, fittings and structures. A guide for reporting details of galloping events was published in 1995 « 21 ».

Interphase spacers are widely employed to restrain motions of galloping conductors. The extent of utilities' use and experience with these devices were surveyed and a summary report was published in 1992 « 22 ».

Fibre Optic Fittings

The recent rapid growth in fibre optic cable use has led to a need for guidelines on support hardware, vibration control and the compilation of data on the mechanical properties of the new cable systems. Utility practices were surveyed and reported « 23 », and guidelines for hardware use and testing procedures are under development.

10. FUTURE ACTIVITIES

Even if the works of SC22 led to significant improvements in the design methods of overhead lines to ensure their reliability and minimize capital costs and to reduce OHL impacts on environment, other works have to be implemented in the future to cover the following subjects :

1. The severe constraints imposed to line designers by the environmental compatibility will continue to favour the development of better solutions to reduce overhead line impact on the environment by :

    - improving tower aesthetic using compact structures with an improved visual appearance better accepted by the public ;

    - reduction of the electro-magnetic fields by using new phase and conductor arrangements ;

    - developing harmonious communication with the public to achieve line acceptance.

2. As today electric utilities are facing increasing opposition against the construction of new overhead lines, they are focused to use at their maximum capacity the existing lines which are 30 to 50 years old and have had only modest inspection and maintenance attention. Therefore SC22 shall aim a number of its activities toward the assessment of existing line condition and performance and the review of available operational methodologies and design technologies for increasing the capacity and availability of existing overhead lines.

3. The unbundling of utilities, the opening of the electricity markets and the increasing competition between electric companies will favour the reduction of construction costs but also an increasing reliability and availability by using optimized components : lighter towers, more performing conductors with high ampacity, faster construction methods, a better knowledge of the effects of the environment on the overhead lines (climatic loads, lightning, pollution, etc.).

In conclusion, we should say that even if many improvements have been made in the past, many new challenges will keep our experts busy in the future.

Therefore SC22 has recently aimed a number of its activities toward the assessment of existing line condition and performance and the review of available operational methodologies and design technologies for increasing the capacity and availability of existing overhead lines.

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STUDY COMMITTEE 23 : « SUBSTATIONS »

INTRODUCTION

The field of activity allocated to Study Committee 23 is:

- Overall design and electrical and mechanical dimensioning of substation and electrical plants of power stations taking into account all kinds of constraints with special attention to maintenance, operation and impact on environment (electrical dimensioning is based on the work of SC 33 and 36).

- Application of new equipment suggested by the Equipment Study Committees.

- Application of measures to achieve optimum availability, reliability, service quality and to minimise life cycle cost of substations and electrical plant of power stations.

1 - GENERAL STUDIES OF DESIGN OF AIR INSULATED SUBSTATIONS (AIS)

In the seventies, Study Committee 23 mainly addressed the construction of substations, studying principles of integrated mechanical design for AIS Structures and Equipment, use of computers for substation design, reliability in design and design of UHV stations taking into account the environmental impact.

In the eighties, when main interconnection systems were established in many countries, the most important task became to adapt the existing lower transmission levels to the more severe conditions at higher voltages and the interest was focused more on uprating aspects related to existing substations.

SC 23 pursued calculation of reliability and availability of substations related to type of faults and synthesised its work on substations design by publishing a general guideline (1) for design, which gives a view of substations realisation practices world-wide.

The SC also worked on earthquake aspects by means of identifying practical means to enhance the seismic performance in existing substations.

In the nineties, when the renovation of existing substations was becoming more frequent compared to construction of new installations, the work of the committee in the field of AIS was turned towards studies of lifetime of equipment, refurbishment of substations and adaptation to the environment.

A number of papers *(2, 3)* on these subjects have been published or presented during conferences.

2 - GAS INSULATED SUBSTATIONS (GIS)

Twenty years ago, when the GIS-technology was in its infancy, the interest of SC 23 was related to design aspects and deviations compared to AIS and their implications for design and testing (Electra reports in 1974 and 1975). One of the topics of study at that time was internal arcs and their effects, another the introduction of locations with reduced dielectric withstand in the design in order to avoid flashovers in disconnecting devices.

As manufacturers and utilities had acquired more experience, the SC started to discuss simplifications of design, diagnostic techniques, accessibility for maintenance, and possibilities to replace components in repair cases.

Later, when the technology of GIS had become widespread, the SC conducted a world wide inquiry in order to get feedback from GIS in service (4). The information collected covers more than 50% of GIS in the world and has been stored in a data base which is regularly updated. An important conclusion is that GIS commissioned after 1985, exhibit a very high reliability level.

This work enabled the SC to issue guides for users and designers, one guide covering the exploitation of GIS, spare parts handling procedures, renovation aspects, principles for extension and another one describing optimisation of solutions for GIS.

The SC addressed the impact of SF6, by publishing in Electra 1991 a paper on handling of the secondary products of SF6. This document was complemented 1995 by a study focusing on the environmental aspects such as the impact of pure SF6 on the ozone layer and its contribution to the greenhouse effect (5). The study demonstrated that SF 6 does not contribute to the destruction of ozone layer and that its influence on the greenhouse effect is negligible. However, improved recycling procedures were deemed advisable.

Therefore work was started 1995 in order to prepare an SF6 recycling guide. A short version of the corresponding document will be published 1997 in Electra and a complete version will be issued the same year as a brochure. This work will be followed by further actions related to the inventory of SF6 usage.

Another field related to the environment is the application of Gas Insulated Lines for energy transmission. In this case SC 23 is starting a cooperation with the Study Committees 21 and 33.

3 - HIGH CURRENT EFFECTS AND HIGH VOLTAGE TECHNIQUE IN SUBSTATIONS

Short circuit currents in substations has always been a field of activity of SC 23, which has regularly published brochures on that matter (1973, 1987,1996). These brochures are as a matter of fact IEC application guides and used world-wide as guidelines for short circuits testing (6).

Studies about high voltage techniques have been conducted in cooperation with the Study Committee 33 for insulation matters and with Study Committee 36 for topics related to electrical fields.

In the seventies, work in order to establish guidelines for safety and insulation distances, comparison in the insulation field between AIS and GIS, and studies of earthing systems were conducted.

The work related to substation insulation characteristics was terminated at the end of the seventies and started again ten years later, this time by studying methods for on site GIS dielectric tests in cooperation with Study Committee 33 (7). This action is not yet finished, since it was concluded that more knowledge is needed concerning techniques for assessment of dielectric conditions of GIS.

As regards electrical fields, SC 23 elaborated in 1978, with SC 36 a guide on electrical fields - a document containing all data necessary to measure and calculate field strength, induced currents and potentials, and transients discharge states in substations.

4 - SUBSTATION SECONDARY SYSTEMS

The first field of activity of the SC related to secondary equipment was influence of the operation of high voltage equipment on auxiliary circuits. Hence it was advised 1973 to earth the screen at both ends, to separate the control circuit cabling from the high current circuits and to make allowance for the high frequency nature of the interference, i.e. to consider not only the resistance of the earthing system but also its inductance.

Another subject investigated was physical design and installation of protection, control and automation equipment. The SC has also provided input to the "Systems" Study Committees dealing with secondary systems in general and power systems aspects.

Over the years numerous contributions have been published on such issues as the effects of transient phenomena on secondary systems, fire protection systems, the selection and implementation of micro-processor based equipment in substations, possible architectures of future control systems, the influence of substation busbar and bay arrangements upon the design and reliability of the control system, the application of expert systems and the renovation of substation secondary systems.

During the past few years, most of these subjects have been addressed in contributions delivered at CIGRE sessions, symposia and open conferences held in combination with SC 23- meetings overseas. These contributions are often the outcome of a close cooperation with other working groups and with experts from various countries (8) ,(9) ,(10) ,(11) ,(12)

Major recent publications include:

« Design aims in high voltage substations to reduce electromagnetic interference in secondary systems ». This publication addresses the impact of high voltage equipment operation on auxiliary circuits and gives recommendations for the screening of cables and the test methods for the verification of the effects.

« Design and maintenance practice for substation secondary systems ». This comprehensive brochure deals with the main features of substation secondary systems and includes both relay-based and computer-based equipment. Its objective is to review current design and maintenance practice. The report content is primarily directed at practising utility engineers engaged in the planning, design, operation and maintenance of secondary systems.

Current activities include the life-time assessment and renovation of substation secondary installations, both the acceptance tests of and experiences with micro-processor based control and supervision systems and the control system functionality and cost implications.

5 - MAINTENANCE

Exploitation of substations and maintenance procedures have always been covered by SC 23. In the seventies, the main topics of the discussion were related to interval between major overhauls and to the availability of methods for checking equipment in service.

With the development of digital techniques, the SC investigated maintenance of substation secondary equipment by publishing in 1994 a CIGRE the brochure: « Design and maintenance practices for substations » (13).

In 1993, the SC organised in cooperation with the SCs 12 "Transformers" and 13 "Switching equipment ", a symposium in Berlin on diagnostic and maintenance techniques.

The SC is supporting the transition from periodical maintenance to condition or reliability based maintenance(14).

6 - ELECTRICAL EQUIPMENT OF POWER STATIONS

Since 1975 Study Committee 23 is studying electrical systems of power plants, especially aspects related to overall design, construction and operation of switchgear and other components of the main and auxiliary circuits within large generating stations.

Important studies have been conducted on availability aspects of AC and DC auxiliary power supply in large power stations and on grounding methods for generators and step up transformer neutrals. Other studies addressed the fire behaviour of cables and the methods to reduce fire propagation along cables in power stations, the practices regarding black start of power stations, refurbishment and life assessment of the auxiliary system of older power stations and isolated-phase metal-enclosed generator busbars.

Recent publications include:

"Choice of large motor drives and variable speed drives" (15).

"Review of service voltage levels, bus arrangements and the transfer schemes in power stations" ***(16)."***

7 - MEASURING TRANSFORMERS

From 1985 to 1989 studies were undertaken on safety and reliability of conventional measuring transformers . Such issues as design considerations, construction, tests, reliability and lifetime were addressed. The work was terminated in 1989 with the publication of a comprehensive brochure covering all relevant aspects ***(17).***

8 - FUTURE SUBSTATIONS

In 1993, Study Committee 23 started to consider the possible evolution of the design of substations over the next 10 to 20 years. To this end a study was undertaken which addressed all relevant aspects including the economical and environmental constraints, the public opinion, the institutional developments and new technologies.

A discussion report (18) was presented during the 1996 CIGRE session, one of the aims being to act as a vehicle for discussion during the session. This report identified four aspects of major influence on future substation concepts: functionality, technology, economy and environment. This conceptual study is now being followed up with more detailed recommendations to those having to decide about future substations.

Presently SC 23 is making a major revision of its strategic plan in order to be able to satisfy new needs in the changing operational environment resulting from the deregulation of the electric power industry. It has been concluded that the main drivers for future substation solutions are environmental requirements, economical constraints, and the technological possibilities. From there drivers the following main technical directions for the work of SC 23 have been derived:

T1. Principles for design/layout of substations in order to minimise costs and environmental impact, by means of utilising new technologies and experience

T2. New concepts, applications and functions including more compact and multi-functional substations constituting integral parts of totally optimised networks, use of sophisticated electronic equipment, taking into account specific demands from network-reliability and customer-demaznd-side availibility points of view.

T3. Environmental issues: identification of development and trends regarding physical, institutional and business environment, assessment of effects on substation requirements. Guidelines for minimising environmental impact during equipment life, LCA-concepts, recycling. Developing risk assessment techniques and environmental management plans.

T4. Maintenance: monitoring in-service experience including digital and sophisticated measuring equipment and GIS, condition assessment, actual short-and long-term needs, opportunities for cost reduction, spare parts.

T5. Renovation/upgrading: life cycle management, renovation concepts, experience with relevant projects, investment strategies, taking into account specific demands from network-reliability and customer-demaznd-side availibility points of view.

T6. Substation management issues: organisational aspects including human resource and training needs, in-service support, software management including quality control and maintenance, asset management including financial and technical aspects..

T7. Strategies: Analysis of trends and development of strategies for the customers covering environmental and business aspects, strategic long term research

T8. Increased functionality of electrical equipment in power stations.

T9. Guides for users covering specification, installation, commissioning, operation and maintenance of substations with their subsystems.

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STUDY COMMITTEE 33 : « POWER SYSTEM INSULATION CO-ORDINATION"

INTRODUCTION

The electrical insulation must be designed, constructed and exploited in a way as to "withstand" the electrical and environmental stresses which can appear in the system without the occurrence of failures (or without the acceptable number of failures be exceeded) where, as failure, it is intended the loss, temporary or permanent, partial or total, of the insulating properties.

More reliable insulation means better dependability and better possibility of exploitation of electrical networks and this entails, in turn, better economy, better quality of the electricity supply service and higher satisfaction of users and consumers.

This strategic goal is achieved by applying the principles and methods of "Insulation Coordination".

Insulation Coordination is, in fact, the discipline which enables to select the dielectric withstand characteristics of the electrical equipment (components, apparatuses and installations), vis-a-vis the dielectric stresses and other relevant constraints, in order to meet specified performance requirements.

As such, Insulation Coordination is, by all means, a highly "horizontal" discipline, concerning all electrical equipment and involving many diversified cultures and expertise.

It plays, in addition, also an important "vertical" role, since a few electrical components are mostly studied within this discipline, because their main function is "insulation" (as line and station insulation made of both pure air gaps and gaps with solid insulation) or because they are just employed to control the dielectric stresses (as surge arresters) or, eventually, because they are used to assess the dielectric behaviour of electrical products (like HV test and measurement equipment).

Within CIGRE (International Conference on Large High Voltage Systems), Study Committee 33 "Power System Insulation Coordination"[1] is the Technical Body in charge with Insulation Coordination and related activities.

According to what mentioned above, SC 33 has, in the CIGRE Matrix, a major horizontal role, acting in support of a number of so called Apparatus Committees and also cooperating with other System and Sub-system type Committees.

It exerts, moreover, an important vertical function being a kind of Apparatus Committee for particular components, such as Surge Arresters, HV Test and Measurement equipment and Insulators.

Due to its wide spectrum of activities, SC 33 also represents the Technical Arm of a number of IEC Technical Committees as, among others: TC 28 "Insulation Coordination"; TC 36

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[1] Formerly SC 8 "Overvoltages and Lightning" until 1968; from 1969 to 1995, SC 33 "Overvoltages and Insulation Coordination"; presently, SC 33 "Power System Insulation Coordination".

"Insulators"; TC 42 "HV Testing and Measuring Techniques"; TC 37 "Surge Arresters"; TC 78 "Live Working"; TC 81 "Lightning Protection".

SC 33 represents, therefore, a fairly comprehensive expression of the international knowledge and expertise of the various scientific and technological aspects of concern for electrical insulation.

The present paper provides an overview of the activity of SC 33, enlightening the major milestones achieved insofar and outlining the future trends and developments.

1 - THE ACTIVITY OF SC 33 : STATE OF THE ART AND MILESTONES

Three main Subjects, which may be subdivided in five basic Technical Areas, are involved in the Insulation Coordination discipline, namely:

- The study of the "Stresses", both electrical and environmental, acting on the insulation of the equipment;

- The study of the "Strength" (dielectric withstand characteristics of the insulation), of both new and aged insulation, taking into account, when applicable, the effects of the environmental stresses, including the study of the "Test and Measurement Techniques" which are employed to assess such strength;

- The assessment of the "Insulation Performance" (usually expressed in terms of risk of failure), in the considered situation of stresses and strength, taking into account the effect of the available "Protective Devices" and techniques.

On the base of these elements, it is possible to determine the required insulation levels and to dimension, accordingly, the insulating systems of equipment and installations.

Note that, in case of pure air insulation which represents an important part of the insulation of overhead lines and open air substations, the insulation design coincides with definition of the shape of the electrodes and the determination of the air clearances between the energized conductors and earthed structures or between conductors at different potential. This kind of knowledge is mostly produced within SC 33. In other cases (combined air plus solid external insulation or internal insulation), the insulation design also involves the selection of proper insulating materials and the definition of their assembly in the insulating system. Here the work of SC 33 is carried out in cooperation with other CIGRE Study Committees.

The progress of the activity of SC 33 is reviewed in the following with reference to the main Technical Areas of work above mentioned. Major publications issued by SC 33, in the last two decades, in form of ELECTRA Reports, CIGRE Session Papers, CIGRE Symposia Papers, CIGRE Technical Brochures, etc.., providing evidence of such progress, are also indicated as References.

1.1 STRESSES

The stresses of concern for the insulation performance are dielectric stresses (system voltage and overvoltages of various kind and origin) and environmental stresses (contamination, humidity, rain, fog, ice, snow, pressure, temperature, etc..).

Dielectric stresses

These include the Continuous System Voltage and all kind of Overvoltages (Temporary Overvoltages, Switching Overvoltages, Lightning Overvoltages and Fast Transients).

The knowledge of the electrical stresses, developed within SC 33, is quite complete and advanced regarding overvoltages of both internal and external origin.

Major achievements concern, among others:

- The assessment of lightning parameters for engineering applications (distribution of lightning currents, ground flash density, etc..) [1];
- The development and application of reliable and effective lightning detection systems [2] [3];
- The substantial progress in modelling of the physical mechanisms of lightning and related applications to practical problems of lightning protection, including the more rigorous assessment of the so called "Striking Distance" [4];
- The modelling of lightning overvoltage propagation in transmission lines [5];
- The comprehensive evaluation of switching overvoltages, by field measurements and calculations, with special reference to phase-to-phase overvoltages in EHV and UHV systems [6] [7];
- The assessment of temporary overvoltages in different system configurations [8];
- The evaluation of fast transients in Gas Insulated Substations [9].

Environmental stresses

For outdoor external insulation, the environmental stress of major concern is represented by the contamination (and wetting) of the insulation surface (insulator pollution).

Other stresses are related to weather conditions at large, such as high humidity, rain, formation of ice and deposit of snow, solar radiation, temperature excursions, etc.. As for internal insulation, thermal stresses (temperature and thermal cycles) may be of large importance. The main results achieved by the work of SC 33 on environmental stresses concern, among others:

- The development of techniques and equipment for the measurement of the on-site pollution severity, including the establishment of qualitative and quantitative scales for the classification of natural pollution levels [10] [11].

1.2 DIELECTRIC STRENGTH

The study of the electrical strength of external insulation has represented a major task of SC 33 and many outstanding results have been achieved in this field. To be mentioned, among others:

- The physical understanding and description of the discharge mechanisms in air and the development of mathematical models for the predetermination of the breakdown voltages [12];

- The assessment of the physical influence of air density and humidity and the definition of more rigorous correction factors [13];

- The quantitative description of the statistical nature of discharge phenomena [14];

- The assessment of the dielectric strength of complex configurations, as those encountered in Live Working, of paramount importance for the definition of safe working distances [15];

- The modelling of the discharge on contaminated insulating surfaces and the related development of optimized artificial pollution test methods, including the establishment of the correlation between natural and artificial pollution severity [16] [17].

The work of SC 33 has also concerned the study of the ageing phenomena which may occur inside the internal insulation (gaseous, liquid/mixed, solid) and on the surface of solid insulation in contact with open air or other gases (e.g. line and post insulators, spacers for compressed gas insulation, etc..), with special reference to:

- The physical understanding of the mechanisms leading to the alteration of the insulating properties, including the determination of the physical parameters representative of such degradation (diagnostic indicators) and the establishment of the correlation between the values of the indicators and the possible reduction of the dielectric strength under service voltage and overvoltages [18] [19].

1.3 TEST AND MEASUREMENT TECHNIQUES

These are the Techniques (and Equipment) which are employed for the assessment of the dielectric behaviour of the insulating systems, at the putting into service (laboratory/factory tests, on-site tests) and during the service life (in-service diagnostics).

Also this field has represented a major commitment for SC 33 and a great deal of work has been carried out in the last few decades. Among the main achievements, the following are to be mentioned:

- The theoretical and experimental assessment of the functioning of large High Voltage (HV) measuring systems which paved the way to a substantial improvement of the related IEC Standards [20];

- The improved definition of response parameters for characterizing impulse measuring systems, also related to the progress of standardization [21];

- The study of the electromagnetic interference phenomena in HV and High Power (HP) measurements and the assessment of the relevant immunity checks and protective measures [22];

- The study and application of digital techniques to HV and HP measurements [23];
- The assessment of traceability in HV measurements [24];

1.4 ASSESSMENT OF THE INSULATION PERFORMANCE

If the stresses (overvoltages and environmental stresses) have been determined and data and methods are available to estimate the related strength, it is possible to dimension the insulation in such a way to minimize the risk of insulation failure in service.

Here the most significant work of SC 33 has concerned, among others:

- The development of the Statistical Approach (risk of failure) and its extensive application to the assessment of the insulation performance under switching overvoltages [25];
- The application of the Statistical Approach to the assessment of the performance of polluted insulators [26];
- The statistical analysis of the lightning performance of transmission lines and substations [27];
- The study of the accuracy of risk of failure calculation and sensitivity to various influencing parameters [28].

1.5 PROTECTIVE DEVICES

The transient dielectric stresses (overvoltages) may be limited by protective devices (surge arresters and protective spark gaps) the proper dimensioning and location of which represents an essential part of the insulation coordination practices.

The work of SC 33, in the last two decades, has accompanied the development of the technology of surge arresters and their growing successful application in electrical power systems, with special reference to "modern" design based on the use of Metal Oxide Blocks (MOA).

The main contributions provided by SC 33 in this area concern, among others:

- The study of the energy stresses under various kinds of overvoltages and in different system conditions [29];
- The assessment of the pollution performance of gapless arresters, providing substantial input to the progress of standardization in the field [30];
- The application of MOAs to HVDC Converter Stations, as a means to improve the feasibility and reliability of HVDC Links [31];
- The application of MOAs to the limitation of the overvoltages in overhead transmission lines, particularly in view of line compaction [32].

Conclusive Remarks

SC 33 has therefore accomplished several important tasks on the way to the development of more effective and reliable HV insulation, providing, together with the other CIGRE Committees, a significant contribution to the remarkable improvement of the performances of electrical power systems achieved in the last decades.

There are, however, many issues where the knowledge is not yet fully developed.

Moreover, the most recent trends of the electroenergetic scenario, reflecting, in turn, major changes in the economy and society, are such to introduce new problems and demands, besides confirming the importance of those subjects where the work is still in progress.

SC 33 still has, therefore, a lively and challenging future of work ahead, as briefly outlined in the following.

2 - FUTURE DEVELOPMENTS OF SC 33 VIS-A-VIS THE EVOLUTIONARY TRENDS OF THE ELECTROENERGETIC SCENARIO

Besides by internal policies and programmes, the activities of an Organization like CIGRE - and of its Technical Bodies as SC 33 - are driven by a number of external social and economical factors which affect the development of the electrical industry worldwide (the so called "electro-energetic scenario"). In reviewing such factors, it is worth distinguishing between industrialized economies and developing ones. Their trends are, in fact, different in many respects and such differences must be taken into account for the proper assessment of the needs for scientific progress and technological development in the fields covered by CIGRE, in general, and SC 33, in particular.

2.1 THE TRENDS IN THE INDUSTRIALIZED ECONOMIES

Here the evolution is dominated by two factors: Environmental Compatibility and Economical Competitiveness (the two E, Environment and Economy).

These entail a number of tendencies for the electrical industry; those of major concern for the work of SC 33 include:

- The push towards the liberalization/deregulation of the electricity market;
- The difficulty in the construction of new generating plants and HV transmission systems, with consequent needs for the maximum exploitation of the existing installations, improvement of the availability/dependability of electrical systems (by predictive diagnostics and live working techniques), uprating of the existing lines and development of new compact lines;
- The development of underground transmission (liquid, solid and gaseous insulation);
- The increasing system interconnection and development of related technologies (HVDC, FACTS, submarine cables, etc..);
- The reduction of chemical and visual pollution;
- The control of the Electric and Magnetic Fields (EMF);
- The increasing international harmonization of standards and procedures for the qualification of electrical equipment;

- The development of quality policies and practices (quality management and assurance) - for both the improvement of the organization (internal target) and the enhancement of the competitiveness on the marketplace (external target) - and related changes of the procurement policies (acquisition of certified products and services).

2.2 TRENDS IN DEVELOPING COUNTRIES

Tendencies in these countries may somewhat deviate from those listed above. Although with a number of distinctions, economical and social trends are essentially characterized by the push towards the quantitative growth which prevails upon other factors. Main trends include:

- Development of generation, transmission and distribution systems; importation of technologies and imitation of the models of industrialized economies;
- More attention to cost than to quality; demand for low cost components;
- Development of education and personnel training activities; creation of local research structures (Engineering Schools, Research Centres, Laboratories);
- Funding of R&D programs (with international financing);
- Increasing involvement in international research and standardization activities

2.3 CONSEQUENCES FOR THE FUTURE WORK OF SC 33

Many of the above trends have an impact on the development of Insulation Coordination principles and practices. The main consequences are outlined below, in terms of new working subjects for the Study Committee (or better focusing of present work), making reference to the Technical Areas (fields of activity of SC 33) presented in Chapter 2. Note that many of these "future" working topics are already in the Agenda of the Study Committee. A few of them will be implemented in cooperation with other SCs (such as SC 15, SC 21, SC 22, SC 23, SC 36) and CIRED.

Technical Area "Stresses"; more attention to distribution systems (< 150 kV), with reference, among others, to the assessment of lightning induced overvoltages; development and application of effective and reliable lightning detection systems; improvement of the physical models of lightning and application to practical problems of lightning protection; study of temporary overvoltages in highly interconnected systems; improvement of pollution monitoring techniques.

Technical Area "Strength"; study of safety clearances/procedures for Live Working; assessment of the correlation between dielectric safe working distances and EMF exposure limits; study of peculiar problems of dielectric strength in Gas Insulated Lines; study of the ageing mechanisms of non-ceramic insulators, with special reference to pollution performance, and assessment of accelerated ageing test procedures; development of suitable diagnostic indicators for non-ceramic insulators and establishment of the correlation between damages and reduction of the strength; development of low cost insulators, with special regard to their pollution performance; study of the pollution performance of surge arresters.

Technical Area "Test and Measurement Techniques"; setting up of effective insulation diagnostic/monitoring techniques and equipment; development and implementation of principles and practices for quality assurance in tests of HV equipment.

Technical Area "Insulation Performance"; study of new procedures and techniques for "Active" insulation coordination; study of specific problems of concern for insulation coordination in FACTS, HVDC links (particularly for voltages > 600 kV) and Gas Insulated Lines.

Technical Area "Protective Devices"; study of the application of surge arresters to overhead transmission lines.

In general, concerning all the above Technical Areas, SC 33 will strengthen the cooperation with other CIGRE SCs and will enhance the collaboration with IEC, both contributing to address the evolution of the Standards and being more effective in answering the requests from the latter.

To better respond to the demand for education and training from the developing countries, SC 33 will improve the diffusion of its knowledge and invigorate its educational function, among others by organizing Meetings of its Working Groups in such countries and delivering Tutorials on subjects of interest for the local engineering communities.

At large, SC 33 will foster the practical application of its know-how to the greatest extent, trying to be less academic and more application oriented and keeping in good touch with the industrial world, being aware of its needs.

REFERENCES

The following list does not represent an exhaustive review of the technical publications of SC 33, being only intended to provide some documentary cross-reference of the main achievements of the Committee in the last two decades. Complete documentation is available from other sources. The enumeration sequence follows the order of presentation of the Technical Areas (and main corresponding working subjects) given in Chapter 2, without chronological sequentiality.

Stresses

[1]	Lightning Parameters for Engineering Applications	ELECTRA N. 69, 1980
[2]	Improved Lightning Flash Counters	ELECTRA N. 66, 1979
[3]		CIGRE Technical Brochure N. 94, 1995
[4]	Evaluation of the Lightning Performance of Electrical Systems	CIGRE Paper 33-13, 1980
[5]		CIGRE Technical Brochure N. 55, 1990
[6]	Phase-to-phase Insulation Coordination	ELECTRA N. 64, 1979
[7]		CIGRE Technical Brochure N. 39, 1990
[8]	Temporary Overvoltages: causes, effects and evaluation	CIGRE Paper 33-210, 1990
[9]		CIGRE Technical Brochure N. 35, 1989
[10]	Measurement of Site Pollution Severity and Application to Insulator Dimensioning for AC Systems	ELECTRA N. 64, 1979
[11]	Insulator Pollution Monitoring	ELECTRA N. 152, 1994

Dielectric Strength

[12]		CIGRE Technical Brochure N. 72, 1992
[13]	Influence of Atmospheric Conditions on the Dielectric Strength of External Insulation	ELECTRA N. 112, 1987
[14]	Statistical Evaluation of Dielectric Test Methods	ELECTRA N. 133, 1990
[15]	Dielectric Strength of External Insulation under Live Working	CIGRE Paper N. 33-306, 1994

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Assessment of the Insulation Performance

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Protective Devices

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[30] Metal Oxide Surge Arresters in AC Systems ELECTRA N. 129, 1990

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STUDY COMMITTEE 34 : «POWER SYSTEM PROTECTION AND LOCAL CONTROL »

INTRODUCTION

The basic task of protection is to detect faults and abnormal conditions on power systems and to initiate corrective actions, in particular selective fault clearance and service restoration.

Local control of substations comprises the acquisition of system state data as well as the execution and automation of switchgear control functions in co-ordination with higher level power system control.

Since the advent of electrical apparatus, protection engineers have tried to develop better methods and devices to reduce the impact of faults and to secure continuity of supply.

The growing size and complexity of power systems resulted in continuously increasing demands on intelligence and operating speed of system protection. On the other hand, the relaying technology has proceeded from plain electromechanical and solid-state relays to multi-functional micro-processor based systems using digital communication.

Local control has recently experienced dramatic changes from traditional mechanical switchgear control to micro-processor based substation automation.

Integrated protection and substation control systems now combine all secondary functions of a substation, including RTU functions, in one distributed micro-processor system with LAN-based communication.

Inherent self-monitoring capabilities allow to change from costly regular testing to more economical condition based on-demand maintenance.

Relay engineering tools have at the same time developed from limited manual calculation methods and analogue test benches to powerful computer programs and computer-based power system simulators with nearly unlimited capability. This allows the complex protection and control systems to be verified in comprehensive design tests close to pratical conditions.

Generally spoken, micro-processor technology, wide-band digital communication, GPS-time synchronisation and expert systems will be the most important driving forces of protection and control innovation in the future.

The fast change of technology combined with the progressive function integration and system complexity has also created new challenges for the engineering and operating personnel with the need for further education and training.

Finally, a technical to economical cultural change has taken place in the power supply industry in the recent years caused by deregulation and an increasingly competitive environment. In the future, more emphasis must therefore be placed on cost-efficiency in the search for technical solutions.

SC34 has contributed to this development with working groups and their reports on the state-of-the-art. Some valuable groundwork has been provided as imput for the work on international standards. SC34 has also provided a world-wide platform for discussion and information exchange in plenary sessions, symposia and colloquia.

1 - TRANSMISSION SYSTEM PROTECTION

The introduction of EHV and the energy transmission over long distances, as well as the growing grid complexity and the increase of short-circuit power led to new demands on system protection in the sixties and seventies. Faster and more selective fault clearance were required to secure system stability and to reduce the risk of fault damage to primary equipment.

These requirements could be met with the transition from electro-mechanical to solid-state technology which enabled better shaped operating characteristics and shorter operating times even below one cycle fore close-in faults.

The need for high speed fault clearance on 100% line length led to an extended use of teleprotection systems with an overall tripping time of about two cycles. [1].

Together with state-of-the-art two cycle breakers, typical fault clearing times of 4 cycles became the standard.

The high speed relay operation, however, increased the impact of current and voltage transients on relay stability and measuring accuracy. Many studies were therefore performed to characterise the nature of transients and to verify the transient behaviour of instrument transformers and relays. [4].

A particular protection problem occurred with the application of series compensation of transmission lines. Traditional relay schemes had to be upgraded to cover the new phenomena of voltage or current inversion and subsynchronous resonance. [3, 6].

Protection reliability and safe fault clearance in case of protection or circuit-breaker failure was also a major subject of working group studies and session discussions. [4].

Remote back-up protection increasingly faced fault detection problems and unacceptable long operating times. Duplicated protection with dissimilar measuring principles and local breaker failure protection, therefore, became the widely practised standard with transmission systems.

Angle, frequency or voltage instabilities of large interconnected systems ask for a system wide protection approach. [5].

Currently conducted studies have the task to optimise protection operation during large area disturbances and to find protection criteria against system voltage collapse.

2 - TELEPROTECTION

Signalling links via pilot wires, power line carrier and microwave have been used since more than 50 years to upgrade line protection.

Various directional comparison distance relaying schemes and phase-comparison relays have been applied. Pilot wire differential relays could only cover short distances. [7, 8].

Since about 1985 digital telecommunication has been used for protection in particular with micro-wave and optical fibre. This allows to transmit more information in shorter time and to use differential protection also on long lines up to some hundred kilometres. [9].

Dedicated optical fibres will be available for protection only in the exceptional case.

Normally, protection will have to use the digital telecommunication network now being installed in most utilities.

In any case, the combined use of digital communication and numerical relaying will lead to a considerably upgraded protection quality.

SC34 has always been closely co-operating with SC35 to explore the use of communcation for protection purposes. An application guide on teleprotection was produced in 1969 and revised in 1987. [1, 8]. Presently a joint SC34/35 working group is again preparing an updated version to be published in 1999.

3 - GENERATING PLANT PROTECTION

In this field, new requirements resulted mainly from the fast growing size of generating units, in particular with the advent of nuclear power plants in the early seventies. [12, 13].

On the other hand, more sophisticated protection principles became possible with the introduction of solid state technology for relaying in the sixties and further with the numerical technology since about 1990.

A report on recent trends and developments in generation plant monitoring, control and data acquisition is under way and will be published in early 1998.

4 - TESTING, MAINTENANCE, TRAINING OF PERSONNEL

It has always been the aim of SC34 to provide the protection engineer with practical guidelines for his daily work. This concerns in particular test procedures and maintenance strategies to upgrade system reliability. In this connection, the introduction of numerical relaying has allowed to change the strategy from time based testing and preventive maintenance to self-monitoring and condition based maintenance.

A number of reports are the result of working group activities on this topic. [12, 13, 14].

5 - NUMERICAL PROTECTION AND SUBSTATION AUTOMATION

First feasibility studies on computer relaying were published around 1970.

During the seventies it was reported on a number of pilot projects based on central mainframe and mini-computers also in a number of CIGRE session reports.

The real breakthrough of numerical relaying, however, occurred only in the mid-eighties with the advent of powerful microprocessors. From 1990 on, numerical relays have then been applied on transmission systems on a larger scale.

Right from the beginning, there was also a trend to unite all secondary functions of a substation in one overall micro-processor based substation automation system.

Such co-ordinated or integrated protection and substation control systems appeared on the market around 1985 and are now state-of-the-art.

SC 34 picked up these themes in the early stage of development as preferential subjects. [15, 16]. Major discussion points have been system configuration, functionality, and communication structure of such distributed substation automation systems including the various aspects of reliability, maintainability and management. [17, 18, 19, 20].

Part of the working results is now used as basis for standardisation.

6 - FUTURE DEVELOPMENT

Newer developments in substation automation aim at the replacement of conventional current and voltage transformers by optical sensors and the integration of intelligent devices for switchgear diagnosis. Serial process bus communication shall then replace the extensive parallel wiring between switchgear and secondary equipement. Expert systems shall assist substation operation and fault analysis.

SC34 accompanies this development with working group activities and expert discussions.

The aim is to carry out further ground work for future standards and to provide guidance for the practical application.

The change from preventive to condition based maintenance has raised questions about system reliability and necessary test procedures for relay parts not covered by selfmonitoring functions. A working group is currently analysing this new situation and will develop guidelines for numerical protection scheme testing.

System protection will benefit in many ways from the growing availability of digital communication facilities. This includes remote relay setting and retrieval of data as well as the use of phase selective unit protection and adaptive relaying methods.

The impact of these new possibilities on the future practice of protection and substation control is continuously followed.

Asset management, refurbishment strategies and the impact of the power utility deregulation on protection and substation control are further subjects that are currently studied and discussed in SC34.

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STUDY COMMITTEE 35 : « POWER SYSTEM TELECOMMUNICATION AND TELECONTROL »

INTRODUCTION

Communications for use in the operation of a power supply network have traditionally demanded a reliability exceeding that available from public providers - particularly in times of environmental stress. Consequently, the industry has generally provided both normal and specialised communications facilities itself. Cigré, through Study Committee 35 and its pre-1968 predecessor, has provided the platform for the study and reporting on the issues and development of this specialised service area of the electricity supply industry.

FIELDS OF ACTIVITY

SC35 has a strategic plan which encourages it to study ...

- **Telecommunications transmission media including** >>>>>

Emphasis has changed through the last two decades from ..

Power line carrier ↘

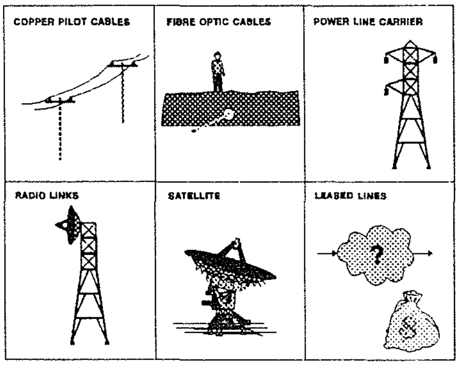
Radio Links ↘

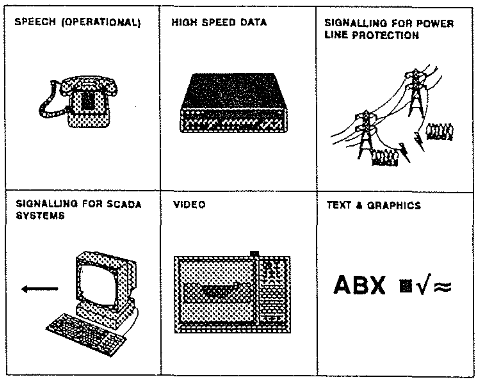
Fibre optic cable

↙

↙ Leased lines

Power line carrier





<<<<<< • **Techniques for the efficient transmission and switching of special services.**

Again since the 1970's, whilst there has been a continuing high priority in the study of telecommunications for protection and control, the emphasis on operational speech has given way to the study of high speed data transmission.

- **Design, construction, operation and maintenance of telecommunications networks.**

This area represents a continuing interest, with studies now examining the potential for outsourcing.

- **Development of telecontrol systems**

A constant effort has been made to understand the variety of proprietary systems and protocols and to influence the convergence of these systems towards more standard approaches. The control of the supporting telecommunications systems is now rivalling the traditional power system control in complexity and 'non-standardisation'.

- **Telecommunications deregulation issues**

Information is now being provided on the business and technical cases for power utilities to enter the telecommunications market.

Major Contributions

SC35 has contributed to the advancement of the discipline of Power System Telecommunications by studying and reporting major issues including...

- **Specialised telecommunications transmission media...**

  ◊ Definition of the modes of propagation of power line carriers signals

  ◊ Recommendations on the best network solutions for the replacement of analogue radio links with digital equipment.

  ◊ The evolution of fibre optic cable being supported in, and on the conductors, and towers of power transmission lines.

  ◊ Recommendations on the use of trunked mobile radio solutions for use by power utilities

  ◊ Analysis of the problems inherent in the second generation change of digital radio link equipment to SDH (Synchronous Digital Hierarchy).

- **Special telecommunications service requirements...**

  ◊ Recommendations for application of protection signalling both for command signalling and analogue information signalling (in conjunction with SC34)

  ◊ Thesis on the mixing of operational traffic and business traffic on Packet Switched Data networks.

  ◊ Proposal for the use of the transport layer of the ITU/T data model in SCADA systems.

  ◊ Reports on available protocol systems for the transport of operational data between control centres..

- **Network construction and maintenance...**

  ◊ Guidelines for planning telecommunications networks in power utilities (initially using analogue technology and later a new issue using digital technology).

  ◊ Guidelines for planning of mobile telecommunications networks in power utilities

◊ In-depth study on the needs and functionality of telecommunications network management as applied in the power industry.

- **Development of telecontrol systems...**

◊ A series of studies into the plant requirements within control centres

◊ Identification of the variety of meshed network possibilities for the architecture of SCADA systems..

- **Telecommunications deregulation issues...**

◊ Catalogue of opportunities for business ventures by power utilities into the telecommunications market.

1 - POWER LINE CARRIER

In the early 1950's protection of interconnected power lines developed to a stage where it was desirable to signal between the relays at the two ends of a line to achieve optimum analysis, and the most efficient clearing, of a fault. Wire line based communication links of telephone companies were considered insufficiently reliable, and were indeed often unavailable in the more remote locations of some power transmission line terminations. The use of the power line as a medium for carrying the communications was conceived and "Power Line Carrier" resulted. The earliest endeavours of SC35 centred around the investigation and reporting of this technology. Although limited in capacity by today's standards, PLC was expanded to carry a speech channel and some control channels in addition to, or in lieu of, the protection "intertrip" signal. This was a significant technical advance but the problems in coupling the signal to the power line conductors, "trapping" the signal within the line section, unwanted radiation from the conductor itself, and transmitting the signal "through" a fault on the line, all needed solving. Further, little was understood of the mechanism of propagation and serious mathematical models were required to develop a theoretical base for adequate design of PLC links.

This work was reported in the 1974 & 1976 Sessions [1] [2] and then more fully in the Guide issued as a technical brochure in 1979 [3].

After a gap of nearly two decades, during which PLC has changed little in character and performance, a new awakening has emerged as manufacturers have started to develop a digital form of this technology. SC35 is studying the engineering aspects of this development and a new output of significance is predicted.

2 - RADIO LINKS

Taking the lead from the public telecommunications industry, (analogue) radio links were introduced to provide greater capacity for power system telecommunications, but immediately there was concern from the protection fraternity about the performance of such media. Studies reported on early installations [4] [5] and eventually this technology became widely used.

With the emergence of digital radio links in early 1984, electricity supply utilities in some countries considered the standards being adopted for the public telecommunications arena were inappropriate for the more modest requirements in the electricity supply industry. Cigré became the forum for the extended debate [6] [7] [8] that ultimately adopted the public international standard.

Now in 1997 the second generation of digital radio equipment (SDH) is being introduced and revealing issues that are not compatible with the specialised use made of it by the electricity industry. The issue is an ongoing study commitment for SC35.

3 - FIBRE OPTIC CABLES

When it became apparent over a decade ago that fibre optic cables were the transmission technology of the future, interest developed on how these cables might take advantage of existing rights-of-way and be strung on power lines. Methods were developed to embed the fibre cable within conductors, to attach them to, or wrap them around the conductors, and to erect them separately as all-dielectric self supporting cables. Cigré SC35 was the venue for debate on the various conflicting claims for advantages and disadvantages of the different techniques, and the reporting centre for problems as they arose. The major output from extensive debate on this subject is the guideline issued in 1995 [9] which is widely recognised as the most definitive work on this subject.

4 - PROTECTION SIGNALLING

Although originally an integrated function within the channel of power line carrier, command protection signalling became a science in its own right. Required to provide a single signal at very infrequent intervals (once every several years!), but with the highest possible reliability, a specialised audio frequency signalling technology developed, with Cigré playing its part as the prime place for information interchange and debate. With the introduction of comparison forms of unit protection, the need was extended to transmit analogue quantities in real time, and again Cigré was a major forum for discussion.

For over 30 years the function has been applied to all evolving types of communication bearers - PLC, wire line, and radio, and a key document guiding the practice was released in conjunction with SC34 in 1969, and was later revised and upgraded in 1987 [10].

In the late 1980's SC35 triggered the need for a technology revival. Digital bearers (radio and fibre optic) were becoming the standard for new installations, and the digital form of protection signalling was seen as more efficient for these bearers. Manufacturers responded [11] and today "Prot Sig" is a single electronic plug-in card in lieu of the half rack of pre 1980's equipment.

5 - TELECONTROL SIGNALLING SYSTEMS

Two decades have seen enormous development in the sophistication of SCADA and other control systems with the average lifetime of these systems being around 8 years. This has attracted a large range of suppliers with many different protocols for transmission, and a wide range of architectural models for networks. Cigré has been unable to manage the process of unifying the protocol spread, but has acted as a platform for debate and has regularly produced papers and guides on alternatives.

The most notable paper was the early publication of an effective inter-control centre data communication protocol. [12]

6 - NETWORK DESIGN

As each new technology has evolved it has necessarily impinged on the logical network design for power system telecommunications and has often affected the interface and operating characteristics of the special services to be carried. Thus progressively with the evolution of usable radio links, fibre optic cable, digital transmission, sophisticated telecommunications network management and more latterly the carriage platforms of ATM and frame relay, SC35 has been actively involved in the assessment of how these technologies should best be used.

Guides were issued on Network Planning [13], Mobile Radio Networks (2) [14] [15], Digital Network Planning [16], and Telecommunication Network Management (TNM) [17].

Indeed, so complex has the issue of TNM become that it has attracted debate not only in Session papers but also in SC35 Colloquia (C35-87) and (C35-95) and in the Helsinki Symposium (S39-95) - section 3.

7 - TELECONTROL SYSTEMS

With other organisations working strenuously on the issue of protocol convergence, SC35 has concentrated on analysing the viable alternative network structures, logical hierarchy, operational shortcomings, and the provision of features for the man-machine interface (MMI) in control rooms. A series of papers, discussions and technical brochures have been completed and whilst none could be said to be major milestones in the development of the art of telecontrol, they have as a whole advanced the technology markedly.

With the short life span of SCADA equipment, and because of the enormous effort involved to replace systems, SC35 has addressed the management of renewal, and the complex issues of administrating contracts for the purchase of plant containing real time software. The consequences of errors existing in real time software in the control of a power system can be extreme, and yet this is the most demanding form of software to develop. When it is remembered that during the lifetime of the purchase it will probably need to have many additions to match the expansion and change of the power system, and that these additions will have to made 'live', it further exacerbates the demands made on the purchaser to ensure that it is error free. The two guides issued on this issue are thought to be unique. [18] [19].

As we approach to the end of the 1990's new methods are being developed for the efficient transport of data at ever increasing speeds. For the power industry this provides an interesting conundrum. Certainly there will be a business need to send large quantities of data between remote locations at higher and higher speeds, but the operational needs of protecting and controlling the power system will continue to require highly secure data transport methods at moderate or even low speeds. Since the availability of commercial transmission plant will always dictate the type of transport platforms economically available, the power system telecommunications discipline is now grappling with how to deal with these widely separated ends of the "supply" and "delivery" chain.

An introduction to the problem has been produced [20] and further active study is continuing.

8 - TELECOMMUNICATION DEREGULATION.

Like 'deregulation' in many other industries, the deregulation sweeping the world in the telecommunication industry is hardly deregulation - more likely re-regulation. But whatever the name, it has provided a competitive environment where previously the provision has been monopolistic. With a significant synergy between the industries of electricity supply and telecommunications, many power utilities around the world have opted to extend their core business and include telecommunications services in their portfolio of offered products. At a time when the rate of growth in the telecommunications industry is far outstripping the rate of growth in the electricity supply industry this is clearly attractive in some countries.

Since most power utilities have had some background in telecommunications provision (albeit not in the public competitive domain), this experience has often been the nucleus of the new business venture.

Accordingly SC35 has in recent years studied the issues involved in power utilities branching into the telecommunications market, and a guide was issued in 1997. [21]

9 - FUTURE CONCERNS

There is no doubt that for the foreseeable future there will be the need to continue to service the needs of teleprotection and control of power systems. This will inevitably lead to the need to continually analyse the technical and economic parameters of existing and new technologies for transmission of data and signalling.

Fibre optic cable appears to be firmly entrenched as the transmission medium of the future and since this is mature, it is more likely that technical studies will centre on the mode of carrying additional quantities of data faster, or how to support old systems requiring unique protocol of transmission.

There is expected to be an ongoing brief to continually assess the management practice of maintaining internal control of operational telecommunications provision against the opportunity of oursourcing the responsibility.

The impact of electricity markets is bringing a new dimension to power system telecommunication engineering. In this field, practice suggests that there will be no need to provide and control telecommunications transmission media, but to innovatively use public offerings secured with protocol protection.

The study of digital PLC (already commenced) will be of advantage in a niche field for renovation of existing plant and for long distance transmission in newly industrialised countries.

Assistance is likely to be required for some time by power utilities venturing into the competitive provision of public telecommunications services.

SC35 remains in a good position to continue to assist the industry in these endeavours.

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STUDY COMMITTEE 36 : « POWER SYSTEM ELECTROMAGNETIC COMPATIBILITY »

INTRODUCTION

The technological evolution of electric power transmission and distribution took place over the last hundred years almost simultaneously with those of radio and telecommunications, and it was inevitable that these diverse technologies sometimes share the same physical space. The engineering community, of which CIGRÉ was a vital part, has therefore recognized quite early that measures should be taken right at the design stage to assure the proper functioning of these emerging technologies. Created in 1968, Study Committee (SC) 36 on Interference has in fact continued the work of its predecessor within CIGRÉ, SC 11 on Telephone and Radio Interference, which was active since 1934. The initial preoccupation of this committee was with interference produced by power transmission lines affecting telephone lines and circuits operating in close proximity. With the steady increase in power transmission voltages, the potential for electromagnetic interference (EMI) with other services and systems operating in the vicinity also increased. At the same time, the rapid evolution of analog and digital electronics technologies and an almost explosive growth in the use of electronic equipment, have made it necessary to take serious consideration of the electromagnetic compatibility (EMC) aspects of power transmission systems. It is for this reason that SC 36 has been renamed recently as Power System Electromagnetic Compatibility, with its scope changed accordingly. A summary of the significant milestones in the work of SC 36 are highlighted in the following.

1 - TELECOMMUNICATIONS CIRCUITS AND BURIED METALLIC PIPELINES

The concurrent rapid growth and development of electric power and communications technologies has inevitably given rise to the potential of dangerous or disturbing effects due to inductive, capacitive and conductive coupling between the two systems. Continuing the tradition of close collaboration with CCITT (International Telegraph and Telephone Consultative Committee), SC 36 participated actively in the task of producing new CCITT Directives [1] in 1988, concerning the protection of telecommunication lines against harmful effects from electric power lines. The main objective of the nine volumes of Directives is to provide the background technical information and design guidelines to practicing engineers regarding such effects which may result in danger to personnel, damage to telecommunications equipment, deterioration of telecommunication transmission quality or in signaling disturbances. The Volume V of Directives, concerning the "Inducing currents and voltages in power transmission and distribution systems" was elaborated by experts of SC 36.

There has also been an increasing tendency over the years to locate buried metallic pipelines, generally used to carry fluids such as liquid or gaseous hydrocarbons, near or within power transmission line corridors. Such proximity gives rise to concerns about possible hazards to safety of people coming in contact with the pipeline and risks of damage to the pipeline coating and metal as well as to equipment connected to the pipeline, especially cathodic protection equipment. A guide [2] has been produced on this subject in 1995, describing the different modes of influence and the resulting problems, simple methods of calculation and measurement of disturbances and the principal mitigation and protection methods.

2 - CORONA EFFECTS

Some of the earliest problems of EMI and EMC were related to corona effects of high-voltage transmission systems. Corona discharges occur due to the partial electrical breakdown of air surrounding the conductors of high voltage transmission lines, and the corona effects of importance to transmission line design are EMI over a wide range of frequencies, but particularly radio interference (RI) in the broadcast frequency range, audible noise (AN), and corona (power) loss (CL). Studies on RI from transmission lines have been carried out since the creation of SC 36 (and, to some extent, even by its predecessor, SC 11), which have culminated in the publication of a guide [3] in 1974, describing the state of knowledge of corona-generated RI, methods of calculation and measurement, as well as design guidelines. In some countries, comprehensive measurements were carried out and calculation formulas were given for 400 kV and 750 kV lines [4]. In the twenty years since publication of this guide, several important changes have occurred in power transmission technology that necessitated the preparation of a complement to the guide. These changes include the use of voltages above 1000 kV for AC power transmission and the consequent use of large conductor bundles, the increasing importance of AN and television interference (TVI) as design criteria for transmission lines, the rapid increase in energy costs and the resulting increase in the importance of CL as a factor in the choice of conductor bundles, and the use of HVDC transmission at voltages up to ±600 kV. In order to take these changes into account, a comprehensive Addendum [5] to the 1974 design guide has been prepared and published in 1996.

3 - ELECTRIC AND MAGNETIC FIELDS AND HEALTH EFFECTS

Power frequency electric and magnetic fields (EMF) and their possible impact on human health have been debated vigorously over the past two decades in connection with high-voltage transmission facilities. This debate was initiated, in fact, by a paper from USSR presented at the 1972 SC 36 Group Session. Since then, extensive studies have been carried out on methods of calculation and measurement of transmission system EMF and on possible physiological effects such as shock hazards which might be caused by these fields, and a guide [6] on these aspects published in 1980. Meanwhile, the controversy relating EMF and health effects intensified, with serious consequences to the process of siting new transmission facilities. Perceiving an important need to inform the general public at large on this matter, SC 36 has prepared and published in 1992 a technical brochure [7] describing the environmental aspects of electric power transmission, including corona and electric and magnetic field effects. Due to the simplified and easy-to-understand manner in which this complex subject of great public interest has been presented, this technical brochure has enjoyed an exceptionally high demand.

Recognizing the importance of the issue, the President of CIGRÉ has created in 1988 a Medical Expert Group to advise him exclusively on the subject of EMF and health effects. After assessing the scientific literature on the subject, the Expert Group has prepared and published in Electra a statement [8] which essentially concluded that there is no persuasive evidence linking exposure to EMF and the incidence of cancer. Following this publication, the Expert Group has been transformed into a working group within the structure of SC 36, mainly to permit a closer liaison between the technical and medical experts. Over the last five years, this working group has prepared and published papers summarizing the state-of-knowledge on several EMF-Health issues, and, more importantly, contributed to informing and educating CIGRÉ membership on this multi-disciplinary subject through the organization of three panel discussions.

4 - CORROSION

Currents injected into the earth as a result of power system grounding practices may be collected by buried metallic structures in the vicinity and may consequently cause corrosion of these structures. These problems have been studied by SC 36 since its creation in 1968. In collaboration with commission VI of CCITT, questions related to cathodic protection, interaction between installations, stray alternating currents in the earth and corrosion due to direct currents have been addressed. Some guidelines have been developed for the design of HVDC earth electrodes as well as for the mitigation of corrosion of buried metallic structures in close proximity to these electrodes [9].

5 - EMC WITHIN POWER PLANTS AND SUBSTATIONS

The EMI generated by sources external as well as internal to the high-voltage power system can interfere with the normal functioning of the substations, power stations and control centers of the power system itself, particularly due to the increasing use of highly sensitive digital electronic equipment for communication, protection, control and data acquisition. Extensive studies have been carried out by SC 36 in order to characterize the EMI in substations generated over a wide range of frequencies by a variety of internal and external sources such as circuit breakers, disconnect switches, relays, compressed gas equipment, lightning, etc. The studies also included an evaluation of the disturbing voltages likely to be induced in the auxiliary wiring and an assessment of the immunity requirements of the electronic equipment used in substations. Information obtained from these studies have been useful in the development of IEC (International Electrotechnical Commission) standards on EMC requirements and test methods. A guide [10] has been developed recently on the characterization of the electromagnetic environment and the EMC aspects of high voltage substations.

6 - VOLTAGE QUALITY

The interaction between high-voltage power systems and certain types of loads connected to them have been known to result in disturbances. A special working group was set up within SC 36 about twenty years ago to make an inventory of different types of disturbances, identify the sources, develop methods of calculation and measurement in order to characterize these disturbances, estimate the potential damage that might result from them and evaluate possible mitigation methods. Four general types of disturbances were identified: voltage fluctuations and flicker; voltage dips; harmonic distortion; and, voltage unbalance. Following the results of an international survey, the working group accorded top priority to studies of harmonic distortion. One of the first reports published by SC 36 on this subject [11] provided results in tabular form of an assessment of harmonic levels in low, medium and high voltage lines, which form the basis even today of international standards on harmonic limits (IEC standard 61000-2-2 (1990) and CENELEC:ENV61000-2-2 (1993)). Studies have also been carried out, jointly with SC 14 on HVDC Links and AC Power Electronic Equipment, to develop guidelines [12,13] for limiting harmonic voltage and current effects in AC high-voltage networks connected to harmonic producing installations, with particular reference to HVDC. Results of these studies, particularly on the question of limits to harmonic voltages and the methodology to apportion them between the different customers, have been used in developing IEC standards.

7 - CONCLUSION

The technological evolution, occurring at an unprecedented pace, in power, communication and transportation systems, which have to exist in close proximity of each other, has a direct impact on the work of SC 36. Recent advances in the application of power electronic equipment for purposes of assuring the reliability and quality of power flows in large and complex networks, coupled with the world-wide trends of freer trade between different countries and deregulated power markets, have increased the need for power system interconnections. These developments also emphasize the need for standardization in all relevant fields of technology. For example, the implementation of the EMC directives by the European Community has spurred international standardization activities in this area. SC 36 hopes to make a significant contribution to these efforts by making timely and pertinent information available on all aspects of power system electromagnetic compatibility.

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STUDY COMMITTEE 37 : «POWER SYSTEM PLANNING AND DEVELOPMENT »

INTRODUCTION

The electricity supply industry in each country has to adapt itself to an ever changing world. If we just look at present evolutions, we see that new institutional arrangements are evolving almost everywhere, concern about the impact of our activities on the environment is increasing, technical changes are taking place at a fast pace (with, for instance, the development of new transmission equipment or the increase in the efficiency of dispersed generation), very large area interconnected systems are created as previously non synchronous systems connect themselves, etc. But we should not believe that our predecessors lived in a static world. In fact, change has been constant.

SC37 has played and plays a central role in assisting utilities to find the best solutions to adjust and accommodate changes, allowing the utilities to increase their efficiency and provide more adequate services to their customers. This goal is at the very core of the mission of the Committee, which is to integrate various elements in order to define the future of power systems. SC 37 is indeed at the cross-roads of many fields : technical analysis, economic analysis, evaluation of the impact of institutional changes, definition of solutions to deal with environmental constraints, relations with decision makers in the energy policy field, analysis of the possible benefits of new techniques to enhance system efficiency.

Before going into the details of past and present activities, it may be useful to recall the definition of the field of activities of CIGRE Committee 37 as it was defined in 1982 :

« Progress in power system planning criteria and methods recognising their possible interaction with other energy systems. Future electric power system development in the context of the overall energy system. Power system development in different countries : information and comparisons. Assessment of new technologies affecting the development of electric power systems. Economic, social and environmental considerations in the development of power systems. »

The lines of investigations to which the Committee has particularly devoted itself during the last twenty years in undertaking this task are summarised below.

1 - PLANNING METHODS ([1], [2])

1.1 - THE FLEXIBILITY OF PLANNING ([3])

Any planner likes, of course, to plan for a future which is well defined, possibly in probabilistic terms. He can then propose well researched optimal solutions within a framework of firm assumptions.

This has, more or less, been the situation as long as the demand for electricity kept growing rapidly, because this growth was an indication of a need of the community which was virtually insensitive to outside influences and because rapid growth brings closer the horizon of influence of the decisions and, therefore, reduces uncertainty.

Things have changed considerably. The rate of growth has fallen. In industrialised countries, electricity is no longer considered as a priority requirement, which makes it more sensitive to financial, political and ecological constraints. The change in the general environment has lead the planner to attach much greater importance to flexibility, defined as being the capacity for the strategies and the solutions which he advocates to be adapted quickly to meet a changing and sometimes hostile environment. Concrete examples of flexibility in planning have been studied.

1.2 - SUB-TRANSMISSION NETWORKS ([4])

Between the extra high voltage (EHV) interconnection and transmission networks, and the medium voltage (MV) distribution networks, there are usually intermediate voltage (IV) networks. These IV networks draw large blocks of power from the EHV networks, which they then disperse and deliver to the MV networks.

The structure of these IV networks is often complicated, for reasons of history. And a lot of money is spent to develop these networks. Jointly with CIRED, SC 37 has carried out an analysis of the role and of the best ways to develop these networks.

1.3 - CONSUMPTION FORECASTS ([5], [6])

An entrepreneur's knowledge of his present and future market is the first link in his action chain. The power utility is no exception to the rule and the planner certainly has a prime role to play in all studies regarding this problem.

For many years, the planner's knowledge of electricity demand could be limited to energy consumption forecasts over a period of several years, with several scenarios if necessary. He did not have to delve further into the profound mechanisms of the formation of his demand and was able, as it were, to live in an electric world developing in an autonomous way.

However, many uses of electricity have fallen within the competitive field and the energy crisis has also meant attaching greater importance to the judicious use of this energy.

The components of demand have been analysed : how can we classify present and future, industrial, commercial and domestic uses of electricity ? How could they develop and with what consequences for power and energy ? What is the interest of demand-side management, from the planner point of view ? By which means, thanks to which appliances ?

1.4 - DEMAND SIDE MANAGEMENT AND INTEGRATED RESOURCE PLANNING (DSM/IRP) ([7], [8])

At the end of the seventies, beginning of the eighties, it was underlined that society needs a series of energy services (light, mobility, heat,...) and not energies that produce them. The key element derived from this is that, when planning, demand-side options should be incorporated on a same level playing field with supply-side options for comparisons of supply and demand alternatives. Moreover, as minimising utility costs does not necessarily mean the best way of meeting society's energy service needs, the Integrated Resource Planning (IRP) approach was introduced to include the environmental impact of electricity production and other costs that affect society-at-large, as distinct from direct financial costs to the utility and its customers.

The Committee analysed key issues in the DSM/IRP approach : the problem of « level playing field », the role for utilities in promoting DSM technologies, the regulatory incentives, the incorporation of societal and environmental externalities into the planning process.

1.5 -SYSTEM PLANNING IN DEVELOPING COUNTRIES ([9], [8])

Power systems at an early stage of development requires somehow specific planning methods. The appropriate levels of reliability and security are to some extent different from those in developed countries. The system designer needs to pay specific attention to determining appropriate design criteria rather than being able to adopt in an arbitrary way the severe performance criteria that can be achieved by highly developed systems.

SC 37 has looked at questions of highest interest in newly industrialised and developing countries, as for example the development of transmission networks for fast growing cities or areas, or the connection of remote generation or load.

The Committee has also examined how « Integrated Resource Planning » techniques can be applied in economies in transition.

2. APPRAISAL OF NEW TECHNOLOGIES ([10], [11], [12])

SC 37 has contributed to defining the future use of various techniques such as new underground cables, new overhead conductors, or FACTS devices. The Committee analyses the value of these technologies from a system point of view, looking at both technical and economic aspects. It also studies the consequences of new technologies on the compared costs for the transfer of energy of solutions based on electrical energy and on primary energy. New technologies on the demand side and their possible impacts on the system have also been studied.

SC 37 has, for instance, devoted much attention to FACTS devices. The new technologies that are becoming available with the advent of this type of devices broaden the planner's « toolbox » of solutions to deal with a wide variety of traditional and emerging transmission network problems. These solutions may, in many cases, be interim cost-effective alternatives to the more traditional approaches of building new transmission facilities. As the electric utility system moves into a more competitive generation supply regime, dictating a greater emphasis on the utilisation of transmission networks for power transfer, a range of system problem may emerge, dictating the need for increased transmission capacity. On the other hand, this will be more difficult to provide, due to the growing opposition to the construction of new transmission lines. The FACTS devices will likely play a role to deal with these emerging but conflicting trends.

On the other hand, FACTS is not a panacea. From it, a host of new problems and concerns will emerge that network planners will need to address. One problem relates to the higher utilisation of existing facilities the FACTS devices will promote. This may be attractive in the short term, but may in the long term involve higher costs due to higher losses, and less security and flexibility to deal with unexpected events. The only way to provide a significant and long lasting improvement in network capability will be the construction of new transmission facilities or the upgrading and reconstruction of existing facilities. Moreover, FACTS devices do increase the system operation complexity, especially if post-fault actions are needed.

3. INTERCONNECTION ([13], [10])

3.1. COMPARISONS OF TECHNICAL SOLUTIONS

Since its creation, SC 37 has worked on the comparisons, from the planner's point of view, of the different technical solutions for long distance transmission and international interconnections. Questions such as the optimal voltage level or the choice between AC and DC solutions have been investigated. Results have been updated on a regular basis to take account of new economic or technical data, notably concerning the cost of equipment.

3.2. EXTENSION OF INTERCONNECTED SYSTEMS

During the last thirty years, the development of electric energy demand has been simultaneous with the creation of increasingly wide interconnected electric systems : the size of formerly isolated systems which have gathered can reach that of a continent. The Committee has examined the advantages and drawbacks related to the extension of synchronous power systems. It has established that it is virtually possible to settle all technical, construction or operation problems linked to the size of synchronous systems. However, if there are no technical impossibilities, there is an economic limit as the transmission cost should not exceed the potential gain. It is generally not the case in areas with a high consumption density.

3.3. FORUM FOR DISCUSSIONS ON A REGIONAL LEVEL

Even if a long way has been covered, the development of interconnection is far from complete. In fact, there is an increasing interest in interconnections, especially in the parts of the world now experiencing rapid industrialisation and economic development. These countries are considering national and international interconnections in the context of a wide range of geographical, demographic and economic conditions and a great diversity of historical experiences. This has lead to a wide range of engineering practices which without co-ordinated planning could inhibit interconnection.

The Committee promotes network connections at regional levels, by facilitating, through the creation of regional task forces, joint studies and the selection of common standards when useful.

4. LINKS BETWEEN PLANNERS AND DECISION-MAKERS IN THE ENERGY FIELD ([14], [15])

On completion of studies which have to be objective, the planner proposes investments which he considers necessary or judicious. But, the final decisions result from discussions often held within words where the ways of thinking are different from his own.

This, in itself, is normal, provided there is however a minimum of mutual understanding between the planners and the decision-makers.

In every country there are methods, procedures, which tend to create, with varying degrees of success, these links of understanding. The Committee has carried out a comparison of these methods and proposed some general rules which may contribute to a better mutual understanding.

On the specific topic of the environmental aspects of links between power system planners and decision makers in the energy area, SC 37 came to the conclusion that the necessary skills for the communication of environmental issues do not differ significantly from the skills necessary for communicating the benefits of a projects as such. There is, however, a trend towards greater involvement of local officials, authorities and the general public in site or route selections and in cost benefit assessment. One way communication and public information are being replaced by dialogue, more and more often within the framework of an Environmental Impact Assessment.

While it seems clear that in the past, lack of involvement has lead to great difficulties for project promoters, it is still too early to judge the success of this increased involvement. It was noticed that, even though the applicant has paid much attention to informing and communicating the environmental impact to media, the general public, authorities and representative groups, attitudes to the project have often remained highly polarised. This fact reflects that however well planned the communication process may be, any project requires a strong and sustainable political support apart from a well performed application process according to existing legal frameworks.

5. SYSTEM PLANNING IN EVOLVING ELECTRICITY SUPPLY INDUSTRY STRUCTURES ([16], [8])

This topic is relatively new to SC 37 : work on it started only a few years ago. But it is now a major field of activity of the Committee. A major difficulty in dealing with this subject is the diversity of the institutional arrangements in place or envisaged all around the World.

SC 37 surveys how power systems are developed in various environments. The ways and means adopted in various countries are analysed and compared and, whenever possible, recommendations are formulated. This includes analysing the role of the various possible actors in various structures (independent system operator, transmission owner, power market administrator, independent generator, distribution company, supply company, integrated company, power trader or broker, consumer, regulator, etc.), and the interactions between these actors.

The Committee has examined the impact of open access on the performance of the network : results reveal no significant difference over the last ten years as regards quality or price between systems with open access and others.

The Committee also works on the pricing of transmission services and ancillary services, and the impact of pricing methods on system development.

SC 37 analyses ways to maintain reliability and security in unbundled environments. It works on how reliability and adequacy levels can be maintained in world of customer choice.

The question of the relevance of « Integrated Resource Planning » in business environments that introduce competition and unbundling of electric utilities has also been studied.

As it was noticed that discussions on these matters were often difficult because people do not mean the same thing using the same words, the Committee has prepared a glossary.

The new institutional arrangements generally imply that planning is becoming a more complex exercise. Its basic function is to elaborate the proper signals to be sent to the market.

6. CONCLUSION

This brief presentation of the activities of SC 37 during the last decades has shown the diversity of the questions which have been covered.

During this period, planners had first to define methods to design systems in a context of rapid load growth. At the end of the seventies and the beginning of the eighties, they had to adapt to slower and less predictable growth as well as to increasing opposition to line constructions. A new challenge finally appeared with the development of new institutional arrangements, which completely modify any aspects of planning.

During these same years, many technological changes took place. Planners analysed the value of these new technologies from a system point of view, looking at both technical and economic aspects.

By allowing an extensive exchange of information and the establishment of appropriate recommendations when relevant, the Committee endeavoured itself to assist the utilities to increase their efficiency and provide more adequate services to their customers.

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STUDY COMMITTEE 38 : «POWER SYSTEM ANALYSIS AND TECHNIQUES »

INTRODUCTION

The activities of Study Committee 38 commenced in 1982. Dealing with "System Analysis and Techniques" the Study Committee 38 has a main task in servicing the other Study Committees with tools and techniques. Therefore the main result of the SC can be divided into two parts, namely the tools and techniques themselves and the liaison activities with other Study Committees.

Field of Activity of the SC 38:

Static and dynamic performance of power system and progress in methods of analysis; means of improving the performance of power systems; the effect of power system components on system performance. Research and testing systems in the field of ultra high voltage.

1. THE PAST. MAJOR MILESTONES IN THE WORK OF SC 38: 1982 - 1996

1.1 REACTIVE POWER AND VOLTAGE CONTROL

Reactive power and voltage control have a basic influence on performance of power systems. In this field Study Committee 38 has contributed to a productive discussion between experts on how reactive power compensation is performed in different countries. Procedures, pros and cons on manual or automatic secondary control of voltage have been studied. Further general lumped models describing the behaviour of the automatic voltage control of generators have been studied for the purpose of a dynamic analysis of networks.

1.2 POWER ELECTRONICS

Static Var Compensators (SVC) is a topic in which the Study Committee has been very interested. Several documents explaining the function of these devices as well as the models to be used in analysis of potential application in power systems have been produced .

HVDC Technology has been studied regarding what models to use for power system planners. Further studies have been performed on the use of the fast HVDC control to optimize the dynamic performance of AC networks.

Load Flow Controllers based on power electronics have been studied for the purpose of the functionality, for analytical models and for potential power system applications.

As new components based on power electronics (FACTS) are still being invented, this technology has been of increased interest to the Study Committee and will be one of the main subjects to be studied in the years to come.

1.3 VOLTAGE INSTABILITY

Voltage instability has been an important topic since the major voltage collapses in the 1970s. Achievements within this area have been the cost effective means to counteract voltage collapse. The conclusion was that this problem has to be dealt with in system planning by using multiple contingencies in order to provide a reliable power system which is robust against voltage collapses. Also the work on indices for predicting a potential voltage collapse or the operation margin to such a situation is worth noticing.

1.4 SYSTEM RELIABILITY

The most important result within System Reliability was an Application Guide on System Reliability Analysis. It presented an overview of system reliability concepts and an outline of the methods whereby these concepts are applied. The concepts exploited lead to advancements within composite reliability evaluation and prediction. Finally, the benchmarks established for testing of programs and other tools within reliability analysis are worth mentioning.

1.5 BETTER UTILIZATION OF POWER SYSTEMS

Today, one of the key issues for system planning and operation is how existing power systems are best utilized. This issue was addressed by several task forces. Work was performed in the area of power electronics and DC (see § 1.2), but also in the fields of excitation systems, automatic voltage regulators, systems for damping of oscillations as well as primary frequency regulators.

The consequences of open trading were also studied as was the impact of open trading on analysis techniques. In the area of operations and operations planning, a thorough analysis was made of the existing trends and needs for dynamic security assessment.

1.6 BENCHMARKS FOR POWER SYSTEM DYNAMICS (SHORT - AND LONG TERM DYNAMICS)

Five test systems for studying long term dynamics have been made. Using these benchmarks utilities and research institutions, utilities etc. can study new control concepts, tools and components for the behaviour in typical networks adapted to special system dynamic problems, like island operation, voltage collapse, transient stability and damping of power system oscillations. The benchmarks have been well received by researchers and engineers.

1.7 FAST TRANSIENT STABILITY METHODS AND DYNAMIC SECURITY ASSESSMENT

Activity has been performed within the topic of fast or direct methods in order to calculate transient stability. Different methods have been investigated and compared with time-domain simulations. The goal has been to assess dynamic security rapidly. Application within and requirements for dynamic security assessment have been reported.

1.8 ARTIFICIAL INTELLIGENCE

Substantial work has been done within Expert Systems, first of all in disseminating the understanding and potential use of this novel technology. A world-wide overview of specific applications within power system planning and control has been performed such as for alarm processing or for power system restoration. Another topic has been its application within education in power system engineering and education of operators.

Artificial Neural Networks have been studied for the purpose of application within the power industry. Achievements have been within the issue of widening the understanding and studying the potential applicability of this new technology, particularly in the area of load forecasting.

1. 9 OPTIMIZATION TECHNIQUES

This field was started in 1993 in order to study and evaluate optimization methods and techniques in use or in prospective use in operation and planning of power systems. Work was achieved in the fields of short term production scheduling and unit commitment, power system network performance. Another topic worth mentioning is transmission costing, which is an important issue in a context of growing deregulation.

1. 10 ULTRA HIGH VOLTAGE TRANSMISSION

The field of ultra high voltage transmission is or maybe was important to certain networks. Developments were made in countries such as Russia, Japan, Italy and Brazil. SC 38 produced reports on fields such as system planning, performance or reliability aspects, including UHV. Topics specific to transmission lines, substations and equipment were also dealt with, as well as topics concerning new facilities and technology. The survey of UHV was concluded in 1992.

1.11 MAJOR LIAISON ACTIVITIES

The Study Committee has, during its period of activity, widened the liaison activities to other Study Committees and other organisations. Feed-back on important tasks which are to be carried out in the future are of crucial importance to the Study Committee. Such liaison activities have always been a major objective for Study Committee 38. At the CIGRÉ main sessions the Study Committee has participated in many panels and joint sessions. The following joint activities with other Study Committees are worth noticing separately:

◊ AC/DC Transmission. Applications and comparisons. 1987 in Boston, USA. (With SC 14).

◊ Operation of Electric Power Systems in Developing Countries. 1989 in Bangkok, Thailand. (With SC 39).

◊ Electric Power Systems Reliability. 1991 in Montreal, Canada. (With SC 37 and SC 39)

◊ Power System Dynamic Performance. 1993 in Florianopolis, Brazil. Regional and International Colloquium.

◊ Power Electronics in Electric Power Systems. 1995 in Tokyo, Japan. (With SC 14 and SC 37)

◊ Workshop on " Voltage Collapse, Fast transient stability methods and long term dynamics ", held in Madrid, Spain, 1995 (in liaison with SC's 37 and 39).

2. THE PRESENT. CURRENT MAJOR ACTIVITIES

The present situation is characterised by "change". This change is caused by the general changes in the electric industry regarding new institutional arrangements as well as the availability of new technologies. At the SC 38 meetings in 1996 and 1997 the structure of the SC has been changed from a "tool oriented structure" to an "application oriented structure". In practice this has been done by changing the SC Advisory Groups from "Components", "System Performance", "Reliability", "Optimization Techniques" and "Intelligent Systems" before the 1996 meeting into "Components", "System Control", "Countries in Transition" and "Open Networks" after the 1997 meeting. Taking into consideration that "Components" will probably be disbanded in 1998 we can conclude that the SC 38 now has three major activities namely "System Control", "Countries in Transition", and "Open Networks". A "major activity" involve that an “Advisory Group” in the SC is established to discuss new actions to take by the SC. Further that 3 to 5 task forces is established to promote the activities in the area.

In this way the SC 38 will constantly adapt to the new situation in the power industry. Taking "Reliability" as an example the idea is not to stop investigating this area but to seek application of reliability methods within either "System Control", "Countries in Transition" or "Open Networks".

It is important to realise that this application oriented structure is not in any way a permanent situation. SC 38 might return to a tool oriented structure in the years to come but in the present situation priority is given to adapting to the new situation in the power industry.

However, SC 38 must realise that working with "Tools and Analysis" we will have our main activity when the subjects are in embroilment. When analysis strategies are clear SC 37 and 39 who are working with planning and operation will take over gradually. For example, "System Control" is a major activity within SC 38 now because power electronics gives us the possibility of applying new techniques to control power systems. When new control strategies are defined, SC 37 and SC 39 will gradually take more and more over and we have to accept that. Another good example is "Open Networks" wherein SC 38 has three task forces looking at "Methods and tools for ancillary services", "Techniques for power system planning with uncertainties" and "Methods and tools for long term contracts in a competitive framework". When it is clear how we should handle open network there may be some work for SC 38 in comparing the methods used in different countries but at a lower level because the experts we want to attract to work in the task forces have moved towards other activities and SC 38 must follow them.

3. THE FUTURE. NEW STRATEGIC DIRECTIONS

As mentioned earlier and in the activity plan of SC 38, the most important part of the SC 38 strategic plan is not to make an ingenious forecast of new activities for a long period forward. It is much more important to adapt quickly to new situations and current needs for tools and analysis methods in the power industry.

However, at the 1997 SC meeting a few items seemed important enough to take up, namely

1. Superconductivity

2. Modelling/ validation/ measurement

3. Analysis of electromagnetic transients

4. Digital simulators for equipment testing

Superconductivity is a promising new technique. At the 1997 meeting the SC 38 decided to form a new task force focusing on the impact of superconducting cables. The reason for this premature action is that such cables may have a substantial influence on the future network control strategies and therefore the application of power electronics is a current important issue. If the superconductivity technique breaks through it must be expected that we will form an advisory group and a few task forces who should look at the different superconducting components (SMES, current limiters etc.).

Modelling/ Validation/ Measurements. Good models are essential for accurate calculations and the conclusion from some recent disturbances indicates that this is an area which could be improved, for instance regarding guidelines for measurements.

Analysis of Electromagnetic Transients is an area which SC 38 has so far avoided because it was considered mostly a question of the equipment withstanding such transients. However, if/when power electronic, superconducting current limiters etc. get a substantial share of the future power system control resulting in fast and frequent switching actions in a substantial part of the network, problems like harmonics and electromagnetic transients will then become system problems and not only equipment problems. It would then be a natural area for SC 38 to study regarding analysis methods and which tools to use.

Digital Simulators for Equipment Testing. Dispatch training simulators are the subject of SC 39 but tools for digital simulators for equipment testing may be an area for SC 38 to take up in co-operation with equipment committees.

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STUDY COMMITTEE 39 : « POWER SYSTEM OPERATION AND CONTROL »

INTRODUCTION

SC39 was created in 1982 when SC32 was disbanded and was given the assignment to explore the field of power system operation and control. This contribution describes the development of this field since 1982 and the results of the work of SC39 and its Working Groups and Task Forces. Co-operation with other committees are pinpointed too.

The main directions of progress which have led the different activities of SC39 have changed the last years due to external pressures.

Fifteen years ago, in a period where the load growth in developed countries was still high but where environmental constraints started to have an impact on the power system development, the electrical supply industry understood that the operating margins would be limited and that the basic state description of the system operation (normal, alert, emergency, restoration) would become a reality in daily life (1), (15).

Today, this situation is still there but on top of above it new externalities have appeared by the process of liberalisation and deregulation : the new institutional arrangements will have an impact on operation, at least by introducing new actors in the industry (14), (16).

The directions of progress identified in the Strategic Plan of 1992 considered this evolution and anticipated the impact of them. They cover fields as :

◊ operation closer to the limit, in emergency, in restoration (15), (5), (11)

◊ interaction between power plants and system, organisation of operation of interconnected systems (9)

◊ maintenance policies and operation; operational performances (10)

◊ control center performances, new information technologies, training facilities (12), (17).

It is worthwhile to pinpoint here that the activities underpinning these directions of progress are covering
operational questions in developed regions, emerging economies or developing countries. The way the questions are raised can be different, but the approach used to give guide lines has enough flexibility to describe most of the existing situations (2).

Co-operation with other SC is done through joint Task Forces or participation, or sometimes chairing Symposium or Panels during the Paris Sessions.

We find so collaboration with : SC11, SC14, SC23, SC35, SC37 and SC38 (see references). The fields of co-operation are covering subjects as :

◊ the influence of generating units on the power system and the related ancillary services question (9)

◊ the influence of FACTS, DC links,... on operation (19)

◊ operational aspects of maintenance of power systems (10)

◊ communication and control centres structure (18)

◊ operational and planning criteria

◊ simulation, optimisation and related tools needed in operation (15)

Let us highlight now the important topics which have been covered by SC39 over the last years.

1 - CONTROL CENTRES

During last 15 years the developments in the field of Control Centres have gone through an important evolution. Computer based control and decision support systems in the Control Centre, among others so called Energy Management Systems, were introduced all over the world. Despite of the successful concept, also difficulties with use, implementation and maintenance were experienced (7). SC39 analysed the critical aspects of control centre performance. Special attention was paid to the development and use of dispatcher training simulators, alarm handling and inter-utility data exchange.

A 1991 study showed that the utilisation and acceptance of EMS application functions had improved and that the development of algorithms seems to have matured but that the use in practice was still problematic (8). Further improvements e.g. in the field of data handling and Human Machine Interface however are desirable. SC39 will continue to try to define the users experiences and requirements to better align with future developments in the field of telecommunication and automation.

Investigation has been done on the subject of the possibility of utilising artificial intelligence in power system operation and control. A growing need of expert systems combined with other AI-techniques in areas with a high level of current operating problems is being observed. A number of practical issues still need to be resolved.

Recently local computer based control systems are introduced in the substations. System architecture has rapidly changed from a mainframe environment towards open systems or client-server systems. These developments asked to pay attention to maintenance and migration problems.

Also the human aspects in the Control Centre have gained more attention. Educational, training and ergonomical aspects are studied. A consistent approach covering software applications and Human Machine Interface seems to be more and more a requirement (13), 17).

2 - BULK ELECTRICAL SYSTEM PERFORMANCES (9), (4)

The problems of defining and measuring the performance of Bulk Electricity Systems (BES) have always been a great challenge for SC39. In the beginning the disturbance performance or delivery point performance was studied. A data base covering many power systems during many years was set up. Now a more general measurement system is in development. Measuring quality, security and BES economy were the main items that were explored for use in operational management.

Practical experiences with large disturbances have always attracted a lot of attention. Reports on many disturbances (causes and effects but also lessons to be learned) were presented.

Also the operation and control of power systems during disturbed and emergency conditions have been studied over the years. Definitions, classifications and criteria were proposed. Recently the importance of good monitoring during the perturbed state was highlighted. Also new developments in co-ordinated restoration of the power system after a black-out are presented. AI-techniques offer possibilities for further improvement in these fields.

3 - OPERATIONAL PLANNING (3), (6)

Several aspects (like methodologies, organisation, data flows etc...) of operational planning have been studied and results have been presented. Generation scheduling, load forecasting, generation and transmission outage scheduling are the main functions. But also the impact of transmission constraints and the possibilities of load management were considered. The need for work in the field of voltage-reactive scheduling, unit commitment and operating reserve (requirements, allocation and costs) was recognised.

4 - POWER PLANT CONTROL -INTERACTION BETWEEN GENERATING UNITS AND THE POWER SYSTEM (6), (9)

The power plant is one of the main elements in the power system. A good system control is impossible without good knowledge of the power plant. Steady state and dynamic power plant models for system control but also for training simulators have been developed. Operating capabilities of power plants and especially nuclear power plants were investigated. The impact of environmental constraints was considered as well.

The interaction between the plant and the system is becoming increasingly important. Therefore focus of SC39 has been set on this particular field (e.g. co-ordination of protection arrangements of generating units and the network). What is the value of the services a power plant can offer to the system operator ? What are the related costs ?

5 - VOLTAGE AND REACTIVE POWER CONTROL (3)

A study on the topic of voltage and reactive power control has recently been finalised. It was concluded that system modelling is quite accurate and system security is the main concern of utilities in this field. Economical aspects come behind. Increasing real-time information exchange e.g. for reactive power reserves, and introduction of automatic control schemes offer opportunities for further development.

6 - MAINTENANCE POLICIES (10)

Strategies and influencing factors as regard utilities maintenance policies, management of outages for maintenance, optimisation of availability/reliability/total cost and policies for equipment replacement and strategic spares are investigated. These factors are considered to be central to the management of transmission assets.

7 - OPERATION OF LARGE INTERCONNECTED SYSTEMS (19)

Power systems developers have always been keen on investing in interconnections because of the strong benefits in increasing reliability and cost reduction. During last years an ongoing trend for the installation of DC-links (cables or back-to-back stations) but also for the enlargement of synchronous systems can be noted. This sets special possibilities but also constraints for the system operator. Organisation of frequency control, trade options but also co-ordination of emergency plans are subjects for special concern. A world wide study on the organisation of these large interconnected systems is under way.

8 - INSTITUTIONAL CHANGES IN THE ESI (14), (19)

At the moment the ESI in many countries all over the world is in a transitional phase. Deregulation, or better formulated, reregulation is applied in order to introduce more competition. Unbundling of the ESI and transparency are elements needed in this process (1). Also system operation and control is highly affected. The responsibility for the reliable operation of the power system is seen as a monopolistic function that should remain attributed to the system operator. However in an open "electricity market" this task is becoming increasingly complex. On the other hand the classical task of minimisation of system costs, is now left to the market players. The "system operator" is not a market player itself but is facilitating the market. This has already led to the definition of a new separate party : the "market operator".

It goes without saying that these developments have a major impact on practically all activities of SC39. Operational planning, the role of the control centre, models for measuring the BES performance, operation of large interconnected systems etc..., all these aspects are now put in a completely new perspective. First results of the work of SC39 in this field are already published very recently. But this is just a glimpse of the work still to be done.

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(1) This happens to have started in developed countries (US, UK,... at first) but exists also in other regions (Latin America, South-East Asia,...) where the introduction of competition could release financial constraints.

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