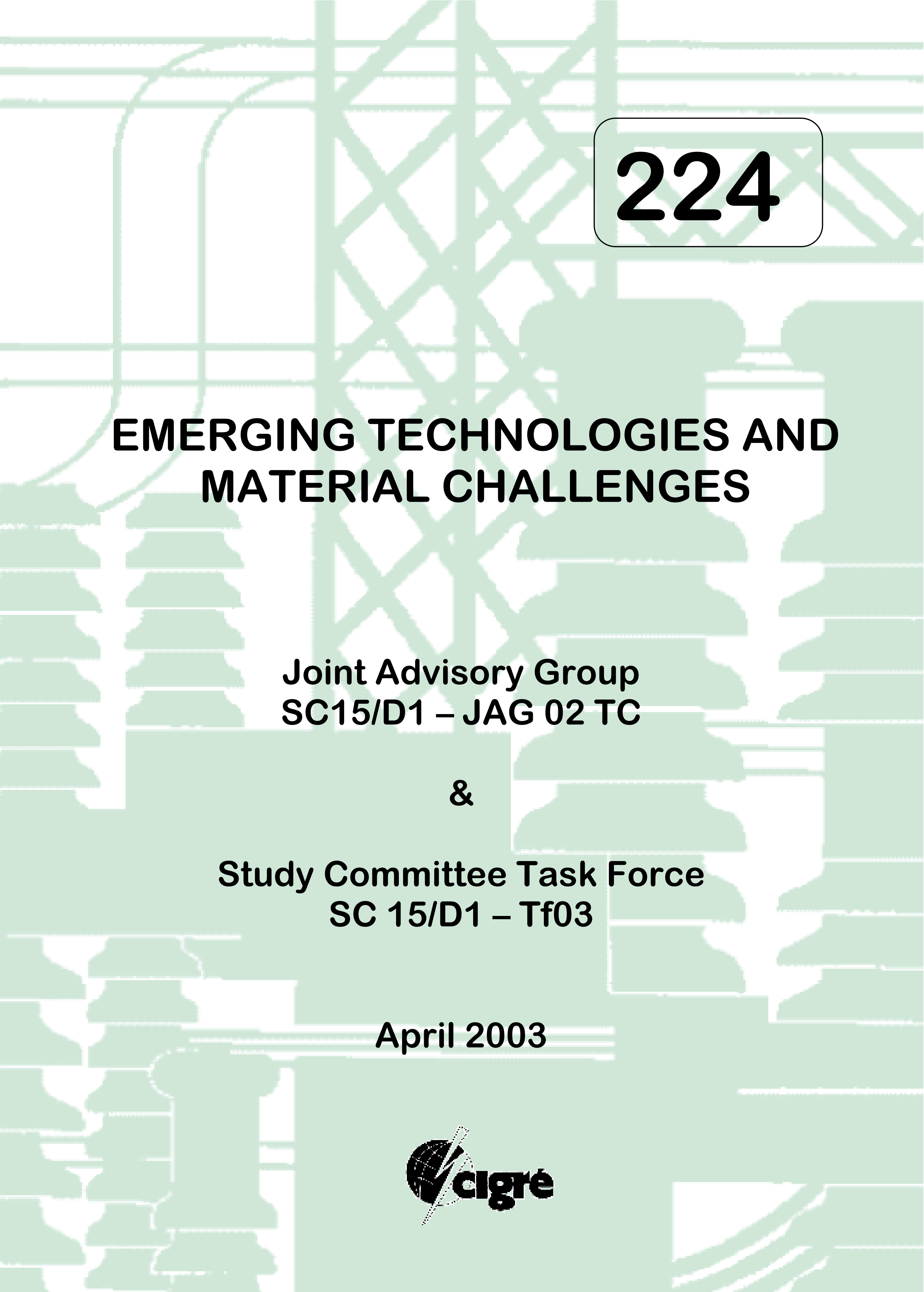

224

EMERGING TECHNOLOGIES AND MATERIAL CHALLENGES

Joint Advisory Group
SC15/D1 – JAG 02 TC

&

Study Committee Task Force
SC 15/D1 – Tf03

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Cigré Brochure

EMERGING TECHNOLOGIES
AND
MATERIAL CHALLENGES

Joint Advisory Group SC15/D1-JAG 02 TC
&
Study Committee Task Force SC15/D1-TF03

on behalf of the Technical Committee

for the 2002 panel “Electrical Power Systems 2020”

Contributors:

J.J. SMIT (NL, chairman JAG02 TC), B.M. PRYOR (UK, chairman SCTF03)*,
D. WALLIS (UK), A. HJORTSBERG (SE), A. PRICE (UK), B. DAVIDSON (UK),
D. AGORIS (GR), R. STEPHEN (ZA), A. BOLZA (IT), D. POVH (DE),
B. WAHLSTROM(SE), G. PHILIPPE(FR), R. BAEHR(DE), A. JANSSEN(NL),
A. ROBERT (BE),S. LARSSON (SE), F. GONZALO (ES), G. ZIEGLER (DE),
E. GOCKENBACH (DE), M. MUHR (AT), M. LAUBY (USA)

INDEX

EMERGING TECHNOLOGIES AND MATERIAL CHALLENGES

Joint Advisory Group ***SC15/D1-TF03-JAG 02 TC***

on behalf of the Technical Committee
for the 2002 panel `Electrical Power Systems 2020`

Contributors:
J.J. SMIT (NL, chairman JAG02 TC), B.M. PRYOR (UK, chairman SC15TF03)*, D. WALLIS (UK), A. HJORTSBERG (SE), A. PRICE (UK), B. DAVIDSON (UK), D. AGORIS (GR), R. STEPHEN (ZA), A. BOLZA (IT), D. POVH (DE), B. WAHLSTROM (SE), G. PHILIPPE (FR), R. BAEHR (DE), A. JANSSEN (NL), A. ROBERT (BE),S. LARSSON (SE), F. GONZALO (ES), G. ZIEGLER (DE), E. GOCKENBACH (DE), M. MUHR (AT), M. LAUBY (USA)

BACKGROUND AND OBJECTIVES

The Electrical Power Industry (EPI) is in a period of rapid change triggered mainly as a result of deregulation. This change is currently recognised within the proposed reorganisation of the CIGRE Study Committee structure. However, major on-going changes are foreseen over the next 20 years and beyond mainly as a result of new and emerging materials enabling prospective solutions in the energy services of future power networks. Developments being directed towards environmental friendliness, low energy loss, more compact design, intrinsic safety/reliability, intelligent solutions coupled with a greater move towards distributed generation and energy storage systems. On the other hand, customer pressure for continuous, reliable, high quality, low cost and environmentally friendly supplies is becoming dominant. The EPI must optimise these issues to the benefit of Society as a whole.

The initial suggestions to the Technical Committee (TC) proposed a 'visionary' CIGRE Group to oversee and monitor all of the changing issues. However, the TC conclusions were that it would first be preferable to highlight the issues within a special CIGRE Panel Session to be held at the August 2002 main Paris Session. SC15/D1 was given the task to organise this Panel on behalf of the TC. The main task of the joint advisory group JAG 02 TC has been to plan the Panel and to bring together the expertise of different SC's in this field. Several JAG meetings were organised with as regular members:- A. Bolza (Chairman SC21/B1), D. Povh (Chairman SC14/B4), A. Hjortsberg (Representative SC23/B3), A. Mallet (Representative SC36/C4), A. Janssen (Representative SC13/A3), S. Vitet (Representative for SC38/C5) B.M. Pryor (Special Reporter), B. Bernstein (WG15/D1.09-convener), J.J. Smit(Chairman), H. van Breen (Secretary). Members by correspondence were R. Stephen (Chairman SC22/B2) and G. Ziegler (Chairman of SC 34/B5).

This Paper is one of four contributions for the Panel Session and its purpose is to review the emerging technologies and material challenges that they present to enable introduction of newer concepts to more rapidly and more efficiently meet the challenges that will result from the drivers now facing the EPI. On the material side SC15/D1-TF03 reported on prospects for Energy services in 2020, however, later on, this was integrated into the present paper with contributions from different study committees.

*Power System Service, 22 Hall Close Whissendine, Rutland, LE15 7HN, UK

Keywords- Large generation - Gas infrastructures – Microturbines - Fuel cells - Renewable technologies - Energy storage – Transmission – Distribution – Transformation - System interfaces - Energy conservation – Materials – Financing - Research & Development.

ABSTRACT

The way in which electrical power companies operate has changed dramatically since the, almost world wide, power industry deregulation and this has, in turn, had a major influence on the role of the electrical power equipment manufacturing industry. Notwithstanding this the physical way in which electricity is supplied to end customers has changed little since deregulation. Electrical power systems still very largely operate in unison, as one large electrical, constant frequency machine where electricity generation is constantly attempting to match the ever changing loads. Perhaps the only major change from the concept of large power stations, remote from load centres and consequential integrated transmission systems, has been the available supplies of gas through existing gas networks. This has allowed gas-fired generation to be more readily applied which can be built quickly and placed closer to load centres.

However the traditional concept of Electricity Supply Networks is now continually being questioned as being the most suitable long-term means of moving foreword. It is believed their role is likely to change significantly over the coming years. This is due to a number of factors typically, economical drivers, environmental pressures, public opinion, customer needs and technology developments. With this background this Paper has attempted to review the current drivers and emerging technologies. It has also examined how material developments are likely to play a critical role in the evolution of the newer, emerging technologies.

Whilst we are now at the stage where cost, instead of engineering, is the dominant factor, it is believed that this situation will rapidly change to that where environmental concerns are dominant with costs second. Engineering however has a crucial role to play in ensuring that both of these objectives are met and, even more importantly, to ensure that society as a whole is appropriately serviced by the Electrical Power Industry. This is particularly relevant in developing countries where large numbers of the population currently have no access to electricity supplies.

This Paper has attempted to identify currently emerging technologies and the very necessary material developments and to assess the ways in which these will influence the supply of electrical power to customers over the coming 20 years.

The main conclusions reached suggest that there is a need for R&D to be coordinated worldwide and a major need to attract highly motivated, innovative, younger engineers into the electrical power industry to ensure that the coming developments are carried through and implemented as appropriate.

If nothing else, the coming 20 years and beyond, will be extremely challenging times for the Electrical Power Industry and it is believed that the pressures will be such that we can no longer continue pursuing 'traditional' approaches to solving the problems of societies needs for electrical energy.

It is believed that CIGRE has a major role to play in coordinating these developments over the coming years.

1. INTRODUCTION

It is now some 12 years since privatisation and deregulation occurred in the UK, the patten of deregulation has since been followed in many industrialised countries. Over this period of time very many significant changes have taken place in the way Electricity Utilities operate. Many have been split into smaller units in an attempt to introduce effective competition. During these changes it has been necessary for 'regulators' to be appointed to see 'fair play'. A spate of company acquisitions followed deregulation and this process is still ongoing.

The major change that has ensued has been in the way that electricity is promoted and marketed, this now being completely different from the way in which electricity was marketed prior to deregulation. However, not withstanding all of these developments there has been little change in the ways that electricity is physically produced, transmitted, distributed and delivered to customers. Electricity systems still operate as one huge interconnected constant frequency machine whereby the generation is continually trying to match the ever-changing load. The processes necessary to ensure that this machine operates continuously, and to provide the required degree of quality to customers, are extremely complex. Coupled with this many companies have been forced to reduce staffing levels and, perhaps unfortunately, engineering expertise has been targeted with the result that many companies have now lost significant technical ‘know how’. This is at a time when very many technological changes are beginning to come to fruition and engineering expertise will be needed to allow the electrical power industry to adapt to these changes.

The drivers behind the changes are many, but could probably be grouped into four main categories, financial, environmental, public opinion and technology development. Financial, because investors are no longer guaranteed long term returns by governments to finance large projects. Three-year returns on investments are now the norm. Environmental pressures to reduce deterioration of the planets eco-structure are becoming dominant and future technologies must be environmentally friendly. Public opinion is becoming a dominant force in many countries and the public’s views cannot be ignored, the electrical power industry has now to be able to justify its actions to the public. Lastly, technology development is now a very important driver, this has come about from the environmental constraints and financial pressures for technical infrastructure to provide a quick return on investments, i.e. they can be located near to loads and put into operation very quickly. Many of the newer technologies have in fact been around for many years but with the new drivers, together with advances in material developments, they are now becoming economically viable.

Coupled with the newer developments, the existing power systems are fed from large generation sites often located remote from loads. Many of the large generating units will have reached the end of their useful life in 20 years time and the question remains as to which technologies will be available to replace these large sources of power generation.

The purpose of this Paper is to examine and co-ordinate these technological changes, which could well have dramatic effects in the way in which electricity is produced and sold to customers over the coming 20 years.

It is of course important not only to focus on the needs of industrialised countries but perhaps even more important to focus on the needs of non-industrialised countries where a very large proportion of the worlds population still has no access to supplies of electrical energy.

Electrical Power Engineers have a vitally important role to play for society as a whole and it is hoped that by focusing on these drivers and developments that CIGRE may be able to co-ordinate the necessary expertise to allow the more rapid introduction of new concepts. We can no longer afford to wait the traditional 10-15 years before the widespread acceptance of new concepts.

2. ELECTRICITY PRODUCTION TECHNOLOGIES

2.1 Conventional Generation

The formation of large Nationalised integrated power systems in the 1950's resulted in the first reliable electricity supply for large sections of the population. The consequential dependence on electricity as a prime source of energy required the careful control and specification of the associated generating and transmission plant. Plant manufacturers developed new plant but generally to meet the specification of the large utilities.

During the period to the early 1980's, the trend was to continually increase the unit size of generators. These were sited to suit the needs of the transmission system, load centres and fuel sources. Central planning and estimation of demand ensured that surplus capacity was controlled but also maintained at suitable levels. Political influence also had a significant effect on the choice of plant, particularly on the type of fuel being used.

In the early 1990's, politics again caused large changes to occur in the Electricity Supply Industry (ESI). Privatisation of the service industries started in the UK and in 1990, it was the turn of the CEGB. As is now the "norm" for this process, Transmission was split from Generation and individual generating companies were formed. In the UK this coincided with permission to burn natural gas for power generation.

Since the early 1990's in the United Kingdom there has been a rush to build gas fired combined cycle gas turbine plant. This technology has rapidly developed over the last 10 years and now accounts for a large proportion of the plant being constructed worldwide.

The rapid development of gas turbines for power generation has curtailed the development of ever-larger machines in centralised power plants. Developers, in locations of their choice, are now building plants without reference to any overall system plan. Market forces and not system requirements drive investment decisions.

However, political interference is still critical to the future development of power generation. International protocols are being agreed that can influence future plant choices. Emission levels for Sulphur and NOx can now be traded in many markets and consumers are being offered "green" power generated by renewables. The need for reliable and environmentally clean power will provide the biggest challenge to the industry over the next 20 years and beyond. It is said that nuclear meets this challenge and that new installations will be necessary in the coming years to ensure availability of adequate power supplies, on the other hand it is also argued that the role of nuclear power might be expected to reduce during this period. Public opinion is likely to play a major role in such decisions.

Renewable energy, particularly from wind and tidal power will become more significant on the power system and the role of nuclear power during this period might be expected to reduce. Large centralised power plants are likely to be replaced by a more distributed generating system. Co-generation plant may also become much more common although this type of plant may need government support to be viable.

Novel technologies are being developed to take advantage of these changes. Energy storage works well in conjunction with wind power and helps with system stability. Solar and geothermal power will be developed in suitable areas and large-scale hydroelectric schemes will begin generating within this period.

Significant changes are also taking place in the type of generators being used in the power plants. The rapid development of gas turbines for distributed power generation has curtailed the development of ever-larger machines and an increased emphasis has been placed on the development of air-cooled generators.

Historically air cooled generators have always covered the lower power range. The convention was that air cooling would be used on ratings to 100 MVA; hydrogen for ratings in the range of 100 - 300 MVA with hydrogen cooling of the rotor winding and stator core together with water cooling of the stator winding being used for rating above this.

They are particularly attractive because air-cooling represents the simplest design, requires no ancillary equipment and incurs the lowest operating and maintenance effort. However, experience of long-term operation is extremely limited.

Efforts continue to develop even larger air-cooled generators. The latest models have ratings over 500 MVA and stator terminal voltages of 23 kV. Although the drive to obtain a low capital cost has been of primary importance to date this may not be the case in the future, particularly where the gas turbine, steam turbine and generator are on the same shaft. With this arrangement reliable operation of the generator is much more important than where it is part of a multishaft arrangement.

With the continual increase in gas turbine rating it may be that the current use of air-cooled generators is only a transient “fashion”. Single shaft 50 Hz Combined Cycle units are now being offered with gross outputs of over 600 MW. At this rating the generator type offered is likely to revert to the highly developed “conventional” machine with hydrogen cooled rotor and stator core and water cooled stator winding.

Whatever type of power plant is to be built for the future the evidence today suggests that its life will not be based on its technical capability but on its economic potential or political drivers.

2.2. Fuel Delivery Infrastructures

Traditionally power from plants using primary fuels, e.g. coal, oil, hydro, nuclear, has been ‘delivered’ via electrical transmission systems. It has long been argued that gas is a prime fuel, which in most industrialised countries has its own delivery network, so why not use this and apply generation more local to the loads. In the past, availability of suitable quantities of gas, together with pricing structures, had made the option both impracticable and uneconomic. With the deregulation of previously nationalised industries some 12 years ago reinforcement of gas supplies ensued and suitable quantities became available for power generation. Revised pricing structures made such an option viable. In parallel with this generation technology moved ahead and packaged, low cost combined cycle generating stations became available. Many independently operated units have now been installed. This was the so called ‘dash for gas’ which, in order to protect other industries led, in some areas, to governmental restraints on the building of new CCGT plants. However, the feasibility of such options remains and it is believed that many are likely to be built in future years.

History tells us however, that it is unwise to rely on one source of fuel and we need to diversify our options. Renewable sources of energy are likely to be located in less populated areas and transmission systems will still be required to carry supplies to load centers.

Many of the newer technologies are small in size and will be located either within distribution systems or at customer’s premises. Fuel delivery infrastructures will be required to supply these, and currently existing gas supply networks provide the fuel source.

Hydrogen is an ideal fuel for many applications but, as yet, no hydrogen fuel delivery infrastructure exists and many problems have still to be overcome, mainly due to the fact that compression storage requires very high pressures. Piped networks do not currently exist. Hydrogen can be produced from other fuels e.g. natural gas, by reformers, but problems of gravity and pollution by-products still need to be overcome.

Methanol is another fuel that could be used for electrical power generation. It is a liquid and could readily be transported using similar technologies existing for gasoline. However, methanol is highly toxic, highly flammable and burns with a colourless flame. These handling problems still need resolution.

Existing gasoline supplies could be used as a fuel to provide hydrogen from local reformers.

Liquid Petroleum Gas supply networks already exist and again could be used as a direct fuel source or indirectly to produce hydrogen with a reformer.

Solar power could either be produced from large remote sites, in which case transmission networks would still be needed to transport the electrical energy, or it could be produced at consumers premises, but energy storage and back-up supplies would still be needed.

For some of the newer fuel sources many delivery infrastructure problems remain to be solved and this fact alone could well limit the use of some of the now emerging electrical power generation technologies.

Perhaps the ideal electrical power generation technology would be one that could readily be adapted at low cost to utilise any of the available fuels.

2.3. Microturbines

Microturbines are small-scale turbines that operate on the Brayton thermodynamic cycle. The definition of small-scale is not precisely defined but it is common practice to regard microturbines as power generating systems in the range of 25 kW to 1MW. A microturbine system has high power density and is extremely compact, having all the hardware components self-contained in a small footprint enclosure. A typical microturbine system includes a compressor, a combustor, a turbine wheel, an electrical generator with power electronics, and a set of heat exchangers. To keep volume to a minimum and to increase system reliability, the microturbine is commonly designed on a single shaft with the compressor wheel, the turbine wheel, and the electrical generator, all mounted on the common shaft and rotating at high speed. To further increase system reliability the single shaft can be mounted on air bearings with virtually no mechanical wear and no need for oil lubrication.

In a microturbine the compressor feeds process air into the combustor where fuel is added and continuous combustion takes place. The hot gases are then expanded in the turbine where the energy is converted to mechanical rotational energy, necessary to drive the compressor and the electrical generator. In a regenerative Brayton cycle the expanded hot gases exiting the turbine are used to preheat the gas coming from the compressor. This process reduces the required energy input from the combustor, thus increasing the system efficiency. An additional heat exchanger cools the exhaust gases, producing valuable heat in the form of hot water or steam, and thus increasing even further the total system efficiency. Existing microturbines that use a recuperator or regenerator can reach 25 to 30 percent electrical efficiency, and those that use an additional heat exchanger, to produce heat in a combined heat and power mode, can reach total efficiency greater than 80 percent.

Microturbines are ideal resources for application in the stationary distributed energy generation, not only because they are compact in size, but also because they have high reliability, low installation operation and maintenance costs, and relatively low emissions. Currently, the installed cost for a microturbine ranges between $500 and $1000 per kW, the operating and maintenance costs range between $0.005 and $0.01 per kWh, and NOx emissions are as low as 5-10 ppm. Today, there are several microturbine manufactures that make units commercially available in the 30-100 kW electrical power range, and install them to serve customers in the commercial, industrial, institutional, and residential sectors. Typical applications in the commercial sector are office buildings, hotels, restaurants, retail stores. In the industrial sector the applications are in the oil and gas, food, chemical and agricultural processes. In the institutional sector, they are schools, hospitals and government buildings, whereas in the residential sector the applications are multi-apartment buildings and medium-size communities.

The applications are diverse and the microturbine operating modes reflect the individual customer needs, that can vary from high electrical power quality, to high thermal loads, to high reliability and availability. The different microturbine applications are commonly identified as: continuous generation, peak shaving, back-up power, remote power, combined heat and power (CHP), waste-gas and biofuel power generation, and premium power.

In continuous power generation the microturbine provides power for over 70% of the time for users that need both quality and reliability and cannot rely completely on the power grid. The users are willing to spend more for generating their own power but the microturbine generating costs may not be excessive.

In peak shaving applications the users operate the microturbine in parallel with the grid during high power demand, usually a few hours in the middle of the day when the demand and the utility prices are higher.

Users that require 100% power availability, such as hospitals, install back-up power generators. In case of an outage, the unit must provide power to the essential equipment. A microturbine is rarely used for such application alone, because its cost is too high compared to internal combustion driven generators and its performance is best at steady state operations and not at cold start up conditions.

In remote power applications the microturbine runs in stand-alone mode, as the power grid is not available. Typical users are the oil and gas producers. In such applications, it is essential that the microturbine be highly reliable and be able to burn liquid fuel that can be easily delivered to the remote locations.

When the users have needs for both electrical and thermal power, then the microturbine includes a heat exchanger and operates in a combined mode to produce electrical power and thermal energy in the form of hot water or steam. This is the most convenient way to apply the microturbine because the system efficiency is the highest. The recovered heat is used in heating and cooling industrial processes and in residential and commercial applications it can be conveyed to efficiently heat and cool office and apartment buildings. The potential for microturbine CHP application is large and partially still untapped.

The use of a microturbine to burn waste-gas and biofuel for power generation is becoming more and more frequent due to the advantageous economics of these applications. In general, the fuel is free or very inexpensive, but it can be a low-energy-content and dirty fuel, available in gas liquid or solid phase, and typically available only in remote locations. Low-maintenance and fuel-versatile microturbines are available for such applications.

Industrial users that must have perfect alternating current waveforms or well-controlled direct currents require premium power. Generally, the users are running well-controlled processes and use sensitive electrical equipment. The same users have back up power needs and commonly install UPS (uninterruptible power system) equipment to solve both problems. A microturbine-based premium power system can conveniently replace a UPS by necessarily including power conditioning, backup generation, and energy storage to carry and follow the loads. These features allow for more flexibility in managing processes that require high quality and high reliability and availability. But the decision to invest in a premium power system is always based on an economic evaluation, where the value of the system has to be considerably higher than the life cycle costs. The user and the product manufacturer have to find optimum solutions that yield the best possible cost-performance ratio. It is evident that the market for premium power is growing as the number of consumers operating highly automated processes is on the increase. Microturbines with full power controllability and energy storage devices with short-time storage capability like flywheels and high-density capacitors can contribute to improve power quality. In an ideal premium power system normal and protected AC loads as well as DC loads can be supplied with power on the low voltage side.

The premium power system consists of a secondary substation and local microturbine power generation units. The secondary substation includes an integrated system for mitigating voltage dips or short-time outages. A low voltage fast switch between the unprotected and protected loads isolates the two parts of the busbar in the event of a fault. Both short-time energy storage devices and local power generation is interconnected via a DC bus. Use of a common DC bus leads to a smaller number of components and allows connection to the grid via one common inverter. The DC link can be configured to enable different complementary units to be easily linked together. As microturbines have limited load-following capability, additional short-time energy storage units are necessary to guarantee stable system operation. The combination of a microturbine and flywheel, for instance, guarantees good load-following performance. The integrated solution results in considerably lower life cycle costs than with traditional, non-integrated versions.

The use of microturbines for power generation is still a young industry. We can expect a substantial further development of this technology. A great deal of development effort is spent today on three key aspects: increase cycle efficiency, increase system reliability, and reduce equipment costs. Advanced materials are under study in order to increase the turbine operating temperature, reliable high speed generators and frequency converters are constantly developed, and new manufacturing processes are implemented to reduce costs. As the volume of production is increased we can expect a continuous reduction of cost and relative competitiveness of microturbines for distributed power generation.

2.4 Fuel Cells (FC's)

Fuel cell technology is not new; the principles have been around for some one hundred and fifty years. Earlier attempts to find commercial applications have been unsuccessful mainly due to the lack of appropriate materials and commercial needs.

Over the last 10 years major progress has been made in reducing costs and on improving the technology. There are still major hurdles to overcome however, these being fuel toxicity, storage, electrolyte poisoning, and lack of fuel infrastructures. Notwithstanding these current technologies are still significantly cheaper than fuel cell alternatives.

One of the main drivers for the technology has been the advent of the Kyoto protocol. In many countries it is the legislation surrounding this that is forcing reductions in atmospheric emissions. These pressures have been particularly relevant in the automotive industry where, whilst low emission technologies have been developing, the number of low emission vehicles is significantly lower than required. Fuel cells could well start making an impact in the automotive sector around 2004-05.

The use of distributed generation (DG) for stationary power applications is growing rapidly with estimates in some areas being as high as 20-30% by 2003. The major drive for DG in industrialised countries has been the growth of the digital economy that requires high quality and high reliability power supplies. Whilst micro-turbines are penetrating the market FC's are also likely to be serious contenders. Trial installations in Japan are already under way and have a good chance of success due to the relatively high price of electricity in Japan.

There are currently five competing FC technologies all of which have pros and cons but, as yet, there are no clear contenders for either stationary or mobile power generation.

A brief description of the technologies follows.

2.4.1. Phosphoric Acid Fuel Cell (PAFC)

The PAFC's are the most mature of the technologies and have been under development for 15 years. The only real application is for stationary power uses, they are ideal for small and mid sized power plants i.e. hospitals, airports and hotels etc. where a constant and uninterrupted power supply is important.

The PAFC uses liquid phosphoric acid as the electrolyte. Hydrogen is the ultimate fuel for reaction but natural gas, LPG and methanol can be used as a raw input and converted to hydrogen using a reformer.

Advantages: -
    Resistance to impurities.
    Allow multiple fuel options and can use less expensive catalysts.

Disadvantages: -
    Low current due to cathode kinetics and power output.
    Lower efficiency.
    Large size and weight.
    Corrosive electrolyte.

2.4.2. Molten Carbonate Fuel Cell (MCFC)

The MCFC has also been under development for 15 years and is suitable for large power applications particularly for base load power generation.

It uses a molten carbonate salt mixture as its electrolyte and it can use a variety of fuels.

Advantages: -

High operating temperature allows for combined heat and power applications and high efficiencies.
Design does not require expensive components.
They are tolerant to impurities.

Disadvantages: -

Molten carbonate electrolyte is highly corrosive.
Corrosion of the cell components adds to capital costs, making them more expensive than the PEM.

2.4.3. Solid Oxide Fuel Cell (SOFC)

The long start up time does lend to the suitability for power generation. Typical outputs average 5MW with 65% efficiencies. The technology is currently less well developed than that for the PEM fuel cells but nevertheless it is believed that they could enter the commercial market as soon as 2004. This fuel cell has set the industry record for continuous operation.

The SOFC's have solid metal oxide, usually Zirconium with a small amount of Yttrium electrolyte. A variety of hydrocarbon fuels can be used such as gasoline, methanol, and even carbon monoxide. They can also reform natural gas internally.

Advantages: -

They are the most efficient fuel cell electricity generator for carbon-based fuels, e.g. natural gas.
Their high operating temperature makes them suitable for co-generation applications.
They do not contain noble metals and do not utilise liquid electrolytes.
Most suitable for base load generation.

Disadvantages: -

The high operating temperatures, app. 650°C, require specialised and exotic materials.
High material and production costs.
The high temperature also leads to material oxidation, enhanced corrosion and breakdown of components.
Start up is very slow hence they are not suitable for smaller applications below 1 kW.

2.4.4. Polymer Electrolyte Membrane (PEM)

The PEM is probably the most versatile fuel cell as its output can vary to meet changes in demand. It can be used for both automotive and power generation, albeit at relatively low power levels. In view of its potentially small size the PEM can be used to power portable appliances such as laptops and mobile phones.

The PEM fuel cell consists of two electrodes, the anode and cathode separated by a polymer membrane electrolyte. The ultimate fuel for the PEM electrode is hydrogen.

Advantages: -

Quick start up and load following.
Solid electrolyte reduces corrosion and the cell is simple and can be made small.

Disadvantages: -

Expensive catalyst is required.
Highly sensitive to fuel impurities.
No infrastructure for hydrogen storage or delivery.
The refining technology has yet to evolve.

Further research and development is required on suitable reformers and methods of reducing costs in manufacture.

2.4.5. Direct Methanol Fuel Cell (DMFC)

The applications of DMFC's are likely to be many but because of the low operating temperature they are the ideal choice for small portable appliances.

The DMFC is similar to the PEM fuel cell in its construction. It differs in that the fuel used is direct methanol.

Advantages: -

Methanol is a readily available fluid, no reformer is required.
Methanol handling procedure already exists.
The start up temperature is around 20°C.

Disadvantages: -

Methanol is toxic and can cause blindness; it burns with a clear flame so additives would need to be introduced.
Platinum catalyst is susceptible to poisoning and is very expensive.
Fuel leakage from anode to cathode reduces performance.

Until there is a clear winner between the hydrogen and methanol fuel cells, many companies are focusing efforts in both areas.

2.4.6. Conclusion

The first major widespread commercial applications are likely to be in small appliances, rapidly followed by use in electric vehicle hybrid power applications. Widespread application in the EPI may take typically 10 years. Much effort is still required on basic fuel infrastructures, particularly for hydrogen.

As the technology matures however, further applications will increase and relative costs will reduce, there can be little doubt that within 20 years, fuel cell technology will play an important role in the production of low polluting, high quality supply of electrical power to the benefit of users and society as a whole.

2.5. Renewable Technologies

2.5.1. What is Renewable Energy?

Renewable energy (RE) is any source of energy that can be used without depleting its reserves. These sources include sunlight or solar energy and other sources, such as wind, wave, biomass and hydro energy, which are indirectly derived from solar energy. Note: If the organic matter has been produced sustainably, then it is considered as being a renewable energy resource.

Fossil fuels such as coal, oil and gas come from biomass that was produced in the distant past and has been transformed by geological activity. World reserves of fossil fuels are finite and are being gradually depleted; they are therefore referred to as non-renewable energy resources. Uranium for the generation of nuclear energy is not a fossil fuel, but still requires the depletion of finite physical reserves, so it is included as a non-renewable energy source.

Some geothermal resources may be regarded as renewable because they are derived from energy sources deep within the earth's interior. These sources are so large that the rate of depletion by a geothermal energy extraction project is negligible. Projects based on using the remnant heat stored in shallowly placed igneous rocks may be non-renewable. However, the use of energy from such sources does not produce greenhouse gases.

Another renewable resource, tidal power, results from a harnessing of tidal currents, which are caused mainly by the gravitational pull of the moon on the oceans as it circles the earth.

However, the various renewable energy technologies are not uniformly mature or cost effective, and most of them still have a significant way to go before they are competitive with fossil technologies, especially for power generation purposes. This will demand intense further R&D efforts.

2.5.2. Advantages of Renewable Energy Sources (RES)

Renewables can supply a significant portion of the world's energy needs, creating many public benefits, including environmental improvement, increased fuel diversity and national security, and economic development. However, these benefits are often not reflected in the prices paid for energy, placing renewable energy sources at a severe disadvantage when competing against fossil fuels and nuclear power.

RE provides immediate benefits by avoiding the environmental impacts of fossil fuels. Using fossil fuels to make electricity dirties the atmospheric air, consumes and pollutes water, hurts plants and animal life, creates toxic wastes, and causes global warming. Air pollution is an especially serious problem for which electricity generation bears substantial responsibility. One of the air pollutants, fine particles, may be responsible for 64,000 deaths each year - more than the number of people killed in automobile accidents. Other important pollutants include SO_2, NO_x, and toxic metals.

Power generation is also a leading source of CO_2 emissions, the key heat-trapping gas that is causing global warming. Although uncertainties remain about the timing and size of impacts, there is strong evidence that global warming effects could be severely damaging to both people and wildlife. The warming predicted for the next several decades (without action to reduce CO_2 emissions) could destroy many coastal wetlands, cause more frequent extreme weather events, put crop production under great stress in some regions, and disrupt public health and ecosystems.

RES can also help replace nuclear generation and reduce its safety, environmental and economic risks. The pollution and other problems associated with fossil fuels place a burden on the worldwide economy also. The greatest economic impacts take the form of higher health care costs, missed work, and lost lives. According to several studies, such health costs may amount annually to hundreds of billions of Euros. Increasing RE use can help reduce these health costs and also lower the costs to industries and consumers of complying with environmental regulations.

By broadening the mix of electricity sources, renewables can make any country that possesses some or all of them less vulnerable to volatile fuel prices and interruptions to the fuel supply. Renewables, like wind and solar that do not depend on fuels, are not subject to price fluctuations, such as the huge leaps and falls in oil and gas prices seen in the 1970s and 1980s. And since they are locally produced, they are not as vulnerable to supply interruptions from outside the region or country.

RE technologies can help create jobs and generate income. A number of regional and national studies have found positive net job impacts from increasing RE use. RE technologies also have enormous export potential. It must be also mentioned that, some RE technologies can be sited in or near locations where electricity is used. This practice, called distributed generation, can avoid costly expenditures on transmission and distribution equipment. Distributed generation can also improve power quality and system reliability.

2.5.3. Technology Description

2.5.3.1. Small-scale Hydropower

With the expansion of centralised, conventional generation many small-scale hydropower sites were abandoned. Environmental concerns have now re-awakened interest in the technology, and many incentives are offered all over the world to increase small-scale hydro deployment.

Small-scale hydropower schemes (typically those with installed capacity of <10MW) generate electricity by converting the power available in flowing water in rivers, canals or streams. The principal requirements are: -

a suitable rainfall catchment area, and a hydraulic head;
a means of transferring water from the intake to the turbine (e.g. a penstock);
a turbine house containing the power generation equipment and a valve gear, needed
to regulate the water supply;
a tailrace to return the water to its natural course;
a mechanical or electrical connection to the load to be supplied

Large-scale hydropower schemes follow the same principle of operation, but include large dams and storage reservoirs to retain water for generation as required to match demand, which have a major impact on ecology.

Pumped-storage hydropower involves the pumping and discharge of water through turbines between an upper and a lower reservoir. Thereby, generation can be matched to the demand, with benefits of rapid peak load response and network voltage stabilisation. However, such systems are net energy consumers, and should not be considered as renewable projects.

The small-scale hydropower technology is efficient and highly developed, with many schemes and suppliers existing in the parts of the world with an exploitable resource. Projects are characterised by long life and low operating costs, with the bulk of their expenditure occurring during construction.

2.5.3.2. Wind Energy

Whilst wind driven rotor technology dates from the 5th century BC, the Dutch and English considerably improved the technology in the 19th century. Current technology development was focused in California, but the incentives that gave a rapid growth in the early ‘80s were gradually removed and the market has been largely stagnant since. From 1988 the fastest growing market has been in Europe.

The rotor of a wind turbine can be set on either a horizontal or a vertical shaft. Horizontal axis wind turbines (HAWT) dominate throughout the world, since they have proven more cost effective than the vertical axis machines (VAWTs). Figure 2.1. shows a generic HAWT system.

The WT components shown in the figure could be broken into 4 basic subsystems:

a rotor, with blades and hub which attach to a low speed drive shaft together with some method of controlling the pitch of the blades;
a drive train, including a gearbox and generator, shafts and couplings,
a method of keeping the rotor orientated to the wind and motor and gears;
a tower and foundation that supports the rotor and drive train; and
electrical controls and cabling, and instrumentation for monitoring and control.

A number of such wind turbines are mounted in close proximity and are interconnected to form a wind farm. This is then usually connected to the local distribution network.

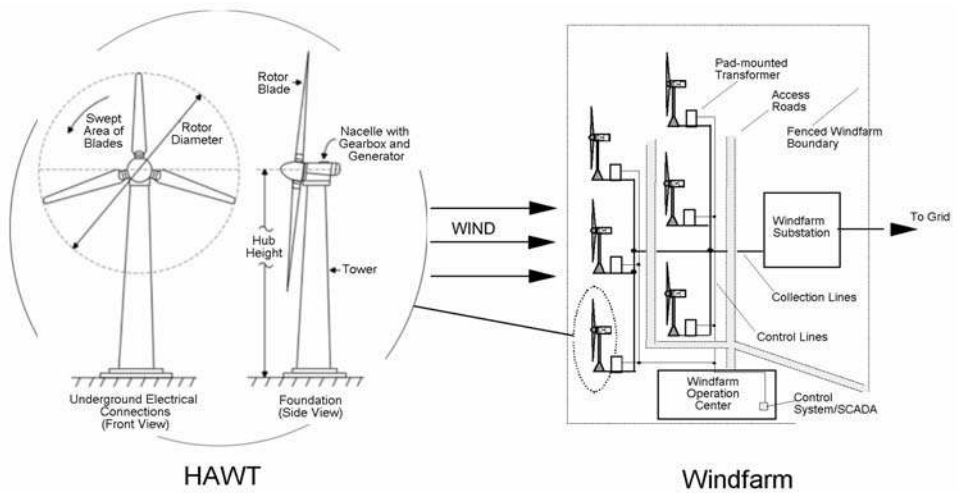

Figure 2.1. Horizontal axis wind turbine and wind farm system schematic

The typical hub height for a modern 600 to 800 kW WT is 45m with blade radius up to about 25m. WTs must be spaced sufficiently apart so that the ‘wake effect’ from one turbine does not greatly affect the wind flow passing other WTs in the wind farm. The system cost effectiveness has improved by a factor of 3 over the last 10 years. Reliability is now also very high with the machines available for generation for more than 96% of the time.

The technology is at a stage where it can deliver large-scale implementation reliably and at a price approaching that for conventional plants. Wind energy markets can be classified based on the end-use application of the technology. Wind energy projects, which are more financially viable in "windy" areas, due to the fact that the power potential in the wind is related to the cube of the wind speed are common for isolated grid applications, however the largest market potential is with interconnected grid-connected applications.

2.5.3.3. Photovoltaic Power

A photovoltaic (PV) system consists of one or more PV modules, the basic element of PV-systems. One PV-module consists of a number of PV solar cells, which convert the light into electricity by means of the photovoltaic effect. When light is absorbed by a solar cell, electrons are released and move according to the internal electric potential, and when a load is connected across the contacts an electric current flows. The voltage across a solar cell depends primarily on the design and materials of the cell, whilst the electrical current depends on the incident solar irradiance and the cell area.

Single-crystal silicon (Si) is the most common semiconductor material used in making PV cells, as is also polycrystalline silicon (in the form of a thin film on a base of glass or plastic). PV modules can also be made of thin films of amorphous silicon, while combinations of other materials (e.g. Cd, Cu, In, Ga, Se, Te) are also used lately. The ratio of the electricity produced by a solar cell to the incident solar irradiance is the PV cell efficiency. Typical cell efficiencies range from less than 5% for the early thin film cells to more than 24% for the advanced crystalline silicon cells.

R&D is continuing worldwide to increase the efficiency of solar cells and to reduce their manufacturing costs. PV modules are made with outputs ranging from a few Watts to more than 100 Watts of DC electricity, and are connected together in series and parallel to form an array that produce the levels of voltage and current required by the load. Other system components, such as cabling, batteries, battery charge controllers, inverters, etc., known as *Balance of System* components (BOS), provide the necessary interface with the grid or the specific application.

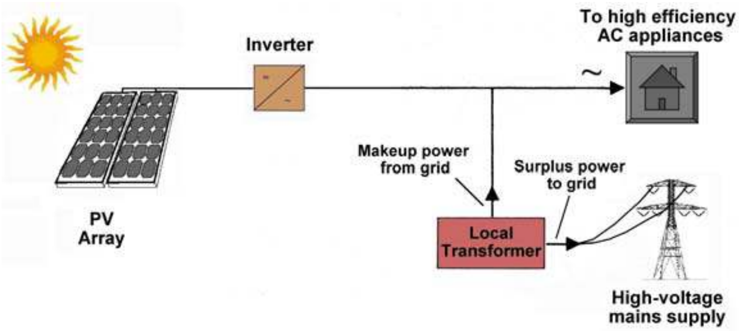

Figure 2.2. Grid-connected photovoltaic system schematic

PV's first major application was to power satellites in the late 1950s, where simplicity and reliability were paramount. In addition to PV's ongoing use in space, its present-day cost and performance also make it suitable for many grid-isolated applications. The technology stands on the threshold of major energy-significant applications worldwide, such as the development of grid connected PV power generation (figure 2.2.). Of particular interest is the integration of PV modules into buildings, where they can also act as architectural building cladding elements.

2.5.3.4. Solar Thermal Electricity

Solar thermal power systems use concentrated sunlight to heat a working fluid that generates electricity in a thermodynamic cycle. Due to the strong dependence of concentrating systems on direct radiation, they are options predominantly for sites where radiation levels exceed 1700kWh/m^2 per year, which tend to be in arid or semi-arid regions. Three general approaches have received development attention.

The first, called the *power-tower* configuration, employs a field of mirrors that track the sun and reflect sunlight to a central receiver atop a tower. The working fluid is circulated through and heated in the receiver, and then drives a conventional turbine. The hot fluid can be stored to decouple the collection of the solar energy and the generation of electricity, enabling the plant to be dispatched like conventional plants. Several experimental or demonstration power-tower systems have been built, but the commercial prospects for this approach cannot be accurately projected yet.

The second approach employs a field of sunlight-tracking *parabolic troughs* that focus sunlight onto their axis. A glass or metal linear receiver is placed along the axis, and a working fluid is circulated through and heated in the receiver. The fluid from a field of troughs passes through a central location where thermal energy is extracted via a heat exchanger and then used to drive a conventional turbine. This configuration lends itself well to hybrid operation with fossil fuel combustion.

Another approach employs *parabolic dishes*, either as single units or in fields tracking the sun. A receiver is placed at the dish focal point to collect the solar energy and heat a working fluid, which then drives an engine attached to the receiver. In contrast to the other two approaches, which are targeted at plants in the 30-plus MW range and use a single turbine fed by all collectors, each dish/engine unit is a self-contained power system typically sized at about 10 to 30 kW, with potential for hybridization. Dish systems using Stirling engines have been deployed since the early 1980s.

2.5.3.5. Geothermal Energy

Geothermal energy is the natural heat of the earth transferred by fluids (steam, water) that absorb the heat within crystal rocks. As is estimated, the stored energy in the upper 3km of the crust amounts to some 43x10^{24} Joules, which would be enough to cover the world energy demand in the next 100,000 years. Such calculations indicate that very large quantities of energy can be extracted from the stored component of geothermal energy, which although is non-uniform, its distribution is globally widespread.

Geothermal electricity can be used for both base load power and peak load demand, as required. In many parts of the world, geothermal electricity is competitive with conventional energy sources. Over 8 GW of installed geothermal electricity generation capacity currently exists in 21 countries around the world. The electricity generated there is about 49 TWh/a (the direct use amounts to about 51 TWh/a).

Other concepts, such as the direct exploitation of heat from magma bodies and energy extraction from geopressured formations, remain longer-term options.

2.5.3.6. Biomass Electricity

To generate electricity from biomass two systems, of quite different character, need to work together, namely a supply system that produces, collects and delivers the fuel, and a power station that generates (and sells) the electricity. Bio-power is different from other RES in that the primary energy source encompasses a variety of feedstocks with wide ranging properties. Four categories of fuel resources can be distinguished: wood and agricultural residues, energy crops, and wastes (including MSW). Conversion technologies can be categorised into the following three groups.

Conventional steam cycle: Biomass is burned (using either grate or fluidised-bed combustion, a third possibility being the suspension firing) in excess of air to produce heat, which is in turn used to raise high-pressure steam in a boiler.

Gasification and other advanced processes: Advanced conversion processes offer methods of power generation with higher efficiencies than combustion-based steam cycles, which are achieved by converting first the solid biomass to liquid or gaseous fuels and then burning these intermediates in engines or gas turbines.

The size of a biomass power plant is constrained by the availability of the resource, the maximum being around 30 MW_e (up to $70MW_e$ in heavily wooded areas). Plants using conventional steam cycles at such small scales have conversion efficiencies of only 25%. Gasification or pyrolysis can raise it to over 36% now, and 45% in the medium to long term. The capital costs per kW_e produced are expected to be comparable with steam plants.

Co-firing with fossil fuels: This has been receiving increased attention recently. The concept is to fire a proportion of biomass with a fossil fuel in existing power plants.

2.5.3.7. Wave Energy

Wave power results from the harnessing of energy transmitted to waves by winds moving across the sea surface. Wave power generation devices fall into two general categories, fixed and floating. Fixed devices, mounted either to the seabed or the shore, have significant advantages over floating ones, particularly in the maintenance area, but the number of suitable sites available for such devices is limited.

The Oscillating Water Column (OWC) generates power in a two-step process. As a wave enters the column, it forces the air in the column up past a turbine, increasing the pressure within the column. As the wave retreats, the air is drawn back past the turbine due to the reduced air pressure on the ocean side of turbine.

TAPCHAN (tapered channel) systems consist of a narrowing channel that causes the waves to increase their height as they move towards the cliff face that eventually spills over the channel walls and into a reservoir positioned several metres above mean sea level. The kinetic energy of the moving wave is converted into potential energy, as water is stored in the reservoir, which is then fed through a hydro-turbine. The low tidal range and suitable shoreline required limit the replicability of this device.

The Salter Duck and other floating devices generate electricity through the harmonic motion of the floating part of the device. In these systems, the devices rise and fall according to the motion of the wave and electricity is generated through their motion. The Salter Duck is able to produce energy extremely efficiently, however its development was stalled during the ‘80s due to a miscalculation in the relevant costs.

2.5.3.8. Tidal Energy

Tidal energy exploits the natural rise and fall of coastal tidal waters caused principally by the interaction of the gravitational fields of the Sun and Moon. Some coastlines, particularly estuaries accentuate this effect creating tidal ranges of up to 11 m.

The modern version of tide mills is a semi-permeable barrage built across an estuary, allowing floodwaters to fill an impounded basin via a series of sluices. At high water the sluice gates are closed, creating a head of water on the ebb tide. Releasing the water through a series of conventional bulb turbines generates electricity. In future schemes the energy yield would be enhanced by pumping water into the estuary on the flood tide (‘flood pumping’), thereby increasing the volume of water released through the turbines on the ebb tide.

A variant is tidal stream (or marine current) technology, aiming to exploit the strong tidal currents found in shallow seas, particularly where natural constrictions exist, e.g. around headlands or between islands. This technology is in its infancy. Devices similar to submerged wind turbines would be used to exploit the kinetic energy in tidal currents. Only one of these devices exists, a 5kW machine operated in Japan since 1990. A 10kW machine was deployed in the UK in 1993 and is still being assessed.

Tidal energy potential has been investigated by a number of countries, notably France where a 240 MW plant was built on the Rance estuary during the 1960’s and has completed 30 years of successful operation. A 400kW device was built by the Russians near Murmansk, followed by a 17.4MW device built by the Canadians at Annapolis, while a series of small plants have been installed in China. None of these countries have progressed to further development.

2.5.4. Market Overview and Trends

2.5.4.1. Current Status

Worldwide, traditional renewable sources of energy are estimated to meet between 15 and 20% of final energy demand – predominantly from hydro-electricity, wood, biomass and geothermal. It is widely accepted that RES have the potential to meet an increasing proportion of global energy needs over the coming decades, but the technologies, markets and supply industries that will contribute to this growth are at widely differing stages of development.

Some, such as traditional hydro-electricity, are well established, whilst others, such as wind with around 9 GW installed worldwide, are being deployed commercially but are not yet fully competitive. Other RE technologies, such as energy crops, are at the demonstration stage, and still others require substantial R&D before they could be demonstrated and deployed. PV is finding competitive commercial application in niche markets and has enormous long term potential but needs further R&D and market development if it is to become competitive on a widespread basis.

Renewable energy technologies (RETs) tend to have high capital costs since they use dispersed low energy-density sources such as wind and low operating costs because fuel is free or low cost such as waste. Studies by the International Energy Agency have shown that promotion programmes over the last decade, including R&D, demonstration and market stimulation, have typically reduced the capital cost of RETs by about half. A further 50% reduction is projected for the next decade, although substantial variations around this average are expected.

Costs are therefore expected to continue to fall faster than those for conventional technologies. However, it is not possible to predict when individual new RETs will be competitive with conventional technologies, in particular given the uncertainty of future fuel prices. Current emphasis on sustainability and CO_2 emission reductions has led most countries to institute policies and programmes to assist RES to become competitive on a widespread basis and to promote their deployment.

International institutions also are seeking to promote renewables, since a substantial part of the large scale-market for RES is likely to be in developing countries away from already established energy supply infrastructure. The World Bank, Global Environmental Facility and International Finance Corporation have launched a series of aid schemes, which include the Solar Initiative, the Solar Development Corporation and the Market Technology Initiative, all with the aim of promoting uptake of RES in developing countries to assist their economic development whilst limiting emissions.

2.5.4.2. Market Barriers

Each of the RE technologies experiences some specific market barriers. In the initial stages of development of each RE technology, technical barriers predominate. However, for the more technically mature technologies, the priority is to become cost-effective in the market and economic barriers, such as inconsistent pricing structures, need to be overcome.

In general, the principal barrier that is currently limiting the uptake of RE technologies is the market’s perception of their costs. This results partly from the failure of the marketplace to fully assess the external cost of competing conventional technologies, and partly from the market’s discrimination against capital-intensive technologies. Therefore, continuing technological development to achieve further cost reductions must remain a priority.

Even for those RE technologies which are approaching economic competitiveness, barriers to their market penetration arise because the institutional, political and legislative/regulatory structures are not in place to specifically encourage the exploitation of RE technologies. For instance, in most countries the electricity grids are designed primarily to connect the existing large centralised power stations to the main load centres and substantial investments may be needed to connect a new RE plant to the grid.

This is particularly true if the RE plant is located in sites that are remote from existing power stations or load centres. This is due to the fact that, despite their widespread nature, RES are usually geographically dispersed and are often most abundant in areas that are remote from high-energy demands. Furthermore many are intermittent and cannot, therefore, offer firm energy supply without some form of storage (e.g. batteries) or alternative backup.

Also, most financiers lack familiarity with RETs, and therefore consider them to be “high risk”. As a result, finance for RE projects tends to be difficult to obtain and relatively costly. On the other hand, lack of familiarity with renewables amongst the personnel in local, regional and national authorities as well as in utilities often leads to problems in the interpretation of administrative procedures, and hence to long delays in the official authorisation of projects.

Finally, there are social and environmental barriers linked to lack of experience with planning regulations and with gaining public acceptance. More specifically, whilst RES undeniably have significant environmental benefits at the global level, their deployment can have a local impact and projects do not always enjoy universal local support. The most familiar example is large hydroelectric dams, which change the character of the local visual environment, interfere with watercourses and wildlife habitats, and cause sediment and mineral deposition patterns downstream.

Wind power needs installations in exposed areas that, by their nature, are often areas associated with beauty. Impacts that are small at the level of a single unit, unlike the noise of a wind turbine or risk of blades shearing off, can assume significant proportions when the number of installations are multiplied to, say, hundreds of units. Finally, RES do not add to the greenhouse effect, either because they return the same CO_2 to the atmosphere that had the same biological system had absorbed, or the same CO_2 would have been produced by decay of wastes anyway.

But emissions are still involved, if the aim is to reduce them as fast as possible. Broadly speaking, the less energy has been bounded up in a resource the less is its impact, but also the less is its usefulness. For instance, small-scale hydro, run-of-river schemes impact minimally, but they also produce proportionately less electricity. For those RETs that can have a significant impact at a local level, retaining local public support will be crucial to achieving major deployment growth in the future.

All of these barriers can be overcome through a concerted effort by policy makers and the industry acting in a systematic and strategic manner. The many global, national and regional benefits of increased renewable energy deployment certainly justify such a concerted effort. What is required is a long-term framework for increasing deployment that integrates market stimulation ("market pull") with technological improvement ("technology push").

2.5.4.3. Future Global Prospects

There have been a variety of studies of how the potential global market for RES may develop, carried out by a range of organisations, such as the International Energy Agency, the World Energy Council, United Nations, and Shell International. These studies involve scenario based modeling, and in general consider two types of scenarios - those driven by economic growth ("business as usual") and those driven by environmental concerns. In scenarios with positive rates of economic growth, increased contributions from RES are stimulated by efficiency improvements and technological progress.

In most of these studies the total contribution made by RES is aggregated (table 2.1). However, it is possible to draw out those technologies that will make the most significant contribution at various time frames. These are:

Short term (i.e. available now): small hydro, energy from waste (from waste combustion or via landfill gas collection), onshore and offshore wind power, active solar, stand alone PV (particularly in niche markets), biomass residues, and high enthalpy geothermal.
Medium term (i.e. should be commercial over the next 10 to 15 years): large scale PV, energy crops, fuel cells, and geothermal aquifers.
Long term (i.e. may be commercial within 25 years): onshore and offshore wave, photo conversion, and solar thermal electricity.

Table2.1. Summary of modelling studies

Study	Date	Renewables contribution
IEA	2010	From 19 to 21% of the predicted electricity production in 2010 (excluding all uses of biomass)
WEC	2050	Over 25% and up to 45% of the predicted global electricity output (between 21 and 30% of the expected energy demand)
UN	2050	Current contribution of 20% will rise to 60% of electricity demand and 40% of the fuel market
Shell International	2060	Up to 40% of total energy supply

[The high market penetration levels predicted by these studies are, of course, associated with substantial levels of investment].

Table 2.2. Shows the degree of penetration of technologies expected by the European Commission by 2010.

Table 2.2. Targets set by the European Commission White Paper [EU 1997]

Energy Source	*Contribution in 1995*	Contribution in 2010
Wind	2.5GW	40GW
Hydro - Large	82.5GW	91GW
Hydro - Small	9.5GW	14GW
PV	0.03GW_p	3GW_p
Solar Thermal Collectors	6.5 million m^2	100 million m^2
Biomass	44.8Mtoe	135Mtoe
Geothermal - Electricity Heat	0.5GW 1.3GW	1GW 5GW

2.6. Electricity Storage

2.6.1. Why Store?

Electricity storage allows production to be decoupled from supply, in order to balance fluctuations in the supply and demand of electricity. Over short time periods (of say less than 1 s) the requirement is essentially frequency control. Over longer time periods the requirements become those of energy management or provision of a contingency against an undesired event. Energy storage cannot replace generation completely, but it can complement other forms of generation whether on a large power system or in a stand-alone or non-grid connected application. If sufficient large-capacity storage is available, generating capacity only needs to be sufficient to meet average demand rather than peak demand. This would allow a typical system to be operated with, say, 40% less generating capacity, for example – with savings in peaking and intermediate plant.

An energy storage device also has applications within the transmission and distribution network. Networks have to be designed and built to be able to carry the expected peak loading, which may only exist for a very small part of its annual operating cycle. This results in considerable over-sizing of transmission and distribution equipment. Additional wires, transformers and other equipment are also needed to provide redundancy in the event of sudden loss of transmission capacity (such as a generator failure or an interruption to a transmission link).

An energy storage device can be used for many network applications. Storage can achieve multiple benefits by combining applications resulting in increased returns on investment. Examples of storage applications are listed in table 2.3.

TABLE 2.3. Some applications of utility scale energy storage

Generation duties	Ancillary services	Transmission and distribution
Energy management	Frequency response	Voltage control
Load leveling	Spinning reserve	Power quality
Peak generation	Standby reserve	System reliability
Ramping / load following	Long term reserve	Incorporation of renewables
	Reactive power	
Increase generation utilisation	Allow unbundling of services from the generator	Increase system utilisation
Reduce total required generating capacity	Reduce cost of ancillary services	Defer investments

2.6.2. High Power and High Energy Applications

Many technologies are available for large-scale stationary electricity storage applications. Almost all of them can theoretically be used for all applications. However, each technology has some inherent limitations or disadvantages that make it practical or economical for only a limited range. The high power applications include power quality and uninterrupted power supply (UPS), where storage technologies, such as capacitors, flywheels, and superconducting magnetic energy storage (SMES), are used within fractions of a second to improve reliability. The high energy applications include energy management, such as load leveling, peak shaving and arbitrage where electricity storage technologies such as pumped hydro, compressed air, and flow batteries, are used in daily cycles for economic gain. In between the two extremes of this electricity storage spectrum is a range of applications where stored energy is used in minutes rather than seconds or hours. This range includes spinning reserve applications for electric power grid stability.

2.6.3. The Technology

There are a number of storage technologies available to power system planners, which can be classified by technology type or by application. Technologies include: -

Mechanical: for example pumped hydro storage, compressed air energy storage, and flywheels.

Electrical: for example superconducting magnetic energy storage, capacitors / ultra capacitors.

Electrochemical: for example batteries, flow batteries.

Of these technologies, pumped hydro storage, compressed air and flow batteries have the capability of delivering energy at high power levels over periods of several hours or more. The other technologies are smaller scale. The Electricity Storage Association of the UK has published a table comparing technologies and this is reproduced as table 2.4.

The capability of each technology for high power and high-energy applications are indicated by the stars. From **** indicating fully capable, to * indicating incapable or not quite suited for the application.

Table 2.4. Comparison of energy storage technologies

Storage Technologies	**Main Advantages** (Relative to others)	**Disadvantages** (Relative to others)	**Power** Application	**Energy** Application
Pumped Storage	High Capacity, Low Cost	Special Site Requirement	*	****
Compressed Air	High Capacity, Low Cost	Special Site Requirement, Need Gas Fuel	*	****
Flow Batteries: **Polysulphide bromide (Regenesys)** **Vanadium Redox (VRB)** **Zinc Bromine**	High Capacity, Independent Power and Energy Ratings	Low Energy Density	***	****
Metal-Air Batteries	Very High Energy Density	Electric Charging is Difficult	*	****
Sodium Sulfur (NAS) Battery	High Power & Energy Densities, High Efficiency	Production Cost, Safety Concerns (addressed in design)	****	****
Li-ion Batteries	High Power & Energy Densities, High Efficiency	High Production Cost, Requires Special Charging Circuit.	****	**
Ni-Cad Batteries	High Power & Energy Densities, Efficiency		****	***
Other Advanced Batteries	High Power & Energy Densities, High Efficiency	High Production Cost	****	**
Lead-Acid Batteries	Low Capital Cost	Limited Cycle Life when Deeply Discharged	****	**
Flywheels	High Power	Low Energy density	****	*
Superconducting magnetic energy storage, DSMES	High Power	Low Energy Density, High Production Cost	****	*
Double Layer Capacitors (SuperCapacitors)	Long Cycle Life, High Efficiency	Low Energy Density	****	***

[Source the Electricity Storage Association (ESA) at www.electricitystorage.org]

2.6.4. The Future

The development of any technology will always reflect both engineering and scientific progress as well as the economic and social framework of the time.

The first pumped hydro storage plants were installed by manufacturing industries in Italy and Switzerland in the 1890's to store surplus power from run-of-the-river use in hydro stations for reducing the peak demand on the following day. Since then, there has been considerable development in pumped hydro storage with many large projects of over 1000 MW generating capacity. Many of these projects were constructed by state owned or controlled organisations, which had sufficient capital to commit to such large expenditures.

We can expect a number of technical improvements in all areas of electricity storage. Mechanical systems, such as flywheels are improving because of improved materials and more advanced power electronics. Compressed air continues to attract attention because of it relative simplicity and potential low costs. New superconducting materials will open up the opportunities for SMES to be used in a widespread distributed manner and improvements in power conditioning and in electrochemistry will increase the usefulness of all types of electrochemical or battery systems. It is impossible to select winners, but many technologies will be associated with small-scale devices, at the consumer level, and others will be more useful at the distribution or sub station level. There will only be a few technologies, such as compressed air, micro pumped hydro, flow batteries and some advanced battery types that will be competitive at large scale of 10 MW or more.

2.6.5. The Deregulated Environment

The power industry throughout the world is changing rapidly. Many countries have undertaken substantial changes in regulation, perhaps more correctly known as re-regulation. At first sight the prospects of change increases the commercial risks of an energy storage project. There is, however, a strong argument that an investment in a flexible technology, such as energy storage, reduces commercial risks, as the plant can have many uses and can draw upon a range of value streams.

The commercial opportunities for energy storage will take into account the owner / operator of an energy storage plant which may be a traditional generating utility, a transmission or distribution company, an electricity supply company or an end user of electricity. New owners / operators may arise, such as developers or promoters of renewable energy projects, energy traders and energy storage service providers.

Within a de-regulated, or more commercial electricity industry, the purchasing decisions for energy storage will reflect initial total capital cost and through life operating cost, rather than long term system considerations. For this reason large-scale pumped hydro storage plants are unlikely, because of the significant capital investment. The trend will be towards smaller plants, which can be more readily sited at key points on a power system. The market will segment into several categories, such as end users, requiring peak shaving and power quality devices, distribution and supply companies using storage for localised network support, equipment deferral and load leveling. Some larger energy plants will be adopted by developers of renewable energy projects, utilities using storage for network management and energy traders using storage solely for commercial advantage.

3. ELECTRICAL DELIVERY TECHNOLOGIES

3.1 Transmission Systems

3.1.1. General

Transmission systems underwent rapid evolution from the 1950’s onwards when the demand for electricity was growing typically at the rate of 10% per annum. This demand could only be met by the provision of large generating stations of rating of typically 2000MW or more. These stations were located remote from land areas and were usually close to the prime source of fuel, i.e. coal mines for coal fired stations or in mountainous regions for hydro generation. In parallel with this nuclear stations were evolving and had to built remote from areas of high population density. We thus had the situation where the outputs from these large generating stations had to be interconnected and the electrical energy transported over long distances to populated areas where the load demand was needed.

This scenario led to the rapid development of high voltage transmission systems which gradually had to be increased in voltage ratings from 100kV to 400kV and in some areas to 800kV. Further, where very large hydro sources were located in remote areas, and many hundreds of kilometers from load sources, HVDC transmission systems evolved as the most economical way of transmitting the electrical energy.

This situation has been rapidly changing over the last 20 years or so. In many areas load growth diminished and at the same time load patterns have been changing. In order to compensate for the unemployment created by the decline in heavy industry, e.g. ship building, coal mining, steel production etc. governments looked elsewhere to attract inward investments, usually from the Far East. These developments being typically to feed the boom in the electronics industries, hence transmission load patterns started to change and system re-enforcement was often required. However, experience shows that many of these new inward investments are of a relatively short-term nature with anticipated life spans of the order of 10 years. Indeed, due to more recent financial restraints in some of the Far Eastern countries and rapid changes in the electronics industry, some of the newly installed very large factories never came into operation. This means that transmission assets are left stranded and in some cases are not even utilised.

In parallel with the rapid changing load pattern, the last 12 years or so have seen rapid changes in generating patterns, whereby gas supplies became economical for the production of electricity. This led, together with deregulation, to the introduction of many independently operated gas fired combined cycle generating stations typically having ratings of up to 1000MW. These stations could be built rapidly, often within two years, were ideally suited to base load applications and could start producing returns on investment within 3 years. The stations are compact, relatively unobtrusive, have higher efficiencies than conventional stations, offer the opportunity of reduced pollution and could readily utilise gas supplies from existing gas infrastructures. These factors meant that gas fired stations could be built close to the loads and could be connected into existing transmission systems.

Transmission systems already have to adapt to these changing, often short term, requirements. One solution is to ensure that any new equipment that needs to be employed is made to be re-locatable so that it can be moved, at minimum cost, to meet the ever-changing load patterns.

With the now required short term investment returns it is improbable that large new non environmentally compatible generating stations are likely to be built in the future unless substantiated by long term governmental financial agreements. Similarly, with the newer technologies described herein it is probable that future generating sources will be smaller in size and situated closer to loads, either within existing distribution systems or at the location of large consumers, i.e. they are unlikely to be connected to transmission networks.

It could thus be foreseen that the role of transmission will change to that of connecting large remotely connected non-polluting generation, e.g. hydro, wind farms, wave farms, existing nuclear, perhaps geothermal and solar power generating units etc. HVDC is also likely to become more widespread, see section 3.1.4.

3.1.2. Overhead Lines

The future system is likely to require that assets are utilised to the full, environmental constraints will limit the building of new lines. Where new lines are built the visual impact needs to be minimised. It is felt that Distributed Generation will have an impact on lines but that bulk power transmission will still be required for some years. This scenario will have the following impacts:

1. The existing lines are likely to be used to their thermal ratings for a high portion of the time. This will be possible due to FACTS devices that will remove other constraints such as voltage and stability limits. In addition systems to monitor the conductor temperature in real time will be wide spread. The power flow down the line is regulated to ensure the conductor temperature is at or near the allowable limit at all times.

2. The allowable temperature will also be increased due to high temperature conductors being in common use. It is possible that conductors with materials exhibiting negative temperature coefficients will be used.

3. Environmental pressures as well as the reduction in the cost of power electronics will result in an increase of DC line application. Upgrading of existing AC lines to DC will also be a viable option in many cases, see section 3.1.4.

4. Environmental pressures will also result in very few new lines being built with the majority of lines being upgraded to transfer larger amounts of power. Upgrading thermally (either by increasing the design temperature or changing the conductor type), as well as by changing the phase and bundle configuration to increase the Surge Impedance loading will be practiced. In certain cases underground transmission lines will be used.

5. The use of FACTS devices and DC lines will allow far more flexibility for the line designer to solve present problems. It will be feasible that different phases from one line need not follow the same line route. Less visually intrusive designs may thus be possible.

3.1.3. Cables

Whilst all the possible system changes that could be anticipated over the coming 20 years could be considerable it is nevertheless vitally important that the systems reliability is not decreased. Coupled with this there is a growing public awareness of the environmental issues, which are unlikely to support the increasing use of new overhead line systems. Cable connection technologies are likely to become more dominant in order to overcome these concerns.

As more and more embedded generation is employed at distribution levels then it is probable that interconnection between these will be by means of cable technologies.

Such cables will be predominantly of the metallic/polymeric insulation type, possibly using some of the more advanced polymers that are now becoming to be viable. As the development of integrated networks advances then local interconnection could well be by means of DC. The increased use of DC cables could be envisaged for these applications.

High temperature superconducting cables operating in liquid nitrogen may find some interesting applications but are unlikely to be employed on a very large scale on the short term. See ref [7] to Section 7.

Similarly, where large power transfers are required over relatively short distances then Gas Insulated Lines could be employed. Significant advances will be required to make this technology more economic at lower voltage and power flow levels.

The development of superconducting materials able to operate at much higher temperatures would, of course, radically change the above picture. Given the current absence of a theoretical framework capable of explaining higher temperature superconductivity however, such a development appears to be some way off.

3.1.4 HVDC Transmission Systems

In the coming decade cross border electricity exchanges will increase, possibly pushing up to around 10% of the overall electricity consumption. Also it is expected that full integration into an interconnected power system could save 10% of the overall thermal generation capacity of 322GW for the European Union, for instance. In the latter case every 1% saving in generation that could be achieved, from savings in transmission losses and reductions in spinning reserves by using imbedded HVDC systems, would save 10million tonnes of CO_2 per year.

At present most electrical energy transmission is HVAC within large independent synchronous zones. However to keep this traditional configuration, without DC interconnection, is counteracted by the following drivers : -

- Liberalization and deregulation processes in the electrical energy market, causing large variations of power flows and their inherent unpredictability, with increasing need for precise control of power and ancillary services

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- Additional flexibility, enhanced stability and security in the operation and management of HVAC synchronous zones.
- Significant public and regulatory attention to environmental issues, with increased difficulties in obtaining new rights of way for overhead lines, very often proving impossible to be built.
- Critical concern and controversial debate, on electromagnetic field impacts on human health.
- Increasing introduction of distributed generation and of renewables sources.
- Progress in HVDC technology, with the introduction of reliable and low-cost voltage source converters (VSC).
- Growing difficulty of managing very large HVAC networks due to increased fault current frequency, local faults spreading to the whole system and increasing sophistication of control of large synchronous interconnected systems.

The intrinsic characteristics of traditional HVDC technology and the new possibilities offered by HVDC based on VSC converters fit very well into the future needs, in particular : -

- DC transmission looses less power over longer distances and DC transmission lines may be cheaper to construct.
- DC systems are considered to allow additional environmental benefits such as no AC electromagnetic field effects and with DC polymeric cables the avoidance of insulating oil leakage and the use of more easily recyclable insulating materials.
- The power electronics required for conversion between AC and DC is now much more readily and cheaply available and is highly efficient.
- DC links can be used to connect independent electrical networks, for example between neighbouring countries and non-synchronised regions e.g. UCTE, UKTSOA, NORDEL.
- DC links may impart additional AC system security, operational flexibility and management advantages.
- Greater flexibility in the deployment of embedded and distributed generation and bulk energy storage in the existing transmission network.
- Lower environmental visual and noise impact.
- Possibility to provide ancillary services, like frequency and voltage regulation (for VSC based systems).
- Short time to deliver a new connection, in particular for new HVDC type based on VSC.

In contrast it is also important to consider some of the challenges that DC systems present, such as : -

- Avoidance of electrolytic corrosion of underground equipment through the ground return circuit configuration.

- Management of possible inductive disturbances to nearby radio and communication lines.

- Converter improvements to manage DC system instability arising from connected AC systems with small short-circuit capacity.

In conclusion revolutionary introduction of HVDC in T&D will depend strongly on two aspects : -

1. Environmental, economic and system operation/security impacts that HVDC systems could impart to the existing AC network.

2. Reliability and cost effective deployment of HVDC cable systems.

3.2 System Interface Technologies

3.2.1. Introduction

In 1996 CIGRE issued Report No 23 – 207 entitled, "The Future Substation : A Reflective Approach", which drew a number of conclusions concerning the development of the future substations, [1], even since this time developments have continued at a rapid pace. This section attempts to review these developments and possible implications on substation evolution over the coming years.

The deregulation of power market has, in industrialized countries, led to an increasing interest in power system optimisation and a focusing on customer demands. This is leading to new requirements on substation functionality, including incorporation of functions related to new principles for power system operation, power system upgrading and power system economical optimisation. Small-scale generation will be connected to the distribution substations making some of them more or less autonomous.

Due to increased reliability of equipment, more sophisticated protection and control and a decreased amount of maintenance, future substations will have a simpler layout and in most cases be smaller to easier fit into surroundings, but, at the same time, the number of stations is likely to increase, particularly at distribution voltages. Visual impact is also a driver for small low profile stations. The economics of substations will be based on extended LCC (Life Cycle Costs) not only including system costs (capital, operation, maintenance, outages) but also customers' costs for voltage dips, outages and other power quality deficiencies. It must also include handling of all material from "mining to scrapping", LCA (Life Cycle Assessment).

Emerging technologies such as new types of semiconductors, HTSC (High Temperature Super Conducting) devices and solid insulation, could result in radical changes of the substation design as well as for substation's role within the system.

To facilitate introduction of new technical solutions, substation specifications must be based on required functions of the substation within the system and must not, as in the past, define detailed layouts and apparatus designs etc.

3.2.2. Substation Compacting

As a consequence of deregulation of the electrical energy market the main criteria for new generations of substations will be economics, environmental issues and changing customer requirements. The result of the questionnaire concerning future substations [2] showed visual impact, noise and space to be the most essential environmental aspects on substation design. The next generation of substations will be built up of exchangeable modules with no maintenance work in the station. Instead of maintainability, exchangeability and relocateability are becoming important issues. Substation compacting can therefore be made by e.g.:

- simplification of lay-outs
- reduction of the number of apparatus
- reduction of insulation levels
- changes in maintenance philosophies.

3.2.2.1. Simplification of Layouts

With increasing reliability and reduced need of maintenance of apparatus, discussions were already started more than a decade ago to use these advantages for the simplification of the substation layouts. Several studies have shown that with improvements of reliability and availability, a change to single busbar system layouts gives a more economical solution [1], [3], [4], [5]. These studies cover both transmission, 400 kV, and distribution substations. As economics is one of the dominating factors for substation design the sought availability is now optimal rather than maximal. These substations are most often built up of modules either AIS or GIS and with cable entrances.

3.2.2.2. Reduction in Number of Apparatus

From reliability point of view the circuit breaker is by far the most critical component followed by the disconnector. A reduction of the number of these apparatuses will in most cases enhance the reliability. In many cases line disconnectors are replaced by easily opened jumpers, [1], [3], [4], or as in [5] connected to the HV line with remotely controlled disconnectors but without a breaker.

Another way of reducing the number of apparatuses is the withdrawable circuit breaker, earlier common in MV systems, now available up to 550 kV.

3.2.2.3. Reduction of Insulation Levels

With lower arrester rated voltages based on better assumptions of the temporary overvoltages occurring, together with shorter distances in module built stations, a substantial reduction of insulation levels can be made. This, together with the fact that no maintenance and repair work would be required in the substation, will make it possible to reduce distances between bays considerably. Faulty modules can be withdrawn and exchanged directly or taken out with no voltage on adjacent bays or by robots. Extra distance between bays will therefore not be needed.

3.2.2.4 Changes in Maintenance Philosophies

In the module built substations no maintenance and repair work will be required on site. A faulty module will be replaced by a new one and repaired in the workshop. A change in maintenance strategy form Time Based Maintenance (TBM) towards Condition Based Maintenance (CBM) is to be brought about in the coming decade with asset management as an overriding driver.

Due to a decreasing number of substation equipment faults, operation closer to limits and lower requirements for maintenance, Operation and Maintenance personnel will need to be guided by condition monitoring and the use of expert systems. Maintenance will not only be based on the equipment condition but also will be based on reliability data. In many cases the maintenance will be outsourced, e.g. to manufacturers, or to specialist companies.

3.2.3. Protection and Control (See also Section 5.1.)

As substations will be unmanned, personnel in control centres need accurate information on substation status.

The trend in protection and control systems is for them to be interconnected, digital and communicate via fibre-optic links. The station computer allows access to the RTU (Remote Terminal Unit), control functions, measuring functions and condition monitoring functions. Protection will be placed in units at the equipment level. Communication with the primary equipment goes via these units and a process bus. Data flow to the substation computer will be via a substation bus. All communication must be according to IEC standard.

The condition and state of primary equipment will be continuously monitored. Information from the automated condition monitoring will be available anywhere via a dial-up system and web technology. Expert system help will also be included. If a fault or an alarm occurs, maintenance personnel will have ready access to all relevant data in order to allow them to optimise remedial actions.

There will not be redundant protection systems but an analytical redundancy will be created. Gathered information with development of new functions, will make it possible to detect a fault in the control system before it leads to system problems. If a fault is detected in the protection, an alarm is sent out to adjacent protection equipment and the faulty protection will automatically be reset to new values to clear a primary fault. Should a system fault occur before the faulty protection can be rectified then the system fault will clear as fast as the original primary protection but possibly with a larger part of network disconnected, [3].

3.2.4. Possibilities with Emerging Technologies

New technologies will, on the one hand improve conventional design of substations and, on the other, will open them for other purposes, e.g. for connection of local production and for power quality enhancement. Some of these advancements may be solved, for example, both by HTSC and new power electronic techniques, preference for one or the other is not going to be given here. In the end the total LCC for the substation will be decisive.

3.2.4.1 Substation Design

3.2.4.1.1 Short Circuit Limiter

Short circuit limiters are of interest for most substations. For older ones in the case of extensions to equipment or where fault levels may have increased, by limiting currents to values below the short circuit capability of existing breakers, transformers and old switchyard parts. For new substations it will open possibilities for new and much lower demands on short circuit ratings. The short circuit limiter may at the same time function as a circuit breaker.

3.2.4.1.2 Circuit Breakers

Circuit breakers in their present form are the least reliable, and the most maintenance consuming, apparatus in the substation. Solutions based on completely different techniques are therefore continually sought. For some years now shorter breaking times have not been specified. However, with possibilities to enhance power quality by reducing voltage dips and supply interruptions, very short breaking times possibly with fault current limitation, will be essential. These will also reduce, or eliminate, the need for standby energy storage devices for quality improvement.

3.2.4.1.3 Transformers (See also Section 3.3)

The acceptance of mineral oil is from the environmental point of view decreasing; also the fire hazard largely prevents mineral oil transformers from being used indoors. SF_6 transformers were designed to solve this problem but cannot be seen as a final solution due to their cost and environmental concerns. A new transformer type the solid insulation based “dry-former” has been introduced and installed. The concept based on cable and transformer technologies solving both oil spill and fire hazard problems, [8]. HTSC transformers exist today, at least for smaller sizes, which also solves both of these problems. A power electronic based solution is a further possible development.

Current and voltage transducers will have optical or a primary sensor based on other than transformer principles, giving digital signals over a fibre optic transmission. They will be built into the HV modules. They must have a high frequency range to cope with power quality guarantees now being specified, which will require very high sampling frequencies.

3.2.4.1.4 GIS and GIS modules

GIS has a low failure rate and requires a minimum of maintenance. The trends of compacting substations can be achieved by full GIS stations or as modules in hybrid stations.

The debate on the environmental aspects on SF_6 has been going on for a long time. CIGRE studies show that although the gas is one of the worst gases from the point of view of the greenhouse effect its contribution to the total amount is very small and decreasing with better handling and lower leakage, [9]. Regardless of this however there will be continuing pressure to find other solutions. Solid insulation and polymer conductors can possibly lead to new solutions.

3.2.4.2. New Purpose Devices

New devices are of interest for: -

- Connection of local power: - Substation based fuel cells, photovoltaic generation systems and nearby wind farms by AC/DC or AC/AC converters.
- Control of power distribution for better use of power lines and substations.
- Control of arrester characteristics.
- Limitation of switching and temporary overvoltages.
- Enhancement of power quality: - Active filters and energy storage systems for voltage dip and interruption limitation.
- Energy storage.

Control of arrester characteristics and overvoltage limitation will allow further reductions of insulation levels but at the same time putting higher demands on the insulation materials.

3.2.5. Functional Specifications

Manufacturers, contractors and engineering companies (solution providers) have, as shown above, developed a number of innovative solutions for substation design. Currently the asset owner or asset manager will specify the availability, maintainability, flexibility and extendibility aspects of a substation. This is done, for example, by requiring a certain type of primary diagram and by positioning the different parts of the substation and even different high voltage equipment in layout drawings. In order to standardise his substation solutions, the asset owner also defines many of other requirements in detailed specifications for the specific plant. One reason for using a detailed specification is the fact that the asset owner can be sure that he will get exactly what he wants.

This approach however, maintains the old concepts and slows the introduction of innovative solutions. It should, nevertheless, be in the asset owners' interest to get better solutions together with minimised life cycle costs. In order to achieve the significant cost benefits that innovations could give it is necessary to change from old detailed specifications to functional specifications, [10].

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To facilitate the introduction of new technical solutions in substation design a new type of specification must be developed looking at the substation as a “black box” which has to fulfill all the requirements for its function in the network.

Functional specifications seem to be most beneficial if projects are ordered on a turnkey basis. Only then can the solution providers ensure the most appropriate optimisation including engineering, installation and construction work. The trend is for turnkey substation projects to become more common even when using detailed specifications. Functional specifications must, however, be effective in handling also extensions, refurbishments and long-term performance of substations.

With the implementation of “functional specifications” asset owners must rely more heavily on “solution providers” for technical substation solutions and consider new concepts with an open mind. The functional specification should also include long-term penalty/bonus schemes for the substations performance against guaranteed availability measures. The functional specification should also be flexible to simplify implementation of future substation extensions not restricting it to the designs and protocols of the original solution provider. This enables/facilitates competition for future extension work.

3.2.6. Summary

Deregulation of the electricity market has, in the shorter term, given a priority to economics. At the same time public awareness of environmental issues is putting a pressure on substation design asking for smaller low profile stations, similarly the emerging requirement for improved performance in quality of supply is having a major influence. Compacting of substations has led to simplified layouts, removal of HV apparatuses and introduction of combined function apparatus. A retained optimal reliability/availability, including customer costs, is essential.

The stations are built up of modules, AIS and GIS type. No maintenance and repair work is made on site only a changing of modules. Extra space allowance between phases is not needed.

Emerging technologies as new types of semiconductors and HTSC will open for new solutions and drastic changes in substation design. Development in power electronics will change the substation role in the power system; the “multi-functional” station will be born.

To facilitate the introduction of new technical solutions in substation design a new type of specification, a functional specification, must be developed looking at the substation as a “black box” which has to fulfill all the requirements for its function in the network.

3.3. Transformation

What driving forces will predominate in the evolving 2020 transformer business? Finance and environment have a high probability of being the key issues rather than any one major emerging technology. The present visionary exercise is based on this hypothesis.

Finance implies high pressure on costs and competition between actors. Such a context reinforces the traditional product based on the paper-oil insulation. Environmental pressures on the other hand will lead to fundamentally different power systems which will, in turn, dictate changing transformer requirements such as low noise, oil free, material re-cycling etc, all geared to reducing the environmental impact. The combination of these influencing factors will lead to a great variety of market opportunities.

In consequence, the 2020 transformer industry is likely to be both very conservative, using the 130 years old paper-oil concept, and very reactive using new technologies such as superconductivity, synthetic insulation etc. The transformer industry is currently adapted to the life extension requirements of utilities and, on the other hand, to the development of short lifetime niche products. This has led to new flexible design tools being developed by manufacturers to ensure appropriate quality whatever the product types.

At the same time, the requirement for utility outsourced maintenance services is increasing. New technologies are being developed which will allow rapid off-line maintenance, in-service monitoring techniques and on site repairs. When a dangerous incipient fault is detected the utility will be able to access an Internet forum to monitor continuously the suspect transformer and to make the best decision with the assistance of appropriate worldwide expertise.

Clearly the two main design parameters that influence the transformer application are its voltage level and rated power. The following sections illustrate some possible future transformer applications, from the largest units in generation and transmission, down to the smallest in distribution areas.

3.3.1 Large Generation Transformers

The market for very large generator transformers is expected to decrease due to the development of local generation with smaller units. The high voltage and high power generator-step-up (GSU) transformer technology remains mainly based on the conventional paper-oil insulation.

Rival innovative equipments are introduced in a few niche markets. One example is with new high voltage generators that allow the connections to the grid without any GSU transformers.
For aged GSU transformers, maintenance is optimised to reduce the forced outage risks and to take account of the various plant life expectations e.g. hydro, nuclear, and thermal. Advanced off-line diagnosis of the transformer is proving helpful with the plant maintenance, e.g. bushing renewal, while other diagnostic techniques can be performed in service e.g. oil treatment.

3.3.2 Transmission Transformers

Manufacturers can now offer sophisticated options, with appropriate techniques, to manage the insulation ageing. Mid-life refurbishment opportunities are now used to upgrade the overload capacity of the transformers, such techniques now include the use of synthetic foils, which can be introduced in the hottest areas and the use of magnetic shunts. Sensors located inside the tank to monitor hot spots could be another option to manage dynamic loading without jeopardising the transformer performance.

For new transformers, the dynamic loading and relevant emergency conditions have influenced the choice of materials, including the conductor insulation. Optimum design combines conventional paper oil, thermal upgraded insulation and sophisticated continuously transposed conductors, including epoxy based insulation systems. Cooling ducts can be built into some conductors to improve the cooling performances. A thermal model can now be provided by the manufacturer to indicate operating limits.

3.3.3. Interface with HVDC Systems

HVDC interconnections within AC networks are applied worldwide and the relevant market for converter transformers is composed of renewal business and new plants. The transformer remains one of the most expensive items of equipment and efforts are continually being made to cut the costs. As a consequence, paper-oil insulation is still used. Developments are focused on the design of the magnetic core and conductors to take into account the high frequency stresses imposed by the newer electronic components.

3.3.4. T&D Interface

For power transformers, this interface is subjected to high environmental pressure. For urban areas, requirements are focused on audible noise, EMC, fire risks etc. Software tools have been developed to specify the appropriate solutions and to allow decisions to be made on the basis of risk assessment studies. Special transformers can be provided where the situation dictates e.g. dry type, gas insulated units, new oils etc. these may require barriers for noise suppression and means to limit damage in the rare event of a possible internal fault. Where oil transformers are used means may be required to prevent oil contamination in the event of a possible internal fault. Sensitive industrial applications also may have special requirements.

In comparison with the long term asset management of the transmission grid some distribution interfaces must align with the continuous evolution of power systems where, for example, there may be a sudden deficit of distributed generation. This would imply specific overload conditions for power transformers. In such circumstances voltage regulators have to work very hard which places stringent requirements on their design, i.e. high reliability and minimal maintenance, possible solutions may include oil free OLTC, solid state diverter and very fast regulators etc.

3.3.5. Distribution Transformers

To meet their stringent contract conditions utilities can now use transformers in combination with power electronic devices to meet the end user requirements for a high voltage quality. In other cases, transformers provide the GSU function to evolving energy supply systems including distributed generation, fuel cells, wind farms and micro turbines, all of which may be associated with energy storage systems. Most of these applications generate high harmonic content, which impinge on transformer stresses and losses. High frequency ac transformers may also be required to reduce weight, dimensions and associated costs.

Transformer technology is developing in many domains including magnetic materials, solid and liquid insulation and superconductivity etc., as well as technologies to allow material recycling, especially in view of the growing trend for short product life. Over the next 20 years it is believed that transformers will continue to evolve using refinements to the current technologies in order to meet the changing power industry needs and that the chances of rapid development of some fundamentally new technology within this timescale is unlikely

3.4 Distribution Systems

Traditionally the electric power flows from the large generating units via the transmission network to the distribution grids. With the implementation of medium size and small size power plants different power flows and a different system behaviour are foreseen. In this respect a large size power plant (hundreds to thousands of MW) is considered to be connected to the transmission voltage level and will have no impact on the lay-out of distribution grids; medium size (tens to hundred MW) can be defined as the size by which individual power plants will have a tremendous impact on the local distribution network; and small size plants (one to ten MW or even smaller, but, in that case, connected to low voltage networks) individually will have only marginal impact, if any, but cannot be neglected when numerous plants are connected to the same MV grid.

Medium size generation will predominantly be based on gas fired technology (mainly steam injected gasturbines and combined cycle gasturbines applied in co-generation plants, but also reciprocating gas engines). The direct connection to a local distribution grid may give problems due to :-

a shortage of inherent short-circuit power (leading to unstable system operation),

an increase of the short-circuit currents (in excess of the capability of the components in the grid),

a completely different, and even varying, voltage profile in the grid (depending on the operational mode of the plant),

voltage dips and long fault clearing times (leading to tripping of the plant),

a lack of current carrying capacity in the grid.

Such problems are normally solved by either a direct connection to a transmission network or by a dedicated (point-to-point) feeder from the main substation, when possible connected via a separate transformer to the transmission grid. In the near future more and more special connections are to be expected, not only for power plants, but also for sensitive industries.

Medium size generators, large industries and sensitive industries should preferably be connected to subtransmission systems or distribution systems with a higher voltage level, in order to prevent disturbances impairing the plant and/or the other customers. However, in a number of countries and regions there is a trend to decrease the number of transmission and distribution voltage levels, especially by eliminating sub-transmission voltages, leading to large voltage ratio's of the HV/MV transformers. Another trend is to increase the rated voltage level of the distribution grids from 10 kV to 20 kV (15 kV to 27 kV, and even a voltage level of 36/38/40 kV is more widely applied), as the costs of switchgear, transformers and lines/cables do not differ too much. The developments mentioned lead to adaptations of the technical specification of the power equipment (overload capabilities, out-of-phase conditions, higher short-circuit current peak values). New designs, new materials, new technologies lead to more compact substations, simple and prefab, to explosion proof and internal arc withstand capabilities, environment friendly solutions, high reliability, high maintainability, advanced technology implementations, telecommunication facilities, advanced protection and control functions, diagnostics and fault location features.

Small size power plants can be divided into :-

predictable generation; geothermal, fuel cells, biomass (sometimes season-dependent), hydro and wave

and unpredictable generation; wind, solar, PV, hydro (to some extend), co-generation and micro-turbines. The last two technologies are mentioned as they will mainly be controlled by the heat demand.

In cases where generating units are at low operation, out of operation or in a failure mode, the distribution network has to provide back-up electricity. This means that the distribution grid has to be at least as rigid as without the small size power plants. Maybe that in the future a large number of predictable power plants, (by probability considerations), will reduce the demands to the (sub)transmission level, leading to cost savings in the transmission infrastructure.

In case of emergencies or in case of optimalisation of costs or losses, co-generation plants (including micro-turbines) may be operated in a electricity demand mode as well, but then back-up provisions for additional heating and/or cooling have to be built. Rather than a shortage of electricity, a surplus may rise. A surplus that possibly gives currents larger than, and opposite to, the load currents.

As with medium size power plants a large number of small size plants will impair the voltage profile along the distribution network. Reactive power control, switched capacitor banks, advanced tap-changer controls will be necessary, maybe even on-load tapchangers for distribution transformers. Dynamic and transient stability form other difficulties, easily leading to tripping of many involved generators. Automatic switching (autoreclosers, capacitor banks), fast fault clearing, synchronous switching, telecontrolled switching, pole-slip requirements, voltage/frequency control, advanced load control, etc, have to be implemented. Special requirements have to be put forward for electricity generation sources with power electronic interfaces to the distribution grid (fuel cells, micro-turbines), as they have to function reliable under circumstances as voltage dips, variations, flicker, transients and harmonics.

Already today a trend towards more intelligent equipment can be seen. For instance autoreclosers, offering the possibility to transmit wireless the information about status, voltage and current, so that it's operation can be co-ordinated with other auto-reclosers and protection equipment. Similarly, accurate information about voltages, currents and power flows will be essential to control an optimal voltage profile. On-line information of the status of distribution networks is also becoming very important with respect to safety precautions in an environment of rather complicated systems with dispersed generation. Adequate network control, dispatching, network restoration and voltage control require an advanced and "intelligent" infrastructure (telecontrol, SCADA, DMS, etc.).

The complexity of future distribution networks however may give more voltage fluctuations and voltage dips, while the equipment connected and its controls are becoming more and more vulnerable to voltage deviations. Moreover, while requirements to the infrastructure increase, the costs of the distribution network per MWh will increase even faster, as less MWh will be consumed.

A loss of performance of the network, a reduction of power quality, an increase of distribution costs, will force customers to look for alternatives, such as expensive connections to a higher voltage level, no-break sets, emergency generators, advanced filters between grid and load, island operation, energy storage. Utilities may offer different levels of power quality, from “take it or leave it” to redundant emergency networks. The cheapest solution or the best price-performance solution will be applied. Instead of the customer, utilities or third parties may own the small size power plants, micro-turbines, emergency generators, back-up services, PQ-filters. In stead of renting such equipment, clients may rent services as well: heating, cooling, steam, DC-supply, etc. Power quality will force such developments and third parties will enter the business with fast, flexible and cost-effective services (comparable with the role of travel agencies and small airlines in the aviation business). Nowadays utilities are already entering the market of TV services, telecommunication services, home appliance services, security systems, waste disposal, etc.

Sometimes it is suggested that in the future the role of the distribution and transmission grids will be of a diminished importance. Islanding operation, self-contained generation, energy storage are mentioned as future features. However, we have to be very careful as experience learns an opposite evolution. The operation of a system completely separated from the interconnected grid is rather expensive, when an acceptable level of reliability and power quality is required. Examples can be found with oil platforms, ships, remote islands. The tendency is to connect these islands, even large islands or isolated systems like the UK and Scandanavian systems.

Self-contained generation, for instance photovoltaic cells (PV) supplying electronic equipment/ PV with battery storage to supply light or telecommunication systems/solar energy with heat storage to supply heat, is still very expensive and its application limited to dedicated purposes with restricted power consumption. The same applies to energy storage systems, the cheapest technology being hydro pump-storage plants, which nowadays seems to be hardly cost-effective, even at a larger scale. Maybe that energy storage at the load side (heat, cooling, compression, pumping) and/or load control (air conditioning with PV when sunlight available, pumping with windmills when wind available) offers much better opportunities, depending on the acceptance in the society. Anyway, it is clear that an economic break-through of substantial electric energy storage systems will completely change the infrastructure of power supply, especially in countries, where electrification is still in an introductory stage.

To evaluate an electrical infrastructure without (large scale) interconnections it may be wise to look at the rural electrification in developing countries. From [1] it can be learnt that: “More so than in the past, the electrification of rural and remote areas in developing countries will be based on decentralised power facilities, including stand alone solar home systems. The latter system is an attractive option for satisfying initial electricity needs. However, as well-being increases so does electricity demand with the consequence, that after time, a more powerful electricity supply will be needed. Grid-based electricity supply systems are often implicitly assumed to be the least-cost solution when compared with decentralised diesel generation. In many developing countries, rural areas offer opportunities to deploy power systems based on small-scale hydro power, solar energy and biomass. Although a renaissance of decentralised power supply is clearly visible, centralised grid systems will continue to play a major role in power supply, though the function of the grid will change.”

The key factor is that on one hand electricity brings light, modernity, progress and prosperity and on the other hand electricity demand is around the clock as soon as society relies upon lighting, medical care, education, more efficient production and agriculture, telecommunication. Even in developing countries the added value of a reliable electricity supply is unquestionable.

In this respect another development foreseen is the investment in “green” technologies. As PV and biomass can only marginally substitute fossil fuels in industrialized countries and the application of windmills will be limited in terms of energy supplied, alternative power generation in developing countries may give a higher environmental efficiency than similar investments in developed countries. Utilities will look worldwide for energy projects giving the best contribution to saving the globe, fulfilling in this way their societal obligations. Such developments will have a large impact on distribution systems in certain regions of the world.

Small is beautiful, but, by its capability to absorb deficiencies, the huge machinery of the interconnected electricity supply offers the technical infrastructure and the safety net to make small solutions possible, feasible and acceptable.

Possible changes in the ways in which electricity is supplied to end-users are many and varied; the only certainty is that there will be many changes. Not least to ensure that the most appropriate, reliable and economic supplies are available to meet users, ever more critical, needs in developed countries but also to ensure that suitable means of electricity supply are available for the needs of societies in developing countries. Further, governments in many developed countries have given commitments to significantly improve environmental efficiency over the next 10 years or so. It is believed that it will be difficult for many of these commitments to be achieved. Firstly, because the financial incentives are often not in place to encourage such development, and secondly because there is currently insufficient engineering expertise, or manufacturing resources, to see these commitments through. The education of a new generation of young engineers is critical, but with the time taken for useable expertise to be gained it is still unlikely that many governmental commitments will be met within the declared time scales.

4. SYSTEM OPERATION AND CONTROL CHALLENGES

4.1. Aspects of Operation and Control

The future of substation automation will undergo a major paradigm shift. The enormous pressure to decrease the investment and operational cost of substations in combination with the shortened life cycle of the secondary components opens opportunities for new technology to be introduced.

Recognition of the financial forces a few years ago led to the start of a fundamental standardization process for the communication and data exchange between Intelligent Electronic Devices in substations and all other control / information systems. This standardization process started as the UCA2^{TM} initiative is leading to a new international standard called IEC61850.

The new standard is more focused on the data model and the substation configuration language than recognizes the communication principles only as a subset of the total.

Most of the applied communication principles are originating from other industrial mainstream businesses. The created openness achieves two major objectives firstly the data and information retrieval from substation-based equipment is simple and standard, secondly the compatibility and eventually exchangeability of secondary equipment and functions of different suppliers will increase competition and decrease the cost. The last is important for asset managers since initial investments will decrease, but the data mining opportunities will allow the asset managers to explore the performance to the substation equipment by easy and open methods. This is one of the major benefits of the open systems approach in the far future.

The high pace of developments in the Internet technology and the deployment of those techniques in power system equipment will definitely have a major impact on the utility operations and departmental boundaries. The inevitable and irreversible usage of Internet technologies together with the standardized data repositories is a major paradigm shift in the operation and control of power systems. The current compartmentalized information and control systems will completely disappear and will migrate to one virtual operation and control environment. Data security mechanisms are developed and applied to guarantee the required levels of security for all data exchange with the power system equipment and the data subscribers.

The Internet communication environment will enable the virtual data space where all utility staff is retrieving its data and information of the power system. The applied technology of data retrieval and communication means will be completely based on commodity techniques as long as they can meet the reliability and availability requirements set by the utility management.
The proprietary and special on the utility industry focused solutions will slowly disappear and be taken over by the mainstream technology solutions.

4.2. Quality Issues

4.2.1. Consideration of Quality Aspects

The quality issues considered here concern all interface points between an electric network and the outside world (producers, consumers, neighbouring electric networks, third party structures, environment...). In the coming twenty years, one can expect a strong increase in the monitoring and reporting needs, the regulatory requirements and in particular with customers increasing demands for higher quality supplies. The offer of new products and services in this area will keep growing, along with the concern for economical aspects. Main concepts are: -

Power Quality. The quality of electricity (often referred to as Quality of Supply) has three main criteria : -

- *commercial quality,* concerning the quality of relationships between the grid operators and the user,
- *continuity of supply* characterized by the number and duration of interruptions,
- *voltage quality,* of which main parameters are frequency, magnitude, waveform and symmetry.

Electromagnetic compatibility (EMC). The concept of EMC is rather broad (the ability of an equipment or system to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to anything in that environment [definition from IEV 161-01-07]). Voltage Quality may be considered as a common topic from Power Quality and EMC. Other phenomena however need to be taken into account; e.g. high frequency disturbances on the electricity supply and all disturbances whether high frequency or low frequency which may reach equipment other than through the electricity supply. Safety aspects and equipment resistive concerns also need to be considered e.g. electromagnetic fields, overvoltages, step, touch and transferred voltages etc.

Environmental impacts. Possible health effects from electric and magnetic fields (EMF) may be considered as a common topic from EMC and Environment. Many other aspects need to be taken into account, visual impacts, noise, pollution risks due to some insulation materials or protective coatings etc.

This section however focuses mainly on Power Quality (PQ).

4.2.2. Regulatory Aspects

Classically, legal standards define conditions for safety issues or environmental impacts. Their number and severity seem to be ever increasing.

More recently, the fear that the electricity market liberalization might result in lower PQ levels has arisen. Therefore, more and more regulators are implementing quality standards [4.2.1]. Two broad categories of such standards are being considered: -

- *Guaranteed standards*. These set targets to be achieved for service delivery to individual customers. Guaranteed standards are always linked to penalty payments, which can be either automatic or subject to customers claim.
- *Overall standards*. These set requirements to be achieved on a company-wide level.

Financial incentives are sometimes linked with these standards, aimed at reaching the socio-economic optimal quality.

4.2.3. Economical Aspects

For safety and environmental aspects, more severe legal requirements may lead to very high costs for the grid operator, and consequently for his customers.

In the PQ domain, a distinction can be made according to the origin of the quality disruption: -

- *Incidents.* The related quality aspects, mainly interruptions and voltage dips, depend on external circumstances such as meteorological events, population density, geography and on the power system quality e.g. planning, design, maintenance and operation.

  Penalties and incentives coming from regulators or from particular contracts may play an important role in the future.
- *Disturbing installations.* The related quality aspects, mainly harmonics, flicker and unbalance, depend on the emission limits. A possible future trend is the development of Power Quality markets [4.2.2]. Starting from parallels in environmental economics, an emission permit/right trading system for the different PQ phenomena, each with a different market, is possible.

4.2.4. User Examples of Practical Aspects of Voltage Disruptions

All of the above described factors are significant for users of electricity but perhaps one of the greatest drivers for future system change could be the effects on users of supply system induced voltage dips. The majority of disruptive voltage dips result from system faults. For faults within the Distribution system the effects are generally localised, for Transmission system faults however, the effects are usually widespread across a large part of the power system and can affect a great many customers. Transmission system faults for example, have been known to cause manufacturing plant disruptions at locations over 600km from the fault point.

Whilst voltage dips have regularly been experienced over many years they have not previously had the widespread impact now being experienced by many customers. The major reason being the now almost universal application of microprocessors and computerised systems, both in manufacturing plant and in commercial businesses and even in domestic premises, a voltage dip can now cause significant consequences to the user. They have been known to cause shut down of oil refineries, paper mills, process plants and commercial organisations, often causing these customers to incur very significant financial losses. It has not been unknown, for example for a severe voltage dip to cause a widespread disruption of manufacturing and business systems in a major world city causing even cash machines to stop working on a Friday afternoon! Such disruptions alienate public opinion against utilities and even governmental actions may result, compensatory payments could be forced upon utilities in extreme cases.

These pressures have caused many utilities to seek ways of monitoring electrical power equipment in order to detect incipient faults and to rectify them before breakdown occurs. This has now largely been achieved for example with GIS where most incipient dielectric faults can now be detected long before resultant breakdown. Similarly, monitoring of power transformers to alleviate faults has also been very successful. Developments of power equipment monitoring will need to continue over the coming years in order to reduce the number of voltage dips caused by system equipment failures.

Faults within distribution systems can also be locally disruptive to customers, indeed the number of disruptions on rural distribution systems has in some cases increased as a result of regulatory pressures, one such pressure, in some countries, being the benchmark requirement for utilities to reduce ‘Customer Minutes Lost’ (CML). To achieve this, many utilities have fitted SF6 reclosers throughout their rural networks. Many transient faults can then be rapidly cleared and associated circuits reclosed. Transient faults commonly occur in adverse weather conditions due to conductor or tree movement for example, when this happens customers are subjected to many rapid disruptions causing annoyance due to digital clocks requiring to be reset, heating systems, televisions freezers etc.rapidly going on and off and possible loss of computer data. Transients generated by SF6 reclosers can have very fast wavefronts and have been known to cause failure of power supplies of domestic electronic equipment.

These 'alleviating' utility actions have allowed them to achieve significant reductions in CML but in some cases have induced greater customer dissatisfaction. Had utilities been encouraged to tackle the real causes of the problems such as replacement of loose or broken poles, broken insulators, appropriate tree lopping etc. then many of the potential faults could have been eliminated.

The problems caused by poor power quality are already very real and are often requiring provision of costly alleviating means, even to the extent that some large industrial and commercial organisations are now installing their own site generation and are operating independent of the utility to ensure immunity from utility induced supply disruptions.

Quality of supply is already a major driver influencing power system changes and this trend is likely to become even more important in the coming 20 years.

5. PROTECTION, AUTOMATION AND COMMUNICATION INTERFACES

5.1. Power System Protection and Substation Automation

Protection and substation control have undergone dramatic changes in the last decade since the advent of powerful micro-processing and digital communication.
Integrated protection, monitoring and control systems are now state-of-the-art.
Multi-function feeder units, so called IEDs (Intelligent Electronic Devices) have replaced traditional conglomerations of mechanical and static panel instrumentation. Modern IED versions have multiple communication interfaces for local and remote PC based setting and retrieval of stored data and the connection to higher monitoring and control systems. IEDs are widely self monitored and allow event-based repair instead of regular preventive maintenance. Function integration is most advanced on distribution level. Combined protection and control IEDs unite all substation secondary functions including mimic display and keypad for supervisory control. They also provide a cost effective basis for future distribution automation. Only revenue metering has so far been exempted from IEDs and kept as stand alone unit with independent communication links.

On the transmission level, separate control and protection devices are still preferred for reliability reasons and because redundant protection schemes (main and back-up) often come from different manufacturers. Integration however has also been progressing here.
In total, a considerable cost reduction could be achieved by saving in hardware, space, wiring and maintenance. Consequently, a fast transition to digital technology took place in the field of power system protection. Higher performance could be offered at a much lower price.

The proliferation of digital substation control systems, however, is still hindered by the lack of vendor independent compatibility and open communication standards. A uniform utility communication architecture (UCA) has already been proposed by EPRI some 10 years ago and standardisation work is under way in IEC TC57. The substation communication standard IEC 61850 is now expected to be issued and approved in the next two to three years.

The trend of system integration can be expected to continue in the future due to the cost pressure in the competitive utility market and the continuing technological progress with all media.

The next larger innovation step will come with the highly integrated substation (HIS) using electronic current and voltage sensors instead of magnetic instrument transformers and LAN based serial communication (process bus) instead of parallel wiring. This will lead to a further 'dematerialisation' of the secondary technology as traditional measuring inputs and relay outputs can be dispensed with.

It questioned whether the current trend to common hardware platforms for protection and control will further proceed to general purpose hardware and even free programmable protection and control software based on open operating systems and standardised protection/control languages.

It can be expected that by 2020 the open communication standard IEC 60850 will be approved in practice and vendor independent compatibility from feeder level up to control centres will be possible.

The further progress in data acquisition (synchronised sampling, higher sampling rate), processing and storage capability (doubling every 18 months as per Moore’s Law) will allow further upgrade of protection functions and seamless monitoring and recording of load, fault events and switchgear state. Wide-band communication LANs and Internet technology (relay integrated servers and browser based dialogue) will make the information available at any place of the enterprise. The problem will however be to select the useful information from the large amount of indicated and stored data. Expert systems will have to take on this task.
The high resolution of sampled fault data will also allow to capture and evaluate high frequency transients (travelling waves) for fast detection, tripping and exact location of faults. Also extended power quality monitoring will be possible in this way.

Adaptive control and relaying may be used more often to allow higher system loading, and special protection schemes (SPS) using system-wide sampled data may be applied in larger scale to counteract power instability, voltage collapse or frequency deviation by automatic initiation of appropriate generation control, load shedding, islanding and system restoration.

Functionality, performance, and operation comfort of substation control will be enhanced corresponding to the current state of media (colour graphics, images, video, voice recognition, etc.). Wireless hand held devices may be used for local operation and services. There will be cross-links through fast WAN to system control and there will be a development towards totally integrated overall control systems. Access for operation and diagnosis will be possible from any place, even world wide via mobile communication.

Substation automation and remote control will increasingly extend to the distribution level. The much discussed distribution automation should have become reality by this time. One reason for that will be the growing complexity of distribution systems caused by the fast growing amount of distributed small-scale generation.

The further rapid system integration raises however application issues, in particular, with reduced technical staff resultant from utility privatisation and deregulation.

Users complain about the complexity of presently offered systems and ask for easy and vendor independent configuration, parameterisation and setting procedures. It remains to be seen if applicable standards and tools will be available by 2020 and if the promised “plug and play” compatibility can be achieved.

5.2. Communication Interfaces

5.2.1. General

Reliable and timely information is today a very valuable asset for any corporation and it will be still more important in the future.

Currently, computation is widespread used in planning, simulation, and optimisation of information data gathered from the field. As the coordination and control through the different players and layers of the network happens on different timescales, some efforts must arise to put them under computer control instead of being based on telephone calls between the system operators (at the utility control centres) and the rest of electric utility’s staff.

It appears clear that a new way towards process integration is needed in order to avoid the current and future constraints posed to power networks and their role in 2020's societies, e.g. decrease energy costs, allow for faster customer payments, improve power reliability and quality, provide the potential for variable priced energy provisions and sales, reduce utility operational costs etc.

The management of an integrated utility must be based on the use of Decision Support Systems that comprise financial, managerial, regulatory and operational information into a single platform that creates the knowledge managers needed to successfully run the business.

Figure 1 shows the relationships between the key aspects that have to be related in a future utility, to obtain the knowledge to manage it.

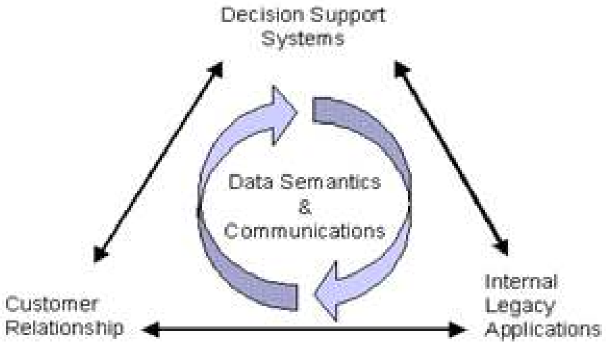
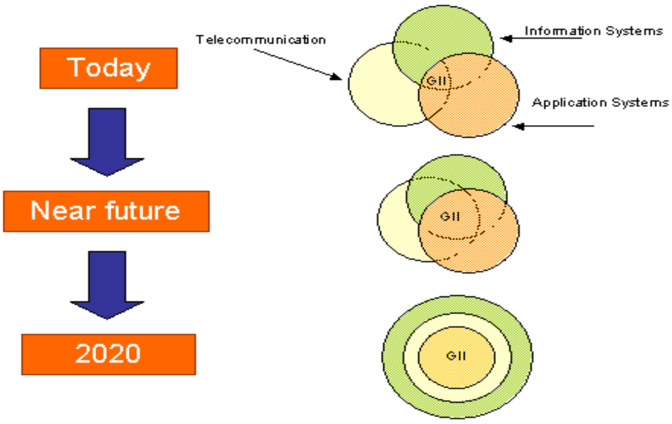


Figure 1

In order to achieve this, the communication infrastructure must be able to integrate all the aspects of the utility. Therefore standard communication methods (including protocols data semantics and security mechanisms to guarantee that every employee or external person only can access to their specific area of information) are required to effectively share data and the corresponding knowledge.

Figure 2 shows the possible evolution of the inter-relationships between communications, information systems and application support programs



GII – Global Information Infraestructure

Figure 2

5.2.2 Communication Issues

It appears that in a future, the main function of a Power network will no longer be the distribution of power but the support of the energy trading. This new working mode will require new protection and control schemes that will introduce greater demands to the telecommunication network and interfaces in terms of both bandwidth and functionality.

We have witnessed many changes in the technology used by Power System Control Networks, from analogue to digital, and evolving towards broadband networks. The change from analogue to digital will be similar to the change from broadband to all optical networks, which are networks that work only with light, that is to say optical interfaces and optical switches without electro-optical conversion at all. We can classify these changes as technological evolution but the changes we could foresee in the future will be more related with the working principles of the network, let's say, the way the network provides and support services. Nowadays, we are facing the second analogue network wave, the all-optical networks. By the year 2020, this wave will have passed and we will probably be starting the digitalisation process again, but this time with digital switching fabrics, networks switching photons instead of the actual wavelength switching, which is, in fact, an analogue system.

By the year 2020, the capacity provided by an access interface is unlikely to be measured in bit/s since some other aspects related with the serviceability of the interface will be much more relevant to the user. Interfaces with an equivalent capacity lower than 10 Gbit/s will be difficult to imagine if we extrapolate the progression of the access interfaces today. In fact, the limitation of the interface will not be the bit-rate but the serviceability, namely the connectivity, the access to certain services and facilities, and the way the service could be provided to the final user. A broadband wireless access network will probably complement this optical network. Nevertheless, the great bandwidth limitations of radio systems and the saturation of the spectrum will confine its use to local access devices not requiring large capacities (lower than Terabits/s).

Thanks to the availability of a new range of bandwidth, and the increase in power computing, the way processes are implemented and distributed will also undergo a tremendous change.

We are moving from pure transport networks to n-dimensional networks. The two main dimensions of this new paradigm will be the "communication function", which will maintain the end-to-end paradigm by acting as a big switching network, and a collection of overlaid layers of computational networks. These layers will host communicating nodules able to incorporate artificial intelligence and to work together to make the paradigm - “The network is the Application” - become operative and a real advantage to the final user.

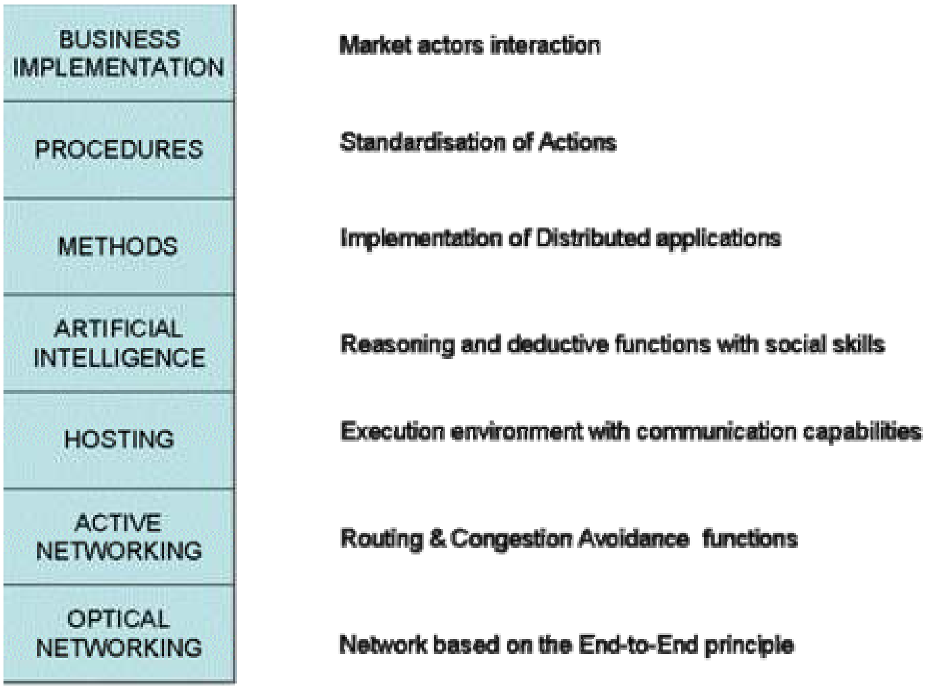


Figure 3. A possible seven layers approach

Under this new scenario, we can propose a new seven layers model - shown in figure 3 – to implement this new paradigm, (the present one is the OSI model of ISO, that includes Application, Service, Session, Transport, Network, Link and Physical Layers). Now the main function of the network is not only the communication of several sites but also the implementation of a distributed business. The access interface provides the connection to a market place, and in a more abstract way, the capability of interaction with a fully distributed application that in fact is the ‘network’.

Under this new model, the control and protection of the Power System is carried out from the business perspective, based on standard procedures and using a distributed intelligence to take decisions that consider the global optimisation of the system.

5.2.3. Conclusions

In 2020 we can expect: -

- Broadband communication channels (> 10 Gbit/s)
- Different physical media: optical fibre, microwave, infrared, PLC etc.
- Advance Distribution Automation, Protection schemes and Billing and Trading procedures (both between companies and company-customer).
- Use of multimedia systems (based on AI developments) for the control of the network.
- The change to “intelligent devices” into the customer premises allowing an increasing rate of information interchange with the different players of the electricity network.

6. ENERGY CONSERVATION

Energy conservation is a logical and a very effective means to reduce the environmental impact of energy consumption and, in many cases, additional generation capacity. However, one has to be careful, as the prime source of energy, the sun, is available in inconceivable large quantities, compared with human consumption of energy, which overall, has no effect at all. Energy conservation is not therefore a consideration for renewables i.e. solar energy, wind energy, wave energy, geothermal energy and even hydro energy, biomass energy or nuclear (fission/breeder/fusion) energy. But energy conservation is an important consideration to avoid fossil energy conversion and even there, not so much because of scarcity of available quantities of specific fossil fuels, but because of the environmental impact of the conversion. Coal and lignite have been found in enormous quantities, gas reserves are still growing, only the exploitation possibilities of oil wells are limited. Oil, by the way, being the easiest fuel to handle, to transport and to store.

It follows that from the point of view of preservation of energy sources, the discussion has to be limited to oil and possibly gas. From the point of view of environmental impact however, the large scale, current, technological solutions to generate electric power (or motive power) are to be blamed. Therefore the technologies as implemented today to convert fossil fuels, uranium and sometimes biomass and hydro, have to be restricted in their application. Maybe that future technological developments could change the scene; for example, by an economic method to encapsulate or exploit CO2.

It is important to consider the size and/or the number of power plants in relation to their environment. Large hydro power stations form a good example of environmental and societal impact by the civil works, the distortion of the hydrographical landscape and the resettlement of people. In the same way, it may be expected that large wave energy conversion plants, large windmill farms, large photo-voltaic systems (PV) or parabolic trough power plants will face resistance within the community. Only at locations far from civilisation, in geographically non-protected zones, will such large infrastructures be likely to be accepted in the future. The same statement is also probably applicable to large nuclear power plants.

In addition to the use of primary energy during operation, an environmental impact is also caused during the construction, operation and dismantling of the power plant and related facilities. For instance the life-cycle emissions in terms of CO2, SO2 and NOx (g/kWh) are minimal for nuclear and hydro and at the best optimal wind power plants; at least 5 times worse for biomass and solar thermal energy; 5 to 20 times worse for PV; and roughly hundred times worse for fossil fuel power [1][2][3]. Of course, in terms of radioactive emission nuclear power will rank very badly, as also do coal fired power plants. In addition, there are the strategic threats, such as proliferation (nuclear), terroristic attacks (nuclear, hydro), political instability (oil, gas) and catastrophes (nuclear, hydro).

Having said all that what is it that we are trying to conserve? It seems to be the conservation of the environment, including a conservation of raw materials, rather than the conservation of energy. However, as long as the use of energy, generated from non-sustainable sources, implies a detrimental effect on the environment, a saving of energy will contribute to a conservation of the environment. Incidently, some predictions suggest that fossil fuels are still likely to provide at least 70% of the world’s energy needs in the next few decades [4][5].

Primary energy can be saved by identifying and eliminating locations where primary energy is lost, e.g. flaring of gas in oil fields, leakages of gas pipelines, leakages and disasters with oil transportation. A further area of wasted primary energy is the loss of technical/economical opportunities to employ wind, wave, solar, biomass, geothermal, hydro, PV energy. Grasping such opportunities and taking account for the societal attitude will encourage these “savings” of energy.

Primary energy can also be conserved by improving equipment efficiencies e.g. improved heat rates (combined cycle plants, super critical boilers, improved gas turbine/steam turbine/hydro turbine blades) and reduced losses (in pipelines/during transportation and in transmission/distribution networks). The effective use of high-value energy (electricity, motion) in combination with low-value energy (heat, dissipation) implemented in technologies such as co-generation recuperation and heat-pumps, will be further deployed in the coming decades. New materials and new technologies will steadily lead to higher overall efficiencies, not only for electricity production, but also for the use of electricity.

However, more efficient technologies may lead to an increase of energy consumption, e.g. insulation of houses leads to heating of all rooms, high-efficiency bulbs leads to more lighting, better transportation to more commuter traffic etc.. Therefore the most effective method to conserve energy is to reduce the application of energy related commodities and services. For example, restrictions on travelling at high speed (aviation) / (TGV), limitations of travelling at normal speed (car).

It is very difficult to judge which applications are useful and where energy conservation can be achieved by a far-reaching limitation of use. Public awareness is important, maybe it has to be marketed as a trend, a drift, a common behaviour. But, as society, economy and individuals will resist a reduction in wealth, freedom and comfort of living, the tendency is to look for technological improvements of commodities and services, in order to conserve energy without eliminating the use of it. The choice for energy conservation solutions is made for both environmental and economic reasons, usually with an emphasis on the latter.

The rational use of electricity will be an essential keyword in the future. This implies a better use of facilities (kW) as well as energy savings (kWh). The potential for energy conservation by efficiency improvements of appliances is huge. Power consumption of systems for cooling, heating, cooking, ventilation and lighting can be reduced by 70% [6]. Such a reduction is only possible if advanced efficient technology is developed and deployed. The cost of such technology would correspond to an average per kWh conserved lower than the average fuel cost per kWh generated [7].

It still is a task of the governments to stimulate environment friendly technologies and attitudes, by means of premiums and penalties, obligations and prohibitions, informative and promoting activities. When the wheel is turning, the momentum of new business will grow and the market will take over, comparable with the recycling of old metals, cars, household appliances, electronics, computers, batteries, cables and wires, used gases, etc. Employment, economic gain, environmental conservation, societal acceptance are going hand in hand. Recycling leads to less waste, less consumption of energy as well as less consumption of raw materials. 80% of the metals can be recycled economically, leading to energy savings of 25% (copper) to 95% (aluminium).

It has to be realized that the global effectiveness of energy conservation will be difficult to be measured, as with the growth of global population and with the growth of well-being, especially in developing countries, energy consumption will increase. Furthermore, the energy share of electricity (at the moment 35%) will double in the coming decades [8]. But this evolution is not as bad as it seems, because the deployment of electricity in non-industrialized areas of the world normally replaces less effective and more polluting energy needs, besides the fact that "new" electricity most probably can be generated by renewable sources, such as small hydro, PV, solar, geothermal, wave and wind energy.

Apart from conserving energy in large interconnected power systems, energy savings are of interest for stand-alone applications and networks. Small scale and application dedicated generation (for instance: PV) will reach a technical/economical threshold earlier in combination with smart, advanced and integrated solutions to save and store electricity. One could imagine optimal DC-voltage levels, batteries integrated in the appliances, less or no conversion of voltages, natural cooling replacing forced ventilation, etc.

Summarizing: despite the fact that there is plenty of energy available, energy conservation is a must to limit the conversion of fossil fuels, to reduce the environmental impact of large or numerous power plants, to facilitate renewable energy sources and to stimulate recycling of raw materials. The possibilities for energy conservations are countless, as well as promising.

7. MATERIALS

7.1. Indoor Solid Insulation

In the last 30 years two synthetic solid insulation materials have been widely used in components of electrical power systems. These are polyethylene used mainly as cable insulation and cast resin materials used in high voltage and low voltage systems. These materials are distinguished, as they are easy to handle, have excellent electrical and dielectric properties and have good resistance against chemical stresses. Where as the operating temperature of Polyethylene (PE) is limited to about 90 °C cast resin materials can withstand thermal stresses up to 300°C. Furthermore cast resin materials have excellent mechanical properties. For this reason this solid insulating material is widely used in electrical applications for switchgear, bushings, rotating machines and transformers. By variation of the moulding material components the properties of the insulating material can be adapted to the application requirements.

An important influence on the electrical behaviour of a filled cast resin insulated system is that internal mechanical stresses are frozen in the solid material during the manufacturing process. This results from different coefficients of thermal expansion of the resin system and associated encapsulated materials e.g. the windings in dry type transformers. The interface between the matrix and the enclosed metal and the interface between the matrix and filler are critical points where cracks may occur. These defects can lead to partial discharges (PD) and finally to an electrical breakdown of the insulating system.

Polyethylene is used mainly as cable insulating system. Nowadays PE-insulated cables are in operation up to a voltage of 500 kV. PE has very good electrical properties. Critical features of PE are PD and water. Improved technologies now allow the manufacture of cables with significantly improved PD characteristics. Similarly special construction techniques minimise water penetration after laying.

A comparison of solid insulation systems with liquid/solid insulation systems shows the following: -

Advantages: -

Easy working properties
No environmental problems
Higher operating temperature is possible with resin systems
Less danger of fire hazard
Mechanical stressing is possible

Disadvantages: -

Heat transfer ability is not good
Susceptible to PD
Susceptible to varying mechanical stress
Susceptible to changing thermal stress

The above descriptions show that very few solid insulation systems are currently used in the EPI. There are very many materials; particularly many polymers that could well have applications in the EPI. Possible future materials should have characteristics ideally meeting the following requirements: -

Higher temperature class
Good PD performance
Good electrical performance
High surface resistivity
High processing performance
Good heat transfer ability

7.2. Liquid and Solid /Liquid Insulation Technology

Although solid and gaseous insulation have become increasingly important during the last decades the use of mixed insulation (solid/liquid) is still essential for some applications, e.g. transformers.Transformers are one of the key components of electric power distribution and transmission systems and their reliability is of paramount importance. Their reliability is limited by the reliability of the winding insulation system which also has to operate as a heat transfer medium, disposing losses from the core and windings. Even today the most frequently used insulation systems in these devices are still the traditionally used liquid immersed paper and pressboard insulation. Due to cost constraints a combination of cellulose paper and mineral oil has been the most common choice of materials, although for special applications different combinations of insulating liquids and of porous solid insulation immersed materials are in use.

Notwithstanding low cost and good electrical properties there are some disadvantages of traditionally used insulation systems, in particular the low fire point, ageing behaviour and environmental aspects. Further, due to the potential fire hazard transformers in domestic areas using mineral oil, PCBs were commonly used. At the beginning of eighties the production of PCB was prohibited in view of its environmental concerns. Since that time there has been a continuing search for PCB substitute materials.

7.2.1. Ester Liquids

When searching for a PCB substitutes, ecological considerations were paramount in the search for a non-combustible and non-toxic liquid dielectric having good cooling properties. Ester liquids consisting of organic esters were proposed for distribution transformers. The method of obtaining such a liquid consists of synthesis. The ester used for transformers consists of Pentaerythritol-Tetraester and different fatty acids. The fire resistance of this liquid is much higher than that of mineral oils. Ester liquids are somewhat in an intermediate position however, between PCBs and mineral oil based on flash ignition and self-ignition temperature. Ester liquid belongs to the HFP (high fire point) liquids also known as “less inflammable“ liquids. By definition a HFP liquid must have a minimum fire point of 300°C. Ester liquids are non-toxic, well digested by micro organisms and posses a low vapour pressure at operating temperatures of power transformers. In a fire they generate no dioxins or toxic products and possess a good ability for biodegradability. Ester liquids can be used for the retro filling of mineral oil filled transformers. Mixing ester liquid with up to 3% mineral oil has not negative influence on the electrical and dielectric properties. Ester liquids possess good ecological properties, this feature together with the ability to dry the solid insulation (impregnated paper) are considered as positive. However, the viscosity, which is the principal parameter for heat calculations, is higher than that of transformer oil; slightly larger cooling channels are generally required. Esters are also prone to the possibilities of hydrolytic detachment through moisture content.

Table 7.1: Technical properties of ester liquid Midel 7131 and mineral oil

General physical properties	**Standard**	**Midel 7131**	**Mineral oil *)**
Density at 20°C at 90°C	DIN 51757	 0,96 g/cm^3 0,915 g/cm^3	 0,856 g/cm^3 0,810 g/cm^3
Pour point		-50 °C	-20 °C
Toxicity		non-toxic	slightly toxic
Ability to biodegradability		very high	high
Water saturation at 20 °C at 100 °C		 max. 2700 ppm max. 7200 ppm	 max. 45 ppm max. 650 ppm
Heat transfer capability			
Cinematic viscosity at 20°C at 90°C	DIN 51561	 63 mm^2/s 7,7 mm^2/s	 16 mm^2/s 2,3 mm^2/s
Calorific capacity			

at 20°C at 90°C		0,165 W/(m K) 0,155 W/(m K)	0,135 W/(m K) 0,125 W/(m K)
Specific heat at 20 °C		1,81 kJ(kg K)	1,85 kJ(kg K)
Expansion coefficient		7,5 10^{-4}/K	6,9 10^{-4}/K
Fire properties			
Flash point	DIN ISO 2590	310°C	150-175°C
Flame point	DIN ISO 2592	257°C	130-135°C
Combustion heat		36,8 kJ/kg 10^3	46 kJ/kg 10^3
Self ignition temperature	DIN 51794	405°C	330°C
Electrical properties (all the data are relative to a temperature of 23°C)			
Breakdown strength (ac)	DIN IEC 156 VDE 0370 Part 5	55 kV	60 kV
Permittivity ε_r (50 Hz)	DIN 57370/1	3,3	2,2
Dissipation factor tan δ (90°C)	DIN IEC 247 VDE 0370 part 2	10 10^{-4}	<10 10^{-4}
Volume resistivity	IEC 247	20 10^{-12} Ω cm	100 10^{-12} Ω cm
*) The data are mean value obtained from many manufacturers.			

Some characteristic properties of the alternative liquids are summarised in Table 7.1.

For many years ester liquids have been used in distribution transformers. These liquids comprise several additional advantages, firstly their lower inflammability and secondly, their high hygroscopicity. High hygroscopicity is usually seen as a disadvantage but may be a benefit when a solid insulation is in contact with the insulating liquid where water, assimilated at the solid insulation, can be extracted.

Further, ester liquids and mineral oil possess an almost similar density. They are completely mixable at any ratio. Almost all electrical and dielectric properties of ester liquids are similar to mineral oils despite the relative permittivity $_r$, which is higher (3.3) than those of mineral oils (2.2). This is however, an additional benefit if the ester liquid is used for impregnating cellulose as the relative permittivity is closer to that of cellulose, (about 6), thus resulting in a more uniform electrical field distribution within the combined insulation.

One of the few aspects, that have not yet been investigated, is the triple surface between the solid insulation, its impregnant and the bulk oil, that surrounds them. If the solid insulation impregnant and the bulk oil are similar in permittivity then this is similar to a transformer that has been completely filled with the liquid used for impregnating the solid insulation. If the two liquids are different an exchange of the bulk oil has taken place. This could happen with the refurbishment of an aged transformer, originally impregnated with mineral oil and now filled with an ester liquid.

Oommen et al point out that the rate of degradation of the insulation in transformer depends on several parameters. The principal parameter being the type of paper, its pulp composition, thermal upgrading, moisture content and temperature. The presence of moisture in a transformer deteriorates insulation by decreasing both the electrical and mechanical strength. The life duration of the transformer is thus assumed to be the life duration of the paper insulation. It means that the life expectancy of a high voltage transformer may be determined by the state of the insulation paper. The higher the water content, the higher the degradation rate and reduction of the expected lifetime of transformer. In general, the mechanical life of the insulation is reduced by half for each doubling in water content. The importance of moisture presence in paper and liquid systems has been recognised since 1920s and is still the core of many investigations and will it also be in future.

7.2.2. Water in Insulating Liquid

Water in the insulating liquid originates from air moisture in the case of ‘open-breather transformer’ or ‘oil-conservator’ types, and as a by-product of oxidation reactions taking place in the insulation liquid and thermal decomposition of cellulose-based solid insulating materials. Water can exist in insulating liquids in three states namely dissolved, emulsified and dispersed. Insulating liquids, such as transformer oil, have a low affinity for water (however, the solubility increases considerably with temperature for normally refined naphthenic transformer oil). Their electrical parameters are strongly influenced by the water content, and a high moisture level decreases the operational safety. Moisture increases electric conductivity and dissipation factor and worsens electric strength. Moisture in oil is measured in parts per million (PPM) using the weight of moisture divided by the weight of oil (μg/g). When the moisture in oil exceeds the saturation value, there will be free precipitated from the oil in suspension or drops.

The purpose of the low limits suggested for water in new oil contained in new transformers is to ensure that both the paper insulation in a transformer and the oil itself are adequately dry prior to filling the transformer.

Typical values for service-aged transformer oils are about 15 ppm to 30 ppm. For example, oil samples provided from operating transformers with operation varying between 18 and 30 years lead to the table 7.2. As can be seen oil and other materials in a transformer degrade with time in service and many of the products of degradation are reflected in the acidic content and consequently on the dielectric properties of the oil.

Table 7.2: Parameters of (mineral) oil samples from service-aged transformers

Service aged (years)	18	24	30
Water content (ppm)	6.1	15.2	25.2
Breakdown strength at 20 °C (kV/cm)	>300	286	258
Total acid concentration KOH mg/g	0.02	0.09	0.08

The water in the oil and the paper insulation of the transformer reaches equilibrium. The correlation of moisture content of the insulating liquids and impregnated paper is shown in figure 7.1 for cellulose paper impregnated with mineral oil, silicone liquid or ester liquid.

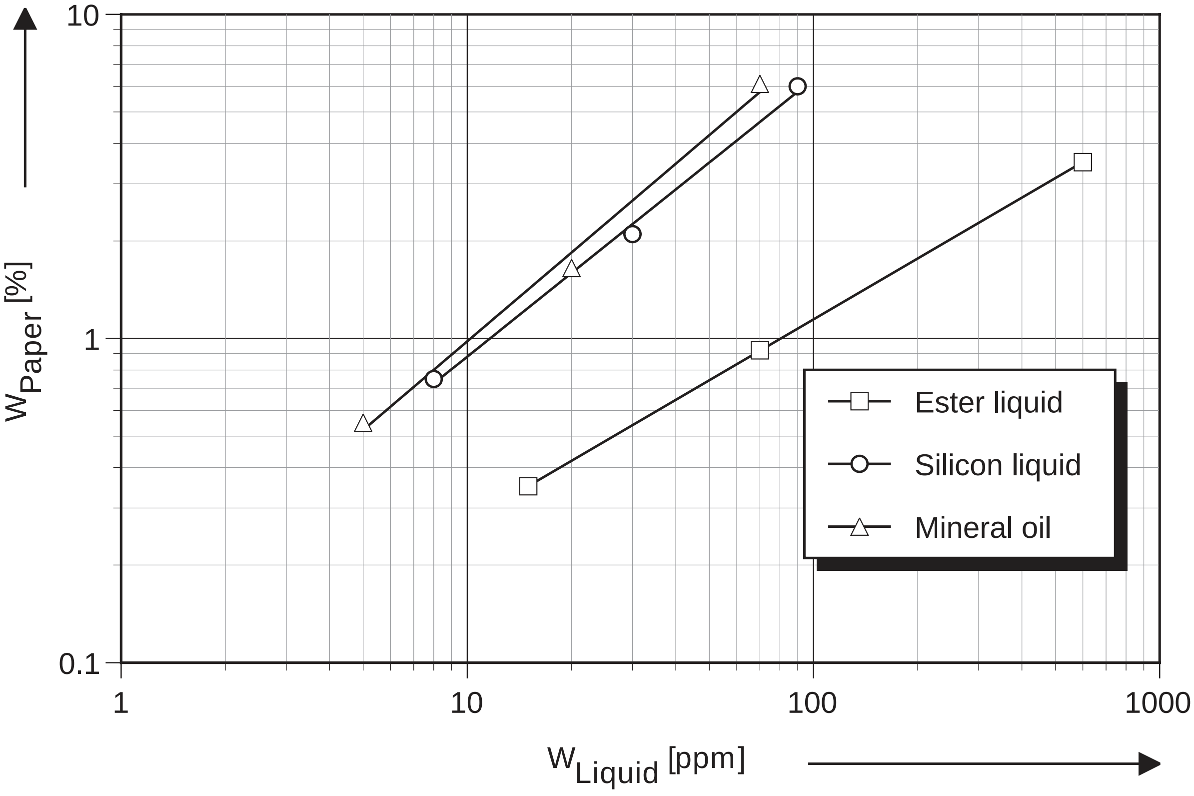


Figure 7.1: Moisture equilibrium of different liquids - cellulose paper complex at 20°C

As can be seen, there is no significant difference between the silicone liquid and the mineral oil. This behaviour is due to the moisture content of the insulating liquids, which is almost the same for the investigated temperature (20°C). The curves also show that using an insulating liquid with a high water saturation limit (ester liquid) a lower water content in the insulating paper results compared to other insulating liquids having the same absolute water content but a lower water saturation limit.

Because of the described advantages, insulating liquids together with solid insulation are likely to remain the most appropriate solution for transformers for the coming decades.

In comparison with solid insulation, solid/ liquid insulation systems advantages are: -

Better heat transfer ability
Convection and self-healing
Possibility of reconditioning or replacement of the liquid insulation if its condition has deteriorated
Less susceptible to PD

Disadvantages are: -

Fire hazard
Possibility of explosions
Environmental hazards resulting from leakage
Different permittivity between solid and liquid insulation can cause field distortion at the interface
Migration of water molecules between solid and liquids can cause failure in the liquid at low temperature
Cellulose as solid insulation does not allow higher operating temperature

Future mixed insulation systems should fulfil the following requirements: -

Environmental compatibility
Non-flammable
High operating temperature
Low ageing characteristics
Long term compatibility between solid and liquid insulating material
Similar permittivity of solid and liquid
Low influence of humidity
In case of fire low smoke production and non toxicity
Last but not least the facility for size reduction

7.3. Gaseous Insulation Technology

In addition to the traditional gases of vacuum and SF_6 there is a trend to create gas mixtures which combine excellent dielectric properties with low cost and improved environmental aspects.

Vacuum interrupters are designed for circuit breakers and load switches in SF_6 switchgear.

SF_6 is in commonly used for the insulation in GIS and GIL. Its disadvantages are a rather high liquefaction temperature, its contribution to the greenhouse effect and its relatively high cost. For these reasons the search for an alternative gas to SF_6 is of considerable interest. SF_6/N_2 mixtures have been proved a substitute from the ecology and economical considerations. N_2 is an absolute uncritical gas in terms of environmental compatibility; it is a naturally occurring gas in large proportions in the atmosphere. Pure N_2 as insulation medium would require unrealistic and uneconomic equipment designs for the desired insulation levels. Adding some SF_6 to N_2 the gas mixture produces a good insulation capability that can be applied in GIS or GIL. The breakdown behaviour of the gas mixture depends on the concentration of SF_6 (5% … 20%) in N_2 and on the pressure.

Insulating gases have to fulfil two main functions in GIS, firstly insulation and secondly to allow arc interruption. Using SF_6/N_2 gas mixtures for arc interruption to is inferior to pure SF6, so the gas mixture cannot be used for this purpose. If we examine the total gas volume of a GIS using a gas mixture of 83 % SF_6 and 15 % N_2 and differentiate between insulating and arc interruption, we get the minimum and maximum saving for SF_6 volume. The SF_6-saving in GIS amounts between 14% and 36,4%. Increasing the pressure from 0,4 MPa to 0,8 MPa ensures the appropriate insulation strength.

The search for alternatives for SF6 has been ongoing for a number of years but to date there seems little hope of finding a more suitable alternative.

7.4. Outdoor Solid Insulation Technology

In addition to ceramic insulators, polymer technology is more and more used for outdoor Insulation. In the table 7.3 electrical and mechanical properties of different materials are shown.

Table 7.3: Properties of Outdoor Insulating Materials

		Ceramic	Epoxy resin	Silicone
Dielectric strenght	kV/mm	20...40	15	23
Volume resistivity ρ	Ω cm	10^{12}	10^{14}	$10^{15}...10^{16}$
Relative permittivity ε_r	-	6	4	3...4
Dissipation factor tan δ	-	5×10^{-3}	1×10^{-2}	$4...10 \times 10^{-3}$
Leakage current resistance	-	KA 3c	KA 1	KA 3c
Density	g/cm³	2,3...2,4	1,6...1,8	1,08...1,53

7.4.1. Silicone Insulators

The components, glass fibre as substrate and silicone as external insulation, combine the advantages of polymer composite insulators. Hydrophobicity, low maintenance costs, low weight, high mechanical strength and good resistance against vandalism are among its advantages. The effect of hydrophobicity is almost independent of the age, pollution and degradation. Performance is dependent upon the different types of silicone are used i.e. RTV, HTV, LTV or LSR. Weathering, corona and flashover can cause the surface to be chemically stressed and leakage paths can damage the insulator. These problems can now be largely prevented by new methods of manufacture and test.

The application of composite insulators to bushings of power circuit breakers made with silicone rubber have proven to be outstanding, offering the following advantages over porcelain insulators: -

Self-renewing and water repellent finish which resists surface contamination,
Higher wet dielectric strength,
Seismic resistance,
Impact resistance,
Explosion-proof,
Light weight.

Composite breaker bushings were introduced in 1990 and today more than 5000 are already installed at voltages between 72 and 550 kV. The largest new composite insulated bushing is for an application at a rated voltage of 800 kV and was produced in one piece. The design of composite bushings is optimised to make them more cost competitive with porcelain, e.g. the shape of new bushings is of straight tubular and conical form to reduce the SF_6 gas volume, weight and to optimise the size of high voltage terminal shielding

7.4.2. Ceramic Insulators

Ceramic insulators can be coated with a layer of RTV silicone. The surface gets a hydrophobic property and the leakage current is minimised. The silicone coated insulators are applied in areas of high pollution where cleaning is difficult, e.g. in tunnels of railways.

Semi-conducting Glazed insulators are ceramic insulators coated with a semi-conductive glaze (SCG). Surface drying effect and uniform voltage distribution due to SCG achieves excellent contamination withstand voltage characteristics, being three times higher than that of the ordinary glazed insulator having the same shape. Further, they suppress PD on the insulator surface, even under contaminated conditions because of its heating and grading effects. The SCG insulators are equipped with a zinc sleeve which is a standard part of the design of these insulators and which helps to extend their service life. The thickness of the SCG layer is a criterion, it is thicker than the normal glaze, but if the layer is too high the benefit effect is lost. A continuous small sinusoidal current flows along the insulator surface; this is further beneficial in preventing early pin corrosion. Pin corrosion is assisted with biased, asymmetrical current flows which are found in partial arcs. The DC component of the current causes electrolytic corrosion. In the case of SCG, even if dry bands are formed, current flows into the glaze so that voltage stress is controlled at a level low enough not to cause partial arcs (see figure 7.2).

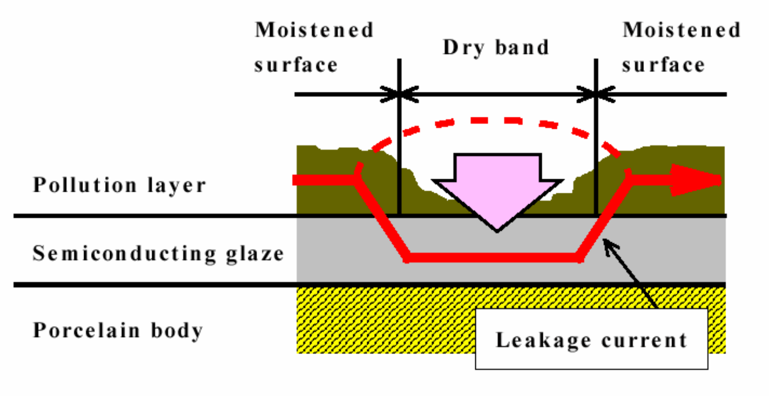


Figure 7.2: Suppression mechanism of partial discharge at semi-conducting glazed insulators [1]

Compared with different insulator types, such as porcelain, air gap and composite types, the flashover voltage in dependent upon relative humidity of the SCG insulator, it shows a smaller rise and it is closer to an absolute humidity of 36 g/m³ (see figure 7.3).

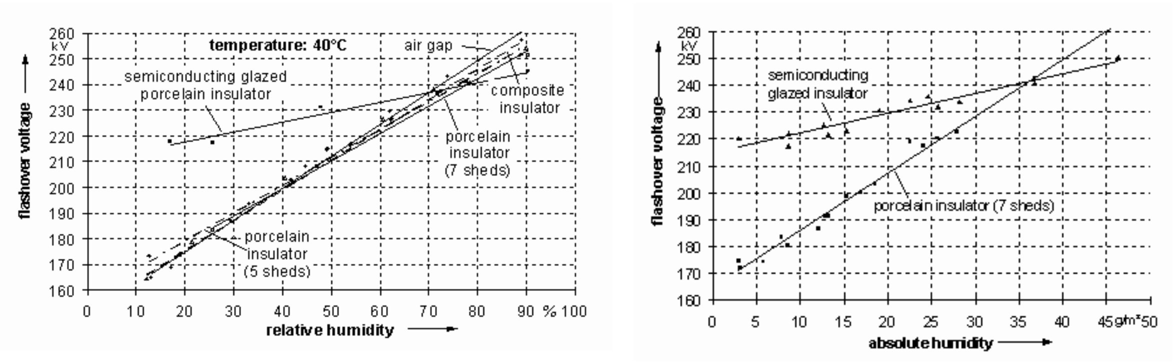


Figure 7.3: Dependence of the flashover voltage on the rel. and abs. humidity for different insulator types [2]

7.4.3. Insulator Surface Phenomena

One phenomenon is the temporary loss of hydrophobicity, under exposure of corona, plasma or UV discharge (direct loss). After the exposure the hydrophobicity recovers very soon, this effect is very beneficial for high voltage insulation systems. Also, contamination of the surface occurs due to a degradation of the hydrophobic effect (indirect loss). Continuous water films are not formed on hydrophobic silicone rubber surfaces and so higher flashover voltages are expected on heavily polluted composite insulators. The physical and chemical mechanism of the hydrophobic degradation and self-healing effect is not totally researched. One fact is that with the pollution of the surface, low molecular components (Low Molecular Weight, LMW) diffuse into the silicone [1].

Another phenomena is the biological contamination of the surface. Three types of biological growth have been observed: fungus, algae and lichen. Fungal growth can become especially important since its roots can penetrate into the material and thereby create a porous structure close to the surface. Usually silicone rubber surfaces exhibit resistance to fungal growth. Nevertheless, such growths on silicone rubber insulators were recently reported from Florida. Algae do not penetrate into the material surface but rather grow over a wider area and therefore may change the surface properties of the insulator. A relationship of a single species of algae and fungus is called lichen. Algae and lichen growths have been reported on porcelain and glass insulators from Papua New Guinea, Paraguay, Mexico, New Zeeland and USA [2].

7.4.4. Cryogenic Insulation Technology

The discovery of revolutionary high temperature superconducting (HTS) compounds in 1986 led to the development of a radically new type of conductor for the power industry. The HTS wire is a ceramic material that becomes superconducting at a temperature of 77 K. This temperature is the boiling point of nitrogen; a technical and commercial application became realistic. Because of the very brittle properties of ceramic materials, the HTS wires are constructed as a multifilament wire. The newly developed HTS wires were used in all power systems for generation and transmission of electrical energy e.g. generators, transformers, motors and cable and also for new technologies for special applications in coils.

Figure 7.4a illustrates the complete loss of resistance to the flow of electricity through wires of an LTS material (niobium-titanium alloy) and an HTS material (bismuth-based, copper oxide ceramic) at the critical temperature T_c which is different for each superconducting material. The specific HTS material in this chart has no electrical resistance below 108K as opposed to the specific LTS material in this chart, which has no electrical resistance below 10K.

Figure 7.4b shows the conditions required for a material to exhibit superconducting behaviour

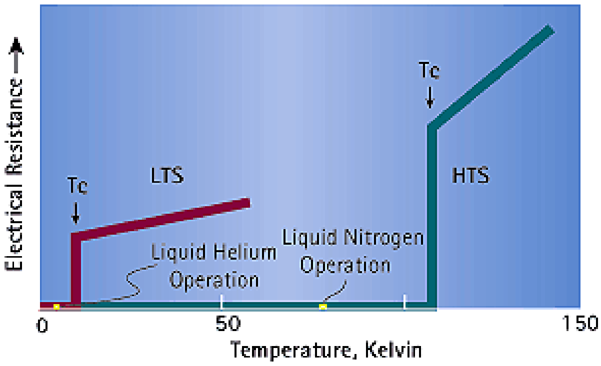


Figure 7.4 a, b: Superconducting behavior of HTS and LTS materials [6]

The manufacturing process of the ceramic HTS filament wires is called OPIT (Oxide-Power-In-Tube). After pre-treatment and filling the silver alloy into tubes monofilaments are extruded and bundled to multifilament wires. Then there are several extrusions until the correct diameter is achieved. The wires can be deformed and rolled to very flexible HTS tapes. A modern HTS multifilament wire such as Bi-2223 has electrical properties shown in table 7.4.

Table 7.4: Properties of Bi-2223 [6]

Thickness (avg)	0.21 (+/-0.02mm)
Width (avg)	4.1 (+/-0.2mm)
Je (min)	13.5 kA/cm^2*
Ic (min)	115A*
Max Stress (77K)	75 MPa**
Max Strain (77K)	0.15%**
Min. Bend Dia.	100 mm**

The HTS tapes are used for the production of electrical power equipment. For example, there are two types of HTS power cables, “warm dielectric cable” and “cryogenic dielectric cable” (see figure 7.5). The first type features a conductor made from HTS wire wound around a flexible hollow core. Liquid nitrogen flows through the core, cooling the HTS wire to the zero resistance state. The conductor is surrounded by conventional dielectric insulation. The efficiency of this design reduces losses. The second type is a coaxial configuration comprising an HTS conductor cooled by liquid nitrogen flowing through a flexible hollow core and a HTS return conductor, cooled by circulating liquid nitrogen. This represents an enhancement to the warm dielectric design, providing even greater current carrying capacity, further reducing losses and entirely eliminating the need for dielectric fluids. A benefit of HTS cables, besides reducing losses, is for replacing existing cable systems to achieve larger current flows at relatively low cost.

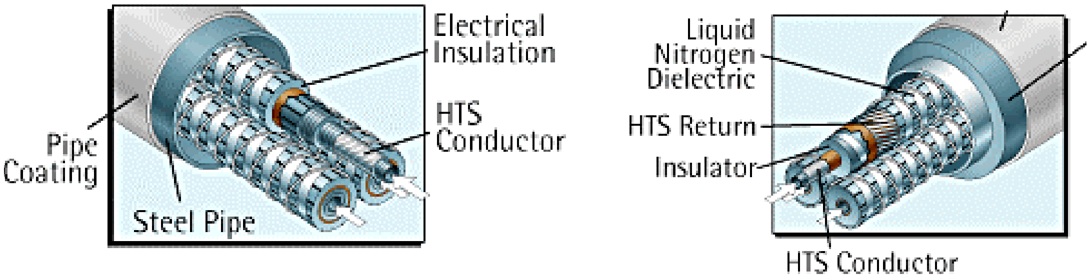


Figure 7.5: HTS cable: warm dielectric cable (left) with conventional insulation and cryogenic dielectric cable (right) with liquid nitrogen insulation [6]

Another application of HTS tapes is in the use for coils, which can be used in transformers. The loss evaluation of conventional transformers shows an efficiency between 90% for traction and up to 99% for power transformers. The efficiency of traction transformers can be increased with HTS technology. In addition, the weight and volume can be reduced up to 40%.

HTS conductors are also used in coils for medical and electrcotechnical devices. A superconducting magnetic energy storage system (SMES) serves to compensate voltage sags and momentary interruptions of the high voltage grid to prevent expensive disruptions of microprocessor controlled machines in manufacturing lines. The essential part of an SMES is the helium cooled superconducting coil. With a SMES voltage sags up to 75 % and interruptions up to a second can be compensated.

A fuller review of high temperature super conductor applications in Electrical Power Systems can be found in Ref [7]

7.5. Conclusions

The foregoing descriptions in 7.1.to 7.3 relate to existing technologies and have attempted to highlight current shortcomings and then to present the idealised requirements for possible new materials. For further detailed information on Advanced Materials readers are referred to ref [8], where an attempt has been made to highlight new materials of interest to relevant Study Committees. Table 7.5. is reproduced from this document.

Table 7.5. Suggestions for advanced materials of interest to different Study Committees.

MATERIALS TECHNOLOGY	***CIGRE STUDY COMMITEE***						
	11	**12**	**13**	**21**	**22**	**23**	**33**
Polymer Composites		X			X	X	
Metallocene Polymers	X	X	X	X	X		
Conducting Polymers		X	X	X			X
Ceramics	X			X			X
Elastomers			X	X	X		X

KEY:		
	SC-11	Rotating Machinery
	SC-12	Transformers
	SC-13	Switchgear
	SC-21	Cables
	SC-22	Overhead Lines
	SC-23	Substations
	SC-33	Insulation Coordination

More specifically, in the current equipment fields the following avenues of investigation were proposed: -

Switchgear:

Advanced epoxy formulations
Modified filler – PTFE formulations

Cables : -

Polymer blends
Metallocene technology
Conducting polymers
Cryogenic issues

Transformers: -

Revisit polyamides (aramids)
PAN
Paper – polymer blend update

Overhead lines: -

Elastomer comparison
Stabilisation issues

Substations: -

Evolution of compact substation needs

This Paper has discussed many of the new emerging technologies and this section has attempted to review current knowledge and shortcomings of commonly used Power Industry materials, avenues for further possible investigation have been suggested. It is perhaps now opportune to undertake a further review of possible idealised material requirements for these newer developing technologies.

8. END CUSTOMER NEEDS

To understand the challenge, and the need for new infrastructure developments, one needs to create a view of the end-user needs of the future. It is from this point, one can determine the R&D investment requirements, and inspire the needed regulatory environment. The key issue is: will the bulk electricity system evolve to become the critical infrastructure supporting the digital society of the 21st century, or be left behind as an industrial relic of the 20th century?

The key trends affecting the energy business are:

- Rise of a universal digital economy
- Heightened productivity growth through networked intelligence
- Evolution of competitive electricity markets
- Proliferation of distributed generation and storage devices
- Heightened environmental concerns

These new environment must be supported by infrastructure changes. Therefore, the power system must ensure that transmission networks support stable wholesale power markets, integrate distributed resources and facilitate differentiated customer services, provide standardize digital devices to achieve “plug & play” compatibility and reduce electromagnetic sensitivity and keep pace with telecommunications and encourage infrastructure convergence. Clearly, this will require a different architecture than currently exists. The power system will need to accommodate consumer choice, be directed by real-time price signals and a myriad of consumer service options and provide much higher reliability.

To support the customer needs, some of the characteristics of the new power system would be:

- Provide a resilient, self-healing electricity supply system
- Open the consumer gateway now constrained by the meter
- Respond in real-time to billions of consumer decisions
- Transform the distribution system from radial to network configuration
- Facilitate communications convergence
- Make more productive use of existing rights-of-way

However, the power system must be enhanced to provide this functionality to meet customer needs. This will require investment in new technology such as:

New technologies will be required
- Sensors for real-time monitoring and complex network control
- Electronic power flow control
- Real-time dispatch of distributed resources
- Interference-free power line communications
- DC micro grids for premium power service
- Digital devices with greater tolerance to power disturbances

Driving power systems towards a low-cost provider of electrons will not support the needed investment in services that customers need. Recognizing the fact that power systems are service providers, rather than simply a commodity provider must be understood more fully, and incorporated into a more integrated approach towards planning and building the system of the future.

9. RESEARCH & DEVELOPMENT OBJECTIVES

In the coming decades electrical energy will remain a major carrier of energy for industrialised as well as developing countries, but the change is in the way we operate and conceive the power system. The latter change is fast and currently driven by new deregulation and liberalisation state policies. R&D has to provide new engineering solutions, which cope with increasing demands regarding availability and quality of life & power, safety and health concern. For instance sustainable performance and the huge increase in local power demand of telecom switches and data hotels of our "digital society" are relying on the progress of new research underlying advanced and complex solutions in the future electric power infrastructures.

For a sound and reliable management of the high-voltage assets, not only technical optimisation is a necessity, but also the economical and societal constraints play an important role. This has to result, amongst others, in more compact and durable concepts, improved lifetime management and safety concepts. Power electronic and electromechanical devices are replacing hydraulic and mechanical devices. Electrical power is converted with more precision at high efficiency in consumer, ICT, industrial and power system applications. New priorities in design and operation of electric equipment are necessary, focusing on intelligent power networks with information support systems and higher power densities in transmission and conversion techniques of special relevance to renewable energy generation.

A silent electric revolution is taking place with breakthroughs in the power technology of the near future, which should fall within the so-called sustainable zone, i.e. new technological concepts will be in the cross section with three performances: the economic, social and environmental (ecological) performances.

Fundamental investigations are necessary as basis for the new technical concepts, which are addressing the future sustainability requirements in the field of high voltage technology concepts and ultimate asset utilisation. In particular the focus will be on:

1. Electrical infrastructure with higher energy densities, e.g. high temperature super-conducting and power electronics devices to allow for high current densities and intrinsic load limitation.
2. Fundamental understanding of ageing processes in high stress materials for HVDC power and industrial applications, addressing more power density and more compact designs and systems, which enables integration with intelligent functions of miniature sensors and self healing and diagnostic materials.
3. Development of new materials and systems which can perform under higher multifunctional stresses, intelligent smart diagnosis systems, compact low-maintenance, self diagnosing systems for use during operational lifetime and new compact designs.
4. New high power density HVDC distribution and transmission systems for long distance applications linking to delocalised feeders or generators (windmills off shore!).
5. Further utilisation of diagnostic principles for localisation and identification of faults, by a deep understanding of fundamental processes of electromagnetic and acoustic wave emission at different defect states in the electrical equipment, and the possibilities of wave propagation modes in complex full scale equipment for early warning intelligence in the future.
6. Basic ageing theoretical modelling to build upon the knowledge rules of decision support systems for extended and/or overloaded use of HV equipment, while including safety and reliability concerns.

Since the policy changes mentioned, the tendency in industrialized countries has been to decrease the number of collective research projects in the power industry. More investigations were kept in-company for reasons of savings and competitiveness. Additionally, fundamental investigations and advanced techniques were more subcontracted and respecified as university research. Nowadays yearly 2-4 % GDP is spent by industries and universities on R&D, which is the driver of the new technology to power our electric future. Important technological breakthroughs are underway which address the abovementioned challenges e.g.: -

From research to development stage: -

- HTSC for high current density systems (cables, generator, transformer, SMES)
- Dryformer, powerformer, both making use of extreme pure quality of XLPE, and as a result an oil-free system
- MW power wind generator
- HVDC transmission systems (space charge solution)
- High dielectric stress density materials for compact/solid substation designs
- GIL gas mixtures, replacement for SF6

New fields of research: -

- New insulating liquids, biological fluids
- Fibre-optics for sensors and protection
- Smart integrated diagnostics
- Remote sensing
- Fuel cells, not producing CO2
- Solar cells, manufacturing cost savings
- HT superconducting materials
- materials for storage, super-capacitive
- DC/AC converters
- corrosion resistant materials for power electronics
- Power electronics from FACTS, HTS systems, to efficient LV consumption
- Conductive plastics

Applied R&D for existing infrastructure and to include ageing as a design property in new equipment: -

- Understanding of aging or deterioration processes of material constructions
- Assessment of better knowledge rules to maintain the future performance of equipment
- Self diagnosing, self healing properties
- ICT support systems for asset management
- Save experts knowledge over the decades to come

Physical/social hurdles: -

- Is there enough fossil fuel after 50 years?
- Carbon dioxide production continues
- Material costs and source location limits renewable energy production
- Market barriers, social acceptation time 10-20 years
- Infrastructure facilities take decades, e.g. hydrogen society

Today's electrical power assets have to meet increasingly stronger economical and societal constraints in addition to higher reliability and loadability requirements than ever before. In this connection technological changes are coming up of more compact and sustainable concepts, of which a better understanding of the fundamental physical and chemical processes is needed in order to exploit the materials at the utmost and to reach at ultimate designs. To enable this in the near future, more knowledge of fundamental physics is required of for example, gas breakdown of microscopic voids, interfacial space charge thresholds and electrical/physical ageing theories underlying new high performance insulating materials stressed at high power densities as well as under extreme lifetime extension and asset management, including the safety and environmental aspects. An interdisciplinary approach, encompassing fields such as material physics, signal analysis, electromagnetic engineering, intelligent diagnostic techniques, digital processing, knowledge support systems, are prerequisites for technological and scientific advancement, being the backbone of the generation, transmission, distribution and consumption of electricity of the future.

10. FINANCING LONG TERM INVESTMENTS IN NEW TECHNOLOGY

Power systems currently provide a reliability that varies depending on regional characteristics, design criteria and operational rules. However, the demands on the current system are changing, as higher reliability is being sought by an increasing number of users. Therefore, not only is price an objective, which is the current driver towards liberalization, but also a new customer requirement is emerging: high reliability to support the customer's digital applications.

Investments in the future power system to meet this need will require Research & Development costs to support its development. Currently, ongoing investments in R&D are not adequate to meet the needs of the future. The power system currently is trending towards under-investment due to regulatory uncertainties and the drive towards efficiency. One must recognize that the most efficient system may not necessarily meet the needs of the future.

There are a number of ways that this financing can take place:

1. Supportive Regulatory Environment and Associated Policies
2. Corporate Investment
3. State-sponsored R&D
4. Venture Capitalists

The most important of these is the regulatory environment. Currently, there are a number of ways to determine the need for further infrastructure investment, from a postage stamp rates to detailed calculations of nodal pricing. However, these methods do not incorporate the embedded goals of an advanced power system that is both smart and meets the needs of the future users of energy. Further, often they are not thorough enough to include distribution level costs, and investment requirements. However, not only should Operations & Maintenance along with new infrastructure costs be included in these tariffs, but also R&D investments must be made to support the future power system, and the rates must also include these investment needs.

The only way they can do so is to ensure that these funds are collected and invested. This takes a view of the future, along with the encouragement of regulatory policies that support appropriate tariffs that will support technology development to meet the needs of users of the future.

Further, power systems that begin meeting the needs of advanced users should be able to recoup their investments at a reason rate of return. This would create an environment that would inspire current and future investment needs.

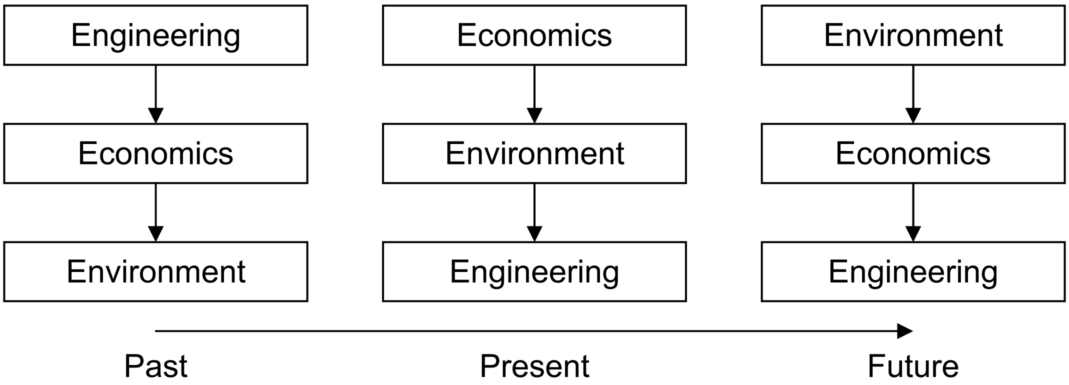
CIGRE, as a representative of high voltage design, and increasingly including lower voltages must involve itself in this discussion. Namely, how does the system of the future look, and what investments will be required to meet the needs of this future system? What is the infrastructure needs and threats? How can we ensure a secure system, but at the same time, one that advances the high technology needs of a varied customer base?

From this platform, CIGRE can take the lead to influence the policy makers and decision makers both in the developed world and the developing world in order to focus the associated investment climates that support the needs and demands of the power system in the future, not just focused to drive down costs and increased efficiencies. If these investments are not made, productivity improvements made possible by advanced end-use technologies will not be realized, and global growth potential subsequently not supported.

11. EDUCATIONAL NEEDS

Over the years the electrical power industry is influenced by three main driving forces, the three E's: Engineering, Economics and Environment. Depending on the local growth scenario the ranking of these different drivers will change in the decades coming-up, see figure 11.1.

Figure 11.1 The three E's of the past, the present and the future



Electrification continues to expand in developing countries, while the electrical infrastructure has reached a mature level in the industrialized countries. In the first case engineering is still a primary objective, while in the latter case the professional society becomes extremely dependent on the availability of electrical energy without any interruption. Contrastingly deregulation, liberalization of the market and privatization drive utilities to work in competition and thereby to exploit their electrical assets at minimized costs and as far as is socially acceptable.

Due to the role of three E's dominating over the technology, the rate of change in the power industry increases in different ways. The engineer of the future has to be well prepared that he or she will enter other working environments more than ever before. So in addition to basic engineering skills education should include economical and environmental aspects, which are of concern to society. Engineering won't be the dominating factor anymore, but it is the basis upon which the students have to learn how more complicated but even more challenging solutions for technology applications have to be found.

A negative effect of the market changes is the major loss of expertise worldwide due to the focus on short term benefits of the business by e.g. reducing salary levels, staffing costs, to ensure at least short term returns to the shareholders. Such policy does not present an attractive image to young engineers to choose the study of electrical engineering. All this happens at a time when the industry is being forced to meet new challenges, i.e. engineering in a multidisciplinary approach.

Students in the western world show a decreasing interest in choosing a mission in typical 'exact' sciences including electro technology. This happens despite the very good educational and research facilities, which are available. There is a need to communicate better to ensure full understanding of the societal and financial relevance of technology. This may be attractive for a wider group of students other than the pure technology "freaks". Moreover, as shown in this report, many new technologies are emerging in the power industry, such as power electronics, sustainable energy generation, high density power equipment, smart sensors for reliability control, asset management-IT support systems and power trade are getting on board in power engineering. Advertising these developments and better PR will attract more young engineers to choose electro technology. We may expect an increasing demand for young academics with a wider scope of electro technology. Signs of this have been observed already, for instance engineers with additional master of business degrees become popular. So the question is how should the curricula be changed in order to meet the societies needs of the near future? And how should we encourage younger engineers at the present, to show that there will be visionary jobs available for them.

Education starts usually with seeing local interests. Therefore local/regional industries and technical universities should collaborate thoroughly to adapt the curricula of their education system needs and to enable students to learn about the role that technology applications play in the companies in their local areas. To get focussed, keynote speakers from industry should explain the importance of new technical developments for the fulfilment of business objectives. Some experienced 'jettisoned' engineers could be of help in this process. Later the scale of interest should expand internationally by students staying abroad some time and by making more use of the beneficial combination of education and research laboratory work as it exists at many universities. Industries should support the laboratories by sourcing out more of their R&D also for the reason of attracting young students.

Learning from experience is of fundamental benefit for students, analytic and synthetic skills are then more easily accepted. Today's terms of reference for learning should put more emphasis on innovation, system/functional levels, system optimization, interdisciplinary teamwork, business deliverables and so on.

A course should emphasize more on the functions than the tools. In the formulation of the curricula inevitably fundamental technical knowledge has to be the main subject, however the new working environment makes the inclusion of economical, juridical and social aspects also to become important. Fortunately, it makes the study even more interesting for those who will work more in multidisciplinary teams and with contacts. The encouragement of acceptance of overall accountabilities and entrepreneurship should be starting with young engineers.

The European initiative works in this direction whereby a series of universities aligns the bachelors-masters structure according to the Anglo Saks model (Bologna Agreement). During a basic study of 3 years students learn skills over a wide scope specific technological fundamentals but also, in addition learn of the societal issues. Students proceed to reach an MSc degree by studying two years of specialization, with the possibility of an international exchange to an MSc course at another university. Given the fast changes in the business world it is expected that training and learning on the job will become of continual relevance, whereby universities have, in addition, to provide up-to-date post-academic courses.

Asset management of the electrical infrastructure is booming now, where diagnostics and knowledge rules are at the core of expert systems. Lifetime condition management tools should provide ultimate utilization e.g. flexible loading of high voltage assets, for which strategic insights on such management methodologies as risk assessment or reliability based maintenance become a stronger part of the engineer's package.

New designs and materials such as super capacitors, high temperature superconductors, fuel and solar cells, high performance insulating/conducting polymers for cables, composites in e.g. wind turbines, electrical energy storage in chemical form, are just few examples of on-going emerging technologies that offer relevant possible applications in the power system of the future. These should inspire young engineers if given the opportunity of investigating and implementing them within reasonable payback times.

CIGRE should be thinking about these issues NOW because CIGRE has the possibility of taking a worldwide overview of the development of the Electrical Power Industry. It should take on an important role to highlight the changing educational needs to the schools/institutes/universities in our field. The horizontal study committee SC-D1 has coordinated the present report in order to kick-off its new duty to stimulate the application of materials and emerging technologies and to bring them to the attention of other SC's and further to exchange information on their needs. Thereby interdisciplinary subjects increase in importance.

In conclusion the main directions we have to go with education are:

1. Emerging technological solutions
2. Economical aspects
3. Social and juridical aspects on behalf of cross border trades and new ways of contracting customers and outsourcing services
4. Environmental aspects which become of growing importance for the sustainability and the image of the power business
5. Management skills for interdisciplinary projects

Entrepreneurship is encouraged more nowadays. Engineers should learn to see the possibilities of taking advantage of new technologies for the business. Much more possibilities exist ranging from distributed generation options to intelligent operation of the networks, using and building IT supported electrical infrastructures, negotiating and contracting with new market parties like service providers, power traders and customers. New engineering solutions have to cope with the interdisciplinary requirements on availability and quality of life & power, safety and health concern, as well as with the deregulation and liberalisation policies. Therefore the scope of the new curricula should include in addition to the hard core of technology, facets on business economy, international juridical aspects, environmental insight and management skills.

12. CONCLUSIONS

This Paper has attempted to review the Electrical Power Industry emerging technologies, from electricity production to delivery to customer, including changing interfaces, communication, operation and control facilities. It has looked at the newer pressures now facing the industry to ensure environmental concerns and customer needs are met and has tried to assess how the development of new materials will accelerate these changes. It concludes that a co-ordinated research and development approach is needed to ensure continual focus and to avoid duplication of effort where resources are limited. It has a plea that the industry needs to encourage appropriate funding for R&D of the newer technologies and in this respect it is important that the Industry is able to communicate its message to financiers and venture capitalists. Finally, it has attempted to review the required needs of the end customer and their needs must continue to be the focus of all the efforts, not only in industrialised countries but equally as important in developing countries. The provision of a reliable, continuous, high quality supply of electricity is key to the development of advanced societies. Electrical Power Engineers have a very important societorial role to ensure that appropriate low cost, high quality, reliable, low polluting supplies of electrical power can be made available. The challenge that is now facing the industry is to find the optimum solution.

The traditional means of generating, transmitting, distributing and supplying electricity to customers has proven to be very successful over the last 80 or so years, but we are now in times of rapid change. Traditionalism is now unlikely to meet customers long term requirements. Whilst it will continue for some years still, the role of the transmission system is likely to change to interconnect large renewable sources of power and possibly new nuclear stations which could be required to replace the ageing coal fired and existing nuclear stations.

There seems to be little doubt that as the distribution infrastructure of fuel resources improves, e.g. the various energy related gases, oil and possibly solar power, then we will see an ever increasing trend to move generation closer to the load, even to the extent that domestic premises could well have their own ‘black box’ which produces both heat and electrical power. Unless these newer sources of power can be made to load follow then energy storage devices will have an important role to play in this scenario.

Whether these new pockets of generation will be operated independent of the electricity utilities network, or whether they will form part of it remains to be seen. As the systems evolve it is probable that they will in fact be connected to the local network, which may well be connected to the power network by DC links. Whatever happens however, communications and control interfaces are likely to play ever increasingly important roles. The extent to which the technologies described will be in place and mature in 20 years time remains to be seen, perhaps the main drive will come from areas of the world that currently have no access to supplies of electricity. In industrialised countries perhaps the major immediate concern is what do we do with the existing large power plants, which will come to the end of their useful lives within the considered time scale? This could depend upon the rate of development and maturity of the newer technologies and perhaps one solution would be to consider life extension of the older power stations by another 10 years or so, in order to avoid the possibility of stranded, large scale, new investments.

If one considers, for example, the idealised characteristics of a new energy production technology it could perhaps be argued that it should be :-

- non polluting
- no emf
- use almost any fuel
- be noise free
- have a high energy output per unit volume
- be capable of load following
- produce both electrical power and/or heat
- have a low cost comparable with existing technologies
- be readily transportable
- high reliability supply

Such a development could revolutionise customers perceived energy needs. Perhaps this is wishful thinking but on the other hand very recent announcements suggest that such devices could well become a reality with commercial units available within four years!

If nothing else the Electrical Power Industry is facing rapid change and developments need to be continually monitored to ensure that societies needs are met in the most appropriate way. In addition, it is vitally important that younger, bright, engineers are attracted into the electrical power industry as it is they who will have to carry the changing concepts foreword.

These are perhaps the challenges now facing CIGRE.

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REFERENCES

To Section 2.5: -

1. “Community Strategy and Action Plan for Renewable Energy Sources”, EC (1997), White Paper, Brussels.
2. “An action plan for renewable energy sources in Europe”, Proceedings of the conference in Madrid, 16-18 March 1994.
3. "Renewables for Power Generation: Towards a Better Environment", IEA (1997).

4. “ATLAS web site”, E^nR (1997), funded by the non nuclear energy programme of the 4th Framework Programme for R&TD (demonstration component 'THERMIE').

5. "International Energy Agency Council Communiqué. Shared Goals", IEA (1993), OECD, Paris.

6. “Energy for Tomorrow’s World”, WEC (1994), London: Kogan Page.

7. “The Evolution of the World’s Energy Systems”, Shell International (1996), Group External Affairs, London.

8. "Renewable Energy: Sources for Fuels and Electricity", by Johannson, T B, Kelly, H, Reddy, A K N, Williams, R H, and Burnham, L, UN-SEGED (1993), Island Press, Washington DC.

To Section 3.2: -

[1] B.H.E. Wahlström, Y. Aoshima, Y. Mino, C. Lajoie-Mazenc, D.R. Torgerson and A. N. Zomers: “The Future Substation: A Reflective

Approach", CIGRE report 23-207, 1996.

[2] M. Kumar, P. Lindblad, P. Mauras and A-M. Sahazizian; "Questionnaire Concerning Aspects on Planning, Design, Operation and Maintenance of Future Substations", CIGRE Brochure prepared by TF23.13 and evaluated by WG23.01, 2000.

[3] P. Norberg, M. Tapper, W. Lord and A. Engqvist: "The Future Substation: Reflection about Design", CIGRE report 23-105, 1998.

[4] B. Wahlström on behalf of TF23.13: "Simplified Concepts for Future Substations - Some Case Studies", CIGRE report 23-107, 1998.

[5] V. Colloca, E. Colombo, A. Di Mario and S. Sciarra: "A New Design for Primary Substations", CIGRE SC-23 Colloquium in Zurich 1999, paper 24.

[6] H-O. Olovsson and C-E. Sölver: "Innovative Solutions for Increasing the Reliability in AIS Substations", CIGRE SC-23 Colloquium in Ciudad Guayana 2001, paper 3.6.

[7] C-E. Sölver, H-E. Olovsson, W. Lord, P. Norberg and J. Lundquist: "Innovative Substation with High Availability Using Switching Modules and Disconnecting Circuit Breakers", CIGRE report 23-102, 2000.

[8] A. Jaksts, M. Leijon, C. Sasse, H. Frank, T, Fogelberg, T.H. Andersson, S. Forsmark, L. Nilsson and A. Sjögren: " A Major Breakthrough in Transformer Technology", CIGRE report 12-101, 2000.

[9] P. O'Connell, F. Heil, J. Henriot, G. Mauthe, H. Morrison, L. Niemeyer, M. Pittroff, R. Probst and J.P. Taillesbois: "SF_6 in the Electric Industry, Status 2000", CIGRE SC-23 Colloquium in Ciudad Guayana 2001, paper 2.5.

[10] J. Finn, D. Karlsson, K. Kuusela, P. Mauras, J-M. Chantron, G. Keely and H-E. Olovsson: "Functional Specification for Substations", CIGRE SC-23 colloquium in Ciudad Guayana 2001, paper 1.1.

To Section 3.4 :-

[1]A.N. Zomers, "Rural Electrification, Utilities' Chafe or Challenge", diss. Twente University, the Netherlands, 2001

To Section 4.2. :-

[4.2.1] Council of European Energy Regulators, Working Group on Quality of Electricity Supply, "Quality of electricity supply: initial benchmarking on actual levels, standards and regulatory strategies", April 2001, www.autorita.energia.it.

[4.2.2] J. Driesen, T. Green, T. Van Craenenbroeck, R. Belmans, "The development of Power Quality markets", IEEE, PES Winter Meeting, Session on Power Systems Analysis, Computing and Economics, New York, 27-31 January 2002.

To Section 6 :-

[1]A.N. Zomers, “Rural Electrification, Utilities’ Chafe or Challenge”, diss. Twente University, the Netherlands, 2001
[2] B. Norton, “Renewable electricity; what is the true cos”, Power Engineering Journal, Febr.1999
[3] Caddet, “All energy technologies affects out climate – not all to the same extent”, Caddet Energy Efficiency Newsletter, Nr.2, 1995
[4] WEC-Report “Renewable Energy Sources: Opportunities and Constraints 1990-2000”
[5] WEC-Report “Global Energy Perspectives to 2050 and Beyond”
[6] J.S. Nørgard, “Low electricity appliances – options for the future”, Electricity, Lund University Press, Sweden 1989
[7] CIGRE SC37, “Impacts of demand side power electronics technologies on power system planning”, Tokyo Symposium 1995, report 210-01
[8]SEED, “Strategies for Implementing Power Sector Efficiency”, Stockholm Initiative on Energy, Environment and Sustainable Development, Nov.1991

To Section 7 : -

[1] K. Chiyajou, “Application Study on Semiconducting Glaze Hollow Insulators to Substation Equipment“, paper 33/110, CIGRE 2000
[2] O. Elsässer, K. Feser, “Flashover Behaviour of Different Insulating Materials under Positive Switching Impulse Voltage Stress at Different Climatic Conditions”, paper ISH 99
[3] H. C Karner, U. Stietzel, H. Janssen, A. Herden, „Hydrophobietransfer und Lebensdauer des Hydrophobie-Effekts“, ETG-Fachbericht 68 Silikonelastomere, 1997, Seite 21-29
[4] S. Gubanski, “Research Findings Comparing Performance of Different Insulator Designs on Distribution Lines in Tropical Environment”, Insulator News & Market Report 11/12 1999, page 46-53
[5] G. Schröder, Entladungsentwicklung in SF_6-N_2 Gasgemischen bei schnell schwingenden Steilstoßspannungen und Blitzstoßspannung, Dissertation RWTH Aachen 2001
[6] www.amsuper.com, February 2002
[7] J.J.Smit on behalf of the Technical Committee of CIGRE “ High Temperature Superconducting Applications in the Electrical Power Industry” CIGRE ELECTRA No 193 December 2000 pages 4-11
[8] “Advanced Materials” CIGRE WG 15-09 Brochure Ref 169 August 2000