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**ELECTRIC POWER
SYSTEMS 2020**

**Joint Advisory Group
SC15/D1 – JAG 02 TC**

April 2003



Cigré Brochure

ELECTRICAL POWER SYSTEMS 2020

*Panel organized by Study Committee 15/D1
at the 2002 Cigré Session
Palais des Congrès de Paris
August 27th, 2002*

On behalf of the Joint Advisory Group
SC15/D1-JAG02 TC¹
Johan J. Smit (chairman)

Key-note speakers:
Walt Patterson
Adriaan N. Zomers
Benard M. Pryor
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Synopsis

In view of the rapid changes within the deregulating Electrical Power Industry, the need to ensure environmental compatibility as well as the utilisation of the ensuing rapid technology changes, the Technical Committee (TC) felt it timely that SC15/D1 had to prepare a Panel in 2002 to oversee and monitor all of the changing issues.

To that purpose a 'visionary' Joint Advisory Group JAG02 was appointed to plan such a Panel with assistance from expertise of different Study Committees in this field. In whatever degree the following groups² were enthusiastically involved in the preparation:

*SC 11/A1, 12/A2, 13/A3, 14/B4, 15/D1,
21/B1, 22/B2, 23/B,3
34/B5, 35/D2, 36/C4, 37/C1, 38/C5
and other experts*

Adjacently the Study Committee Task Force SC15/D1-TF03 has carried out an extensive study to underlie the wider scope of work of the future SC15, which converts into SC D1, Emerging Technologies and Materials. The scope of the latter includes the scientific and visionary tasks to chart the near future.

In part the TF03 study integrated with the JAG02 investigation. The study resulted into a separate Cigré brochure, entitled "Emerging Technologies and Material Challenges".

Finally the Cigré Panel Session was held at August, 27th, 2002 during the session of SC15/D1 in Salle Bleue of the Palais des Congrès de Paris. The aim of the panel was to incorporate the different points of view of industry, governmental and research institutions, utilities and Cigré, i.e.:

1. a global view of the changing Electrical Power Industry, looking 20 years ahead
2. a global view of projects to be financed in future both in industrialized and non industrialized countries
3. a scientific and visionary background study
4. an electrical power industry opinion, looking ahead and suggesting some possible alternative scenarios.

² 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).

To address these perspectives the panel has been composed of four contributions and a Panel discussion. The following respectable persons were willing to address the different perspectives:

- I. ‘A Global View of the Changing Electrical Power Industry’ by Walt Patterson – Associate Fellow of the Royal Institute of International Affairs UK.
- II. ‘The Challenge of Rural Electrification’ by Adriaan Zomers – Advisor to the Dutch Ministry of Foreign Affairs.
- III. ‘Emerging Technologies and Material Challenges’ by Bernard Pryor – Independent Consultant, on behalf of SC15/D1.
- IV. ‘Electrical Power Systems 2020. A prospective View’ by Michael Chamia – Immediate Past President of Cigre.
- V. Discussion – Led by Graeme Burt, Strathclyde University.

The executive summary of the SCTF03 study mentioned-above has been presented as the third contribution, which completes the overview of the future changes in the electricity business.

I

**Contribution to panel on Electrical Power Systems 2020
August 27th, 2002**

A Global View of the Changing Electric Power Industry: or, Keeping The Lights On

by

Walt Patterson

*formally with the Royal Institute of International Affairs
– UK*

A Global View of the Changing Electric Power Industry: or, Keeping The Lights On

Walt Patterson

formally with the Royal Institute of International Affairs – UK

Cast your mind back to 1984. I don't mean the 1984 of George Orwell and Big Brother. I mean the real 1984, eighteen years ago. Were you working for the same company then? WAS it the same company, with the same name and in the same business? Somehow I doubt it. Can you recall what world electricity was like? It was made up of monopoly companies, with franchise territories inside national borders. Its generators were almost all either large dams with water turbines, or large coal-fired and nuclear stations with steam turbines. Natural gas was a premium fuel, widely banned from use for generation. Gas turbines were for emergencies. Renewables were a curiosity for weirdos. Chernobyl had not happened. Electricity systems and companies were planned, operated and managed by engineers. Most electricity systems belonged to a single owner, all the way from generators to meters. Those that did not divided up responsibilities in cosy partnerships. No one thought of competition or markets for electricity. No one from outside a country owned its electricity assets. The major environmental issues centred on acid rain, and on the anticipated vast expansion of nuclear power, including fast breeder reactors and plutonium fuel. No one had heard of climate change.

Does this sound at all familiar? You may have forgotten what world electricity was like, only eighteen years ago. But you probably realize why I chose 1984. Today, in 2002, we are eighteen years away from 2020. Can you imagine how much world electricity is going to change in the next eighteen years? In 1984 change had scarcely begun. Now it is in full, headlong flux. The momentum is going to carry us a long way - much farther, I suggest, than most of us can yet imagine. Unless we are very lucky it is going to be a seriously uncomfortable ride, even for the most fortunate among us. This morning I'll try to indicate why.

The starting point is what I call 'traditional electricity', the common technical model replicated all over the world during the past century. In this model, large central stations, remotely sited, generate electricity as alternating current and deliver it to users over networks including long high-voltage transmission lines. The traditional electricity system holds a monopoly, granted by government, in its franchise area. Within this area no one else is permitted to generate electricity for sale. The monopoly franchise guarantees a revenue stream, and allows system planners to make very large long-term investments, notably in power stations and networks, because the captive customers of the monopoly bear all the risks

Throughout the past century this traditional model was remarkably successful, making electric light, electric motive power and other electricity services part of the everyday fabric of industrial society. But the traditional model arose for one key reason: the economies of scale of the generating technologies then available, particularly steam turbines and water turbines. Making these generators larger steadily lowered the cost of

the electricity they produced, up to generators of enormous size, despite the cost of the accompanying delivery network. The technical configuration of traditional electricity was modeled on that for town gas; and the analogy was effective and useful for most of a century. Now, however, it is seriously misleading. The emergence of economic and small-scale decentralized generation as an option is going to invalidate the key premise underlying the traditional model of electricity. Moreover the traditional model has failed to deliver electricity services to some two billion people - one-third of humanity; and its key technologies - large dams, large coal-fired and nuclear steam-cycle stations, and overhead transmission lines - all face problems, particularly financial and environmental, that may become insuperable. The entire conceptual framework of electricity, its role and nature in human society, now requires urgent and fundamental reassessment.

This is because electricity is different. Despite all the prevailing assumptions to the contrary, electricity is not a fuel, nor a commodity. A fuel such as natural gas comes out of a hole in the ground at a specific place; if you want to use it anywhere else you must physically transport it there. Electricity, by contrast, is a physical phenomenon happening instantaneously throughout an entire interconnected system. You can generate electricity anywhere, at a price. You can store a commodity such as copper, wheat or coffee, and withhold it from the market until you get the price you want. But you cannot store electricity, in the form and quantity in which we now use it. If you are to satisfy your customers you must have a vast array of physical assets in place and in operation continuously, whether or not your customers want electricity from you. If you have a monopoly, that does not matter. If you don't, other factors come into play.

At the beginning of the 1990s the governments of Chile and the UK, ideologically committed to so-called 'free markets', overthrew the traditional model of electricity system, abolished the monopoly franchise and introduced competition in generation and supply to customers. The first unexpected consequence was the dramatic advent of gas turbine generation, fueled by cheap and abundant natural gas, both economically and environmentally beneficial. But gas turbine generation marks a sharp change in the historical trend. Historically, a better power station was a bigger power station farther away. With the gas turbine, however, a better power station is likely to be a smaller power station, easier to finance and to site, quicker to build and commission, more efficient and cleaner, closer to users and possibly indeed right where the electricity is required. In a competitive context, a large-scale long-term investment in traditional hydroelectric or steam-cycle generation is seriously risky; and the risks are borne not by captive customers but by shareholders and bankers. If a less risky option is available, traditional generation loses its appeal. Gas turbine generation, smaller-scale and more decentralized, is opening the way for even smaller and more numerous generators, down to household scale, that will soon be commercially available and attractive. This is going to cause trouble.

Three years ago I published a book entitled *Transforming Electricity*. I called Chapter 6 of the book 'Bumpy transitions'. At the time, however, I did not fully appreciate just how bumpy these transitions would prove to be. For the past three years I have been working on a follow-up book, entitled *Keeping The Lights On*. The longer I work on it, however, the more difficult I think keeping the lights on is going to be. Traditional central-station electricity is simply not compatible with innovative decentralized electricity, either technically or institutionally. This is most obvious with networks.

Traditional networks are radial and one-way, designed to carry large quantities of electricity at high voltages from remote large-scale generators, and to divide the electricity up among loads several orders of magnitude smaller. Innovative decentralized electricity, with very large numbers of small generators connected at low voltages, broadly similar in size to the loads, will require meshed, two-way networks, different in both configuration and function. Can networks evolve smoothly through such a dislocation? I hope so; but I don't yet understand how.

We are already seeing problems arising from traditional networks, as a consequence of liberalization. Traditional networks were never intended to function as a framework for market competition between generators with different owners, and especially not across system borders, much less national borders. Despite liberalization in Europe, the US and elsewhere, electricity networks continue as regulated monopolies, effectively centrally planned, paid for by captive customers as before. Issues of system stability, reactive power and other technical concerns arising from small-scale decentralized generation are aggravated by the insistence of some traditional system people that any significant move to decentralized generation will endanger system stability. A fully decentralized electricity system would offer an entirely different approach to stability; once again, however, the problem is how to get there from here.

Technical issues such as these are complicated in turn by the decision-making and financial procedures that have arisen with liberalization. The whole process of liberalization, as it has been implemented in OECD countries and elsewhere, is based on what appears to me to be a fundamentally misguided premise: the premise that electricity is a commodity, that the relevant market is a commodity market in anonymous units of electricity as measured by a meter, and that what matters most is the commodity price per unit of electricity. However, the price of a unit of electricity is made up in substantial part by the capital charges attributed to the system assets, especially the monopoly networks. The price of a unit of electricity to the final user is thus effectively arbitrary, a thoroughly unsatisfactory criterion by which to evaluate the success or otherwise of liberalization or reform of any kind. It is also an unsatisfactory basis for market transactions between system participants, especially when the future evolution of the electricity system, reconfiguring its physical assets, is going to require major long-term capital investment, on some acceptable basis, by someone.

As I wrestle with these problems I am sometimes bemused, that so many other commentators seem unconcerned - or perhaps not so much unconcerned as unaware of them. The reason may be that liberalization has drastically shortened the time-scale of thinking about electricity and its future. To the extent that most commentators have any long-term vision of electricity in society, they appear to believe that it will look and function much the same in 2020 and 2050 as it does in 2002. I think they are wrong.

The risk profile of traditional large-scale assets is increasingly ill-suited to a commodity market in instantaneous and ephemeral units of electricity. In some liberalized competitive systems, including that of the UK, the unit electricity price is now so low that some generators cannot even cover their cost of capital. Some generators are already shutting down power stations that do not earn an adequate return for operating. This reduces the redundancy on the system, with a negative effect on reliability. For many modern loads, system reliability and power quality are already a problem. That makes the option of decentralized on-site generation more attractive, not least as

insurance against disruptions on the network. If the growing proportion of sensitive users install their own generation and remove their loads from the system, more system generation will become surplus to requirements and face shutdown, further weakening the system. We could see a feedback loop developing, in which those users who can leave the system will do so in favour of their own decentralized generation, while users still dependent on the system have to accept steadily deteriorating service.

If we were starting now to electrify society, with the technologies now available, electricity and electricity systems would be very different. But we would strive to attain some of the key attributes we still associate with traditional electricity. We would want electricity services to be reliable, convenient and affordable. We would also, however, want attributes that traditional electricity does not and cannot achieve: we would want electricity services from systems clean and environmentally acceptable throughout; and we would want these services to be available to all, not merely to the fortunate two-thirds of us on the planet.

Let me give you a brief outline of what seems to me a promising vision. Electricity services such as illumination, comfort, motive power and refrigeration are not commodity services but infrastructure services. You don't measure them or buy them by the unit; you pay for the assets that deliver them to you when and how you want them - the buildings, the fittings, the appliances and so on. We have known for decades how to make these assets deliver much higher performance. We've called the objective 'energy efficiency', but I dislike the expression, because you do not measure either the energy input or the useful energy output of, say, buildings - much the most important part of our energy service infrastructure. For at least three decades we have failed to take advantage of the opportunities to improve infrastructure performance, for a variety of reasons, not least the so-called 'hassle factor' - 'I just can't be bothered'.

Now, however, with decentralized electricity generation, we have a whole new way to approach the issue. Local electricity service systems, incorporating generation, networks and high-performance end-use technology, including buildings, could be integrated and optimized for maximum economic effect. That would be attractive both to customers and to the companies that would design, establish and operate the systems. A contract for energy services would create a long-term link between company and customer, a much more stable form of business relationship than competing to sell anonymous units of electricity at a meter. Decentralized electricity systems, with their economic, social, political and environmental advantages, could be a crucial step toward 'sustainable electricity', in OECD, transition and developing countries alike.

Nevertheless, whatever 'sustainable electricity' may look like, how do we get there from here? The disruption and dislocation involved may be severe. The challenge for you, as electricity professionals, is to avoid the pitfalls and seize the opportunities, while keeping the lights on. It will not be easy. I wish you success.

Thank you.

II

**Contribution to panel on Electrical Power Systems 2020
August 27th, 2002**

The Challenge of Rural Electrification

Adriaan N. Zomers

*Energy advisor to
the Dutch Ministry of Foreign Affairs*

The Challenge of Rural Electrification

Adriaan N. Zomers

Energy advisor to the Dutch Ministry of Foreign Affairs

In his presentation, Walt Patterson asked you to catch your mind back to 1984. I am even going back to 1961, the year with the first manned space flight: a striking example of mankind's capabilities. Today, only **thirty** years later, mankind is capable of having a number of people remaining extraterrestrial for many months.

The power available on board of Space Station Alpha for housekeeping and medical care, could fulfil the basic electricity needs of several hundreds of rural households in developing countries by using modern energy-efficient appliances.

The situation on earth doesn't look so bright. Although the electrification of our world commenced over **one hundred** years ago, currently one third of the world's population have neither access to electricity, nor to sufficient other non-traditional energy forms. Leaving fairness, equity and socio-economic development aside, the world can no longer continue to neglect, in terms of access to affordable energy, the still unserved rural and remote areas. In this respect electricity will play an important role and the question will not be, are rural areas to be electrified, but rather when and how.

A recent study³ addressed the various aspects of rural electrification with the aim to identify and assess relevant developments and trends, to look ahead for opportunities for electricity supply to rural and remote areas in the developing world. The results were translated into critical success factors and recommendations for decision makers.

In this presentation I touch upon a number of findings, including those of an analysis of past and ongoing rural electrification activities in various industrialised and developing countries.

Let me first give you some facts.

Two billion people on our planet have no access to modern forms of energy, including electricity. Most of them are poor and live in the rural and remote areas of developing countries. A majority of these rural poor already spend a substantial share of their income on energy services, such as kerosene, candles and woodfuel. Contrary to what is often thought most of them give priority to modern energy over many other necessities. Their willingness to pay for better and safer energy services is large but the affordability limited.

Rural electrification is potentially a desirable investment in many countries but there has been considerable discussion about the socio-economic and environmental benefits, and the costs of the electrification of these areas in developing countries. There is general agreement that the cost and benefits of rural electrification are very difficult to value. The results of ongoing research based on an advanced assessment of the benefits suggest that the socio-economic benefits of rural electrification are much higher than earlier assumed.

³ "Rural Electrification; Utilities' Chafe or Challenge?", published last year by the Twente University Press, Enschede The Netherlands; ISBN 9036515556; full text available at www.tup.utwente.nl, select "catalogus" and then "management".

Because of its versatility and increasing pervasiveness, electricity plays a key role in development and should be assessed as a fully-fledged component of a rural development programme. For many rural people in the Third World the electrification of their areas means modernity, progress and, above all, light in the darkness. The electrification of rural areas can thus be seen as socially and politically very important.

Which lessons can be learned from the electrification of the rural areas in industrialised countries?

The survey of a number of cases revealed that economic circumstances were not apparently a decisive factor in the wide-scale electrification of rural areas in industrialised countries.

It is also fair to conclude that at a national level, in most cases, politicians have been far from proactive. The power of lobbies and pressure groups was probably a larger determinant. In many countries the rural population had to rise up against neglect before any actions on the electrification of their areas were taken. In general, the political leverage of the rural population in developing countries is low and this underlines the importance of a proactive and worldwide approach to the problems that rural populations experience.

A general conclusion is that rural electricity supply has always been considerably more expensive than the supply to urban areas and, as a consequence, utilities have been reluctant to extend the service to rural areas. In general, private organisations were not interested in rural electrification because of the low rate of return and the high risks.

If the principle of "the customer pays the real costs" were to be generally applied, the poorest of the rural population in particular would be unable to use electricity despite the fact that they usually consume a very limited number of units (as low as 10 kWh per month) and could afford to pay for their consumption against a lifeline rate. In nearly all countries affordable electrification was only achieved through special national programmes and financing arrangements. Up to 50% government subsidies have been given towards the initial investments, and long-term, low-interest, or interest free, loans were provided to finance the electrical infrastructure. Cross-subsidisation was and still is generally applied.

In many countries, either a national or a provincial power utility was considered appropriate in order to avoid municipal boundaries hampering the development of an economically justified electricity infrastructure, and to achieve an acceptable area coverage and sufficient uniformity of tariffs.

Small-scale private rural utilities have seldom proved to be successful. In quite a few countries co-operatives have been successful, but success seems to be linked with the specific situation and culture in the country, and the opportunities for technical, administrative and managerial support.

The experience in many countries shows that the performance of government-owned utilities can be satisfactory provided they are able to operate at an arm's length from the politicians and are reasonably autonomous. Such organisations have established and maintained a reliable and affordable electricity supply and have also demonstrated in other respects an appropriate performance.

There is a salient difference between presently developing countries and the industrialised nations around 1900. The latter already had reasonably developed economies and rural infrastructures, and they could afford to invest in electrification.

The economies of the majority of developing countries are weak and do not allow major investments in infrastructure.

Let me elaborate on some of the recent observations related to utilities serving rural and remote areas.

It is generally accepted that there are well-performing utilities in the developing world, even in terms of electrification of rural areas. But there are also developing countries where efforts to provide electricity to rural areas have only had limited success and, despite international support, many of the utilities concerned continue to show substandard performance.

Among the main causes of the substandard performance of these utilities and the disappointing results of a number of rural electrification projects in some developing countries, are the uneconomically low tariffs, low load factors and levels of demand, a lack of operational autonomy and, in some cases, extreme political interference.

The unsatisfactory situation in several developing countries demands reforms to the electricity sector. However, the extent of any reform should be approached with "a healthy degree" of scepticism: the market is relatively small, the infrastructure is limited and expanding, and often the human resources needed for strong regulation are lacking. Industrialised countries could ask themselves the question what is the *maximum* amount of power sector reform that is desirable. But the question for the developing regions could be what is the *minimum* reform needed to achieve proper working relations between the political elite and utility management.

The analysis of a number of electrification projects and a cost estimation revealed that the average investment cost of a rural connection to a central grid, including the cost of generating capacity, transmission and distribution grid, and service connection amounts to approximately US\$ 1900.

The electrification of rural areas has traditionally been based on electricity supply from a central grid. Decentralised schemes with, for example, diesel generators often led to relatively expensive electricity supply systems. However, as a result of recent technological advances, various alternative options have emerged involving both traditional and renewable sources. These technologies that offer enhanced opportunities for decentralised power systems include photovoltaic systems, wind turbines, biomass-fuelled combined heat and power units, storage facilities and fuel cells.

Although a renaissance for 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. In countries with a mature electric infrastructure, the emergence of decentralised generators has already caused the function of some distribution grids to change from a passive one-way system into a dynamic multi-functional one. In some cases, expensive adaptations to the existing grids are needed to safeguard power system stability.

During the creation of the electricity infrastructure, many power utilities were vertically integrated to ensure an appropriate tuning of generation, transmission and distribution of electricity. In many industrialised countries, deregulation changed the monopoly-based electricity sector into one with a competitive market in both generation and retail sell of electricity. The unbundling of generation, transmission and distribution is seen as a necessity in establishing a successful open electricity market. But this unbundling implies a fragmentation of the electricity supply sector with the associated risk of insufficient co-ordination between the sub-sectors. Such a situation might

perhaps be acceptable and manageable in case of mature infrastructures and low demand growth, but it involves substantial risks if the infrastructure is expanding and demand is increasing at more than just a few percent per annum, as is the case in many developing countries.

This brings me to the critical success-factors of rural electrification programmes.

Continuation of the “business-as-usual” approach is not a solution for the two billion people still without access to electricity. In view of the currently available technological options and potential international community support rural electrification should be seen as a challenge. To succeed in this challenge and to successfully implement future rural electrification programmes the appropriate circumstances are needed and in this respect the study has revealed a number of critical success factors:

- *A politically and socially stable environment.*

Support from the international community. The majority of the rural population in developing countries are poor, but nevertheless willing to pay a substantial part of their income for reliable electricity. Despite this, subsidies on initial investments and appropriate financing schemes with smart subsidies for the beneficiaries will be needed.

An appropriate electrification process. To meet the demand for energy services in the most efficient, sustainable and environmentally and socially acceptable ways, the electrification process should consider all the local opportunities for power production. Electrification should preferably be a component of an integrated rural development programme.

More so than in the past, the electrification of rural and remote areas in developing countries will be based on decentralised power facilities, including 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. This evolution is one of the reasons why any rural electrification activity should be designed and implemented within a policy framework and in a well-planned manner.

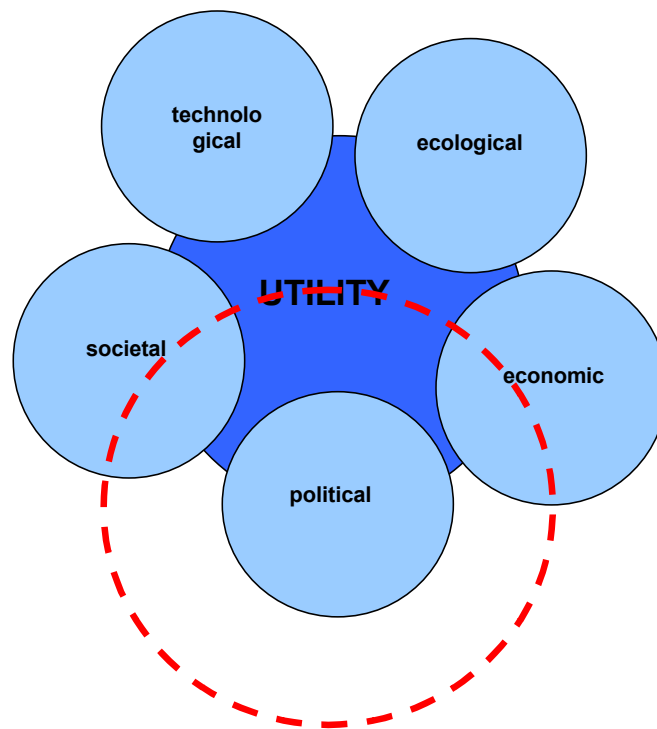
Excess power generated by rural industrial enterprises can be used to support public electricity supply and small-scale independent power producers should be seen as fully fledged suppliers of electricity. These observations require a close co-operation between the utility and rural customers, and thus a well-developed marketing and technical function.

An adequate strategy, utility organisation and business approach. The strategy should be based on the importance of establishing close relationship with all stakeholders, on energy efficiency focus, consideration of a “multifunction utility” and the deployment of local available renewables.

The organisation of the utility should be adapted to the environment in which the utility has to operate, and be based on decentralisation and operational autonomy. Given the differences in the business environment and available human resources, utilities in industrialised and developing countries are often not comparable in terms of organisation and management. The degree of maturity of the infrastructures, the technology deployed for rural electricity supply and backgrounds differ from country to country and, as an obvious consequence, the decision makers will have to adopt those solutions which are appropriate to their local circumstances.

Proper institutional conditions. Appropriate legislation and regulation is needed to enable a commercial approach to power supply and operational autonomy of the utility. The displacement model shown here illustrates the potential negative influence of, for

Simplified displacement model



example, extreme political influence on utility operations. Even the societal interests could be jeopardised. The message from this figure is clear: the various domains need to be equally addressed. It is extremely important that the national government provides for the appropriate enabling environment.

The challenge for the next decades.

The linkages between sustainable development and appropriate rural energy services has long been debated but it is now generally accepted that they are critical. For the electrification of the currently unserved rural communities in the developing world some 400 million connections are needed corresponding with some 800 billion dollars. This seems a large amount, but it accounts for less than 25% of the total expected investments in the world electric infrastructure in the next twenty years.

The development of a future-oriented electrification process and the selection of appropriate technologies which takes all local opportunities into account involves a challenge in itself.

Energy service businesses need to be developed and established, strong commitment of the international donor community must be achieved, international financial support for investments in rural development must be mobilised, human capacity must be developed and a business environment created.

And last but not least: a world-wide coordination and cooperation of all stakeholders must be realised. And I can assure you that this is very difficult to achieve because every organisation including donors, development banks, United Nation entities, they all have their own agenda.

Despite liberalisation and deregulation efforts there are indications that the private sector is not interested in the electrification of rural areas in the developing world. There is growing consensus among international development partners that an integrated global strategy to tackle rural development is needed to meet poverty reduction targets and the energy needs of the rural population.

In the past few years several international energy-related mechanisms have been implemented such as Joint Implementation, the Clean Development Mechanism and the Global Environment Facility. Though the efforts have linkages with sustainable development most of them were basically initiated to tackle climate change and actually very few have the reduction of rural energy poverty as their starting point.

However, the contribution of the electrification of rural areas in the developing world will only marginally contribute to climate change. If the households of all 2 billion rural dwellers would be supplied with electricity generated with an average fuel mix the effect, in terms of carbon dioxide emission, would only add about 1% to the 2000 global emission of carbon dioxide. From this point of view there is little reason to expect that rural electrification will particularly benefit from most of these carbon reduction initiatives.

One of the promising initiatives in the field of the energy supply to rural and peri-urban areas is the Global Village Energy Partnership. This partnership *in statu nascendi* is supported by a large number of countries and organisations, and seeks to create a global alliance focused on the implementation of modern energy services to those presently unserved.

To that end the initiative will facilitate the development and implementation of service delivery models, catalyse the scale-up of investments in rural energy development projects and programmes and help building relevant human capacity.

This challenging effort would capitalise on existing expertise and would bring together developing and industrialised country governments, public and private organisations, multilateral institutions, beneficiaries and suppliers, and other key stakeholders. The next step is to elaborate on the concept and to determine support for this initiative from additional partner organisations, governments, development organisations, the private sector, the financial community, and non-governmental organisations such as CIGRÉ.

If this partnership is successful, the next twenty years could see for many rural people in the Third World better living circumstances, progress and, above all, light in the darkness.

Thank you for your attention.

III

**Contribution to panel on Electrical Power Systems 2020
August 27th, 2002**

Emerging Technologies And Material Challenges

Study Committee 15/D1 brochure
presented by

Bernard Pryor

Consultant

Panel on " Electrical Power Systems 2020"

**Emerging Technologies and Material Challenges
(Executive Summary)**

Task Force on behalf of the Technical Committee

JAG 02 TC

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NOTE : This Paper is an executive summary of a full Paper which will be published as part of a CIGRE Brochure to be issued of the Panel Session on 'Power Systems 2020' to be held on 27 August 2002 at the start of the SC15/D1 Session discussions.

BACKGROUND AND OBJECTIVES

In view of the rapid changes within the deregulating Electrical Power Industry (EPI) , the need to ensure environmental compatibility as well as the utilisation of the ensuing rapid technology changes, a proposal was submitted to the Technical Committee (TC) for a 'visionary' Cigré Group to oversee and monitor all of the changing issues. As a result a special Cigré Panel Session had to be held at the August 2002 main Paris Session, for which SC15/D1 was given the task of organising this Panel on behalf of the TC. A joint advisory group JAG 02 TC was appointed to plan the Panel with assistance from expertise of different Study Committees in this field.

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 forward. 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.

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.

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

1 INTRODUCTION

With deregulation in the 1990's transmission was split from generation, which was itself split into a number of independent companies and distribution has also operated as separate entities within regulated trading agreements and operating procedures between players. Post 1990's, due to the availability of suitably priced gas supplies there has been a rush to build gas fired combine cycle gas turbine plant, this trend is occurring worldwide.

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.

Also, 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 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.

2 ELECTRICITY PRODUCTION TECHNOLOGIES

2.1 Continuing and Emerging Technologies

With the greater application of the so called embedded generation major changes will be required to the way in which power systems operate. The trend is for the adoption of smaller, environmentally acceptable, power plants located closer to the load requirements, thus minimising transmission costs and losses. However, such a trend still requires the availability of the prime fuel and this has led to the need for development of fuel delivery infrastructures. Currently the most suitable fuel delivery structure, in industrialised countries, is that for supply of gas and this is the fuel that most modern power plants are using.

Delivery infrastructures still need development for other sources of fuel and indeed, the current lack of such facilities could well be the limiting factor of application of new technologies. Typically, hydrogen and methanol have significant advantages for power generation but many difficult delivery problems still need to be resolved. Existing gasoline and liquid petroleum gas supplies are available which could be used either as a direct source or indirectly to produce hydrogen with a reformer. Similarly, solar power has long term potential either for large remote sites or by local production at consumer's premises.

A further source of small generation is the development of microturbines that can have outputs ranging from 25kW to 1MW. This technology is already commercially available and can also be used to provide a heat source. Whilst the use of microturbines for power generation is still a growing industry further developments of the technology can be expected.

One of the main drivers for the development of fuel cells has been the advent of the Kyoto environmental protocol. The pressures being greatest from the automotive industry where fuel cells could well start making an impact in the sector around 2004/5. For use in static power applications, in distributed generation, fuel cells could well become serious contenders to microturbines. Trials of fuel cells are already underway in Japan and other installations around the world are planned. Of the five currently available fuel cells technologies the Phosphoric acid Fuel Cell (PAFC) probably has the greatest potential for stationary power applications. The Molten Carbonate Fuel Cell (MCFC) could also be a serious contender.

2.2. Renewable Technologies and Energy Storage

Environmental concerns are now beginning to introduce ever increasingly important pressures on the EPI, whereby many governments are now offering incentives to utilities to install renewable energy sources, particularly from wind and tidal power and the role of nuclear can be expected to reduce. Novel technologies are being developed to take advantage of these changes. 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.

The current state of development of these technologies is : -

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.

To ensure continuity of supply when renewable sources are not generating will require the application of electricity storage. Such technologies could be pumped storage, compressed air, flow batteries, metal-air batteries, sodium sulfur (NAS) batteries, Li-ion batteries, Ni-Cd batteries or other advanced battery technologies, also lead acid batteries, flywheels, superconducting magnetic energy storage (SMES) and super capacitors. Many of these will have applications at low energy storage levels but for large scale storage of 10MW or more the only contenders are likely to be compressed air, micro pumped hydro, flow batteries and some advanced battery types.

3.0. ELECTRICAL DELIVERY TECHNOLOGIES

3.1. Power System Networks

Transmission systems evolved to carry the power from remote generating stations to load sources and are still used as the 'backbone' of the electrical power delivery network. However, as the introduction of more and more embedded generation continues and large older coal fired and nuclear power generating stations become decommissioned then the use of the transmission system is likely to decrease. The utilisation of transmission systems is changing and there is a growing trend for new installations of equipments to be relocatable to allow more economic matching of the changing system requirements.

Should there be a re-emergence of the use of nuclear power then clearly transmission networks will be required to interconnect these installations to load centres. Similarly

with the development of large remote site for wind or wave generation then transmission networks will need to connect these generation sources to load centres. Hence it is envisaged that in the longer term the use of transmission systems will change to adapt to the newer generation patterns.

Distribution systems on the other hand will need to be developed to allow the connection of embedded sources of generation to allow multi directional flow of electrical power. This will require fundamental reconsideration of such factors as voltage control, frequency control, short circuit fault levels, stability, protection and communication systems, and how the overall system will be controlled. Further, whether generation sources will run islanded from the grid, how will power flows be monitored and billed etc. Many issues remain to be resolved.

The advancement of HVDC technologies will allow greater flexibility in the way that both transmission and distribution systems operate and we could see greater use of DC interconnections.

3.2. System Interface Technologies

Substations are located at nodes in both transmission and distribution systems and their development will progress rapidly. 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).

Transformers are a major plant cost item. The basic traditional technology has changed little over 130 years and the 'conservative' technologies are likely to continue in the short to medium term. In the longer term more economic devices could be achieved by operating in conjunction with HVDC technologies; further there remains the possibility that HVDC and HTS technology may reduce or eliminate the need for conventional transformers.

3.3 System Operation and Control

The Quality of Supply is already becoming a major criteria for many users. The need for continuity of supply and appropriate voltage quality (frequency, magnitude, waveform and symmetry) is now of paramount importance. This situation has come about mainly because of the widespread use microprocessor technologies in almost all walks of life. A small disruption to the relevant power supply can cause very major losses to large industrial or commercial organisations and even consternation among members of the public. This issue is already forcing the introduction of self contained electrical power supplies such as microturbines.

The use of Intelligent technologies will be a major paradigm shift in the operation and control of power systems. Similarly, traditional protection systems are changing rapidly with the introduction of so called IEDs- Intelligent Electronic Devices. Whilst these developments are becoming common place within transmission networks, substation automation and remote control and data exchange will need rapid extension to the distribution level.

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 serviceability of the interface will be much more relevant to the user.

4.0. ENERGY CONSERVATION

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.

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 life-cycle emissions for fossil fuel power are roughly 100 times greater than for nuclear, hydro and optimal wind power plants.

So 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. 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.

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.

5.0. MATERIALS

Current carrying conductors have traditionally been of copper or aluminium, but more recently radical new types of conductor have been developed for the EPI resulting from the discovery of high temperature superconducting compounds (HTS). The HTS wire is a ceramic material that becomes superconducting at 77K, the boiling point of nitrogen. In view of their brittleness HTS conductors are constructed as multifilament wires. Such conductors can be used in generators, transformers, motors and cable and also for new technologies for special applications in coils.

Liquid insulation has traditionally comprised of paraffinic or naphthanic oils but these are readily combustible and there has been a continuous search for non-combustible and non-toxic liquid dielectrics having good cooling properties. The development of Ester liquids has allowed an intermediate position to be obtained between traditionally used insulating oils and previously used PCB's. Ester liquids are referred to as being 'less flammable'.

Trends in solid insulating materials are to concentrate on potential developments of polymers, only a few are used in the EPI and there are many other types and variations which could offer technical and economic advantages.

With gaseous insulation SF6 is still the main contender and with appropriate equipment design and handling procedures can still be used with minimal environmental impact. SF6/N2 gas mixtures have advantages for insulation but are not suitable for arc interruption.

It is important that material experts work closely with equipment designers to ensure that appropriate requirements for the newer technologies are achieved in the most efficient and economic manner.

6 0. END CUSTOMER NEEDS

The needs depend of course on the end user. In underdeveloped countries, in remote villages for example, the provision of a supply of electrical power can bring major social benefits, i.e. industry, hospitals, schooling, communications etc. Such supplies could well be provided by microturbines, fuel cells, solar or wind energy. Investments would probably need to be of a long term international nature.

For developed industrialised countries users are looking for continuity, quality and low cost with little or no environmental impact. They are looking for the provision of services i.e. electrical, heating, cooling, communications, media etc, they are not looking at kW/hrs. The objectives are thus changing from those traditionally provided by supply of electricity and the industry must respond to these changing drivers.

Clearly, with the emerging technologies there still needs considerable R&D effort and again this is at a time when R&D funding within the industry has been severely curtailed.

Financing of long term investments in new technology clearly needs a fundamental rethink. 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. 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. However, not only should Operations & Maintenance along with new infrastructure costs be included in the tariffs, but also

R&D investments must be made to support the future power system, and the rates must also include these investment needs.

7.0. 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.

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.

These changes are happening at a time when the EPI has lost much of its technical expertise. We therefore need to encourage new young highly motivated engineers to join the industry. Education and training must match the industries needs, they are no longer solely technologically driven, but new engineers need to be familiar with the wider social issues and must have knowledge of environmental issues and a greater in depth understanding of financial issues. In short the new school of electrical power engineers needs to be entrepreneurial and it is up to the EPI and individual employers to allow and encourage this approach.

It is important that the EPI faces these issues to the long term benefit of society as a whole. It needs to have greater political influence with governments and needs to involve environmentalists, financiers and educationalists in discussion of the issues.

CIGRE should be thinking about these issues NOW because CIGRE is perhaps the only international organisation that has the possibility of taking a worldwide, in depth, view of the development of the EPI.

IV

**Contribution to panel on Electrical Power Systems 2020
August 27th, 2002**

Electrical Power Systems 2020 A prospective view

M. Chamia

Immediate Past President, Cigré

ELECTRICAL Power Systems 2020 - A prospective view M. CHAMIA*

1. INTRODUCTION

Predicting the future has always fascinated mankind. In ancient times Babylonian astrologers and magicians interpreted various omens from heavenly bodies (moon, sun, stars) as well as from thunder and earthquakes in order to predict the future. Even nowadays, fortune-tellers use the same approach to entice their clients.

My keynote speech today is about the future, more precisely about the how electrical power systems might look and operate in 20 years time. Unlike the Babylonian astrologers and their followers, I will use another technique in order to look into the future. I will revert to the use of drivers and changes in order to arrive at a somewhat coherent and worldwide vision about electrical power systems in 2020. As you know, visionaries come in two flavours: the high flyers and the down-to-earth. Considering the relatively short time span involved here I will stay with the latter kind. So, without further ado let's start our journey into the future!

2. THE DRIVERS

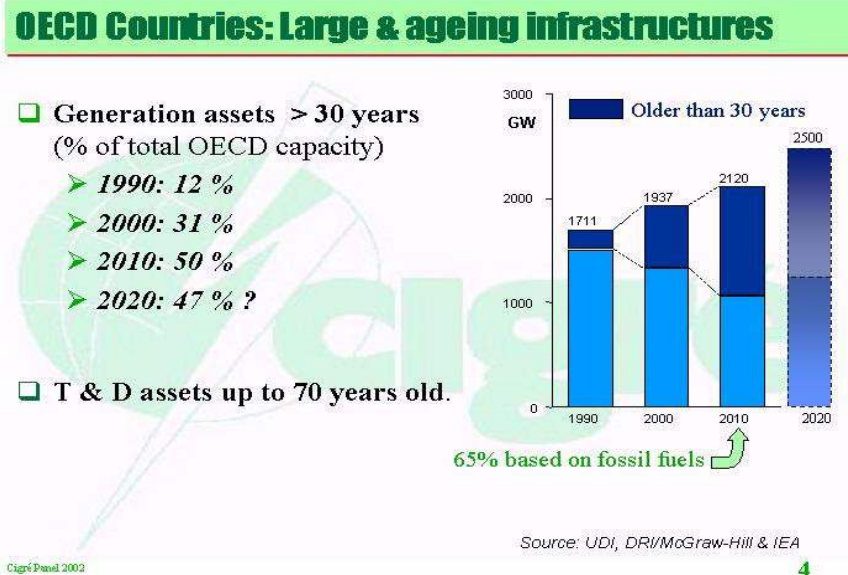
I have opted for a definition of drivers pertaining to two groups of countries rather than trying to identify worldwide drivers. I believe that the accuracy of prediction will benefit from such an approach. However, it must be understood that aggregations can only reflect main directions and that variations will occur when looking at specific countries or regions. The two groups selected are the OECD (Organisation for Economic Co-operation and Development) and the Developing Countries respectively. In electrical terms they are quite representative since they together amount to 90 % of the world's electricity consumption (the remaining 10% relates to countries characterised as Transition Economies).

2.1 Drivers in OECD Countries

The electrical infrastructure in most OECD Countries is typically composed of rather large power systems with ageing generation and grid assets. For example, in the year 1990, generation capacity (GW) aged more than 30 years made up 12% of the total OECD capacity. The share grew to 31% in the year 2000 and it is projected to reach 50% in 2010. By that time, close to 65% of this generation will be based on fossil fuels with average thermal efficiency below 35%. In order to break this trend and increase generation efficiency a substantial replacement and refurbishment program will have to be initiated within the next ten years in order to make a difference by the year 2020. By then generation capacity will have grown to 2500 GW (from 1900 GW in the year 2000). The historical development of transmission and distribution assets is closely associated with the development of generation but the technical lifetime is often longer. For example, the electric grids in many OECD countries have large infrastructures that

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are close to 70 years old. Hence the growing need for replacement and refurbishment also in this field.



Another important driver is the increasingly strong focus being placed on environmental issues. This encompasses generation as well as transmission and distribution. In the field of generation, environmental concerns drive the search for cleaner technologies (less or no green-house emission) as well as higher energy conversion efficiencies. In the transmission (and to some extent in the distribution) area, the drive is towards a reduction of the visual, electromagnetic and acoustic impact of the power delivery infrastructure and the use of environmentally sound materials.

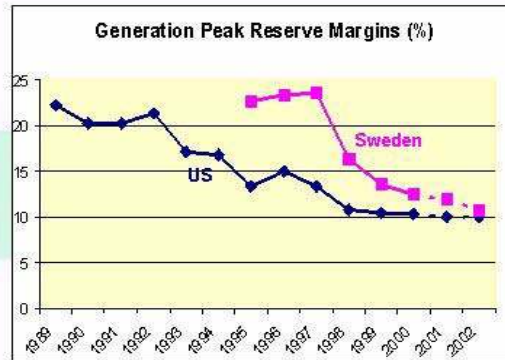
Yet another driver is the liberalisation of energy markets currently taking place, which influences the economical and technical dynamics of such markets. In the electricity sector, investments have been kept at a relatively low level for the past decade due to competitive pressures, market imperfections and regulatory uncertainties. For example, generation peak reserve margins in the USA and in my country (Sweden) have dwindled from a level well above 20 % in 1990 to around 10% in the year 2000. At the same time, cross-border exchange of electricity is encouraged and possible, but bottlenecks located both within grids and at the cross-border interfaces are becoming a limiting factor. Regulators and investors therefore actively seek new mechanisms for investment and new technical solutions are being developed by manufacturers and system planners/operators in order to cope adequately with the electricity market dynamics. These activities have a profound long-term impact on the development of electrical power systems.

OECD Countries: Liberalisation of energy markets

New market dynamics → Uncertainty → Limited investments

Generation

- ↗ Competitive pressures
- ↗ Shrinking reserve margins



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OECD Countries: Liberalisation of energy markets

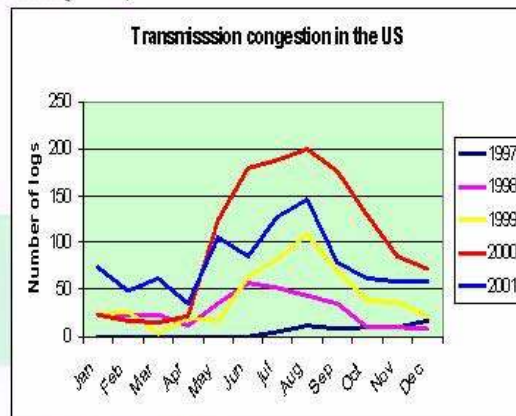
New market dynamics → Uncertainty → Limited investments

Generation

- ↗ Competitive pressures
- ↗ Shrinking reserve margins

Transmission

- ↗ Cross-border electricity trade
- ↗ Bottlenecks



Investors, Planners, Operators, Manufacturers seek new mechanisms to deal with electricity market dynamics

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2.2 Drivers in the Developing Countries

The per-capita electricity consumption in this group of countries varies between 340 and 3400 kWh p.a. (the corresponding range for the OECD countries is 2200 –22000 kWh p.a.). The political decision makers in the Developing Countries are well aware of the fact that electricity brings about substantial improvements in health, education, economy and quality of life to their citizens. Electrification programs are therefore promoted. The growing demand for electricity is an important driver that is further propelled by an ongoing trend towards urbanisation. Urban population in the Developing countries is predicted to grow from 2.1 to 3.5 billion people between the years 2000 and 2020. Comparatively speaking, the urban population in the OECD countries will only grow marginally (~10%) in the next 20 years. As we all know, urbanisation results in a shift in usage from non-commercial to commercial energy forms of which electricity is an important vector for the industrialisation and economic development of nations.

The electrical infrastructure in most Developing Countries is relatively young. For example in the year 1990 generation capacity aged more than 30 years only made up 5% of the total capacity in Developing Countries. The share grew to 16% in the year 2000 and is projected to reach 27% in 2010. By that time, close to 73% of this generation will be based on fossil fuels. Generation capacity is thus growing at a relatively high rate: From 1050 GW in the year 2000 it is projected to reach 2400 GW in 2020, i.e. almost the same capacity level as in the OECD countries. Transmission networks are growing in size and geographical coverage. Their morphology is still fragmentary in many countries, thus the strong need to develop nation-wide transmission infrastructures and interconnections between regions and countries in order to cope with the rapidly increasing demand for electricity.

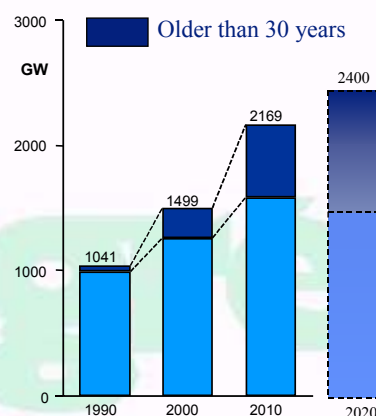
Developing Countries: Young infrastructure

❑ Generation assets > 30 year (% of total capacity)

- 1990: 5 %
- 2000: 16 %
- 2010: 27 %
- 2020: 43 % ?

❑ Fragmented T&D grids

- Development of nation-wide grids



73% based on fossil fuels

Electricity infrastructures are capital-intensive with long payback times. Hence the keen focus of Developing Countries on a good economy of investment. This is a strong driver for achieving economies of scale, for repetitive application of modular designs and for demanding low-loss/ high efficiency solutions to the problem of electricity generation and delivery in a high growth environment. The latter attribute dictates large steps in capacity addition in order to economically meet the demand. (At this scale of demand growth, small steps would create a logistical problem and require more manpower to administer and execute the projects).

3. THE CHANGES

Although many changes are bound to occur in the next twenty years, I will restrict my analysis to two main aspects, namely changes in generation mix and changes in electricity market environment. I believe that these two changes are instrumental to shaping the look and operational features of power systems in 2020.

3.1 Generation mix

According to the International Energy Agency's (IEA) World Energy Outlook 2000, the reference scenario for the OECD countries indicates a dramatic increase in the use of natural gas for electricity generation: From ~1200 to ~3700 TWh between the years 2000 and 2020, corresponding to an increase in share of total electricity generation (TWh) from 14% to 31% in the next 20 years. Other fuels such as oil, and nuclear will see their share dwindle during the same period of time while coal usage will maintain a steady share of the total. Hydroelectricity's share will also drop (from 15% to 12%) and other renewable sources of energy (geothermal, wind, solar etc.) will double their share from 2% to 4%, still remaining marginal in the total balance of electricity production.

For example, in the European Union (EU), the use of natural gas for power production increased by 128% between 1990 and 1998. A dramatic increase in CCGT and small gas turbines is predicted in the next twenty years with a nearly 10-fold growth factor. If current plans are implemented gas-fuelled plants could account for more than 40% of the total installed capacity (GW) in the EU by 2020. Presently close to 6% of Europe's energy is generated using renewable resources (wind, geothermal, solar and biomass). Current thinking aims at increasing this to 12 % by the year 2010.

Obviously, such changes in fuel mix and associated generation technology will affect the morphology of the power systems of the OECD countries. The traditional large central generating units will be complemented by a growing number of medium-to-small size units. In other words, centralised plants will not be replaced to any significant degree, but dispersed generating facilities will respond to specific market needs.

In its Reference scenario, the IEA's projections for the Developing Countries indicate a substantial growth in the use of natural gas for electricity generation: From ~700 to ~2600 TWh between 2000 and 2020, corresponding to an increase in share of total electricity generation (TWh) from 13% to 23% in the next 20 years. The share of coal will grow slightly during this period. Oil and hydro will account for a smaller share at the end of the period with nuclear expected to keep a steady (~4%) but small share of

the total. Renewable sources of energy, other than hydro will essentially maintain a constant (~1%) but small marginal share.

Electricity generation in China represents roughly one-third of the aggregated generation in the Developing Countries. However, in China, the use of coal is instrumental to electricity generation. It is projected to amount to ~2600 TWh in the year 2020, i.e. the same level as gas-fuelled generation for the Developing Countries altogether. During the next 20 years coal-fuelled generation in China will account for 70% of the country's electric energy (TWh) and 64 % of its generating capacity. Second in rank is hydroelectricity, which is expected to maintain a steady share (roughly one-fifth of the total). The conditions in China clearly exemplify the variations that can occur from the general scenario established for a group of countries.

The relatively moderate change in fuel mix for electricity generation projected for the Developing Countries is not liable to introduce dramatic changes in the basic constitution of their power systems in the next twenty years. However, the development of nation-wide grids will introduce new operational demands and require new solutions.

3.2 Electricity market environment

At the dawn of the new millennium, the electricity markets of the OECD Countries were gradually being liberalised and opened. This process resulted in unbundling of the vertically integrated utilities, in competition between generators while the delivery infrastructure i.e. transmission and distribution remains a natural monopoly. New actors have entered the arena: Regulators, Traders, Aggregators, Electricity Exchange operators, etc. It has become apparent that market models and regulatory frameworks differ from country to country and that most have imperfections while some have serious flaws.

I believe that by the next ten years most electricity market imperfections will have been ironed out, thus promoting a healthy development of power systems. For example, equitable mechanisms will be in place to ensure an economically viable recovery of investment in peak generation capacity. In the field of transmission, non-discriminatory, cost-reflective and simple tariffs will be commonplace and we will also see a regulatory environment favourable to electricity infrastructure investment, thus propelling both grid strengthening and interconnection. Merchant transmission will form niche markets that co-exist with the natural monopolies. In other words, the initial "transient phenomena" created by the introduction of liberalisation in the OECD Countries will have completely subsided by 2020 and the electricity business will be conducted just like any other business.

As these changes unfold in the OECD countries, the Developing Countries will be readying themselves for initiation of the restructuring of their electricity sector. Drawing on the experience gained from other countries, and taking into account the strong social dimension of electricity, the transition is bound to occur over a longer time period in order to ensure a smooth and robust process. By 2020 the electricity sector of some Developing Countries will operate in a similar environment as for the OECD countries.

4 ELECTRIC POWER SYSTEMS 2020

The Drivers and Changes discussed above will shape the main features of the electrical power systems in the next twenty years. I will revert to the use of two scenarios in order to give you a flavour of the future.

The first scenario assumes that centralised generation is still prevailing. I propose to call it the “distribution scenario” because the centralised generation approach leads eventually to the task of distribution of power received at central points in the power system. The power flow is then from transmission to distribution to consumption.

The second scenario features power systems with a 20-30% share of dispersed generation, the remainder being based on centralised generation. I propose to call it the “mixtribution scenario”. At this point, I should perhaps explain what I mean by “mixtribution”. When a substantial portion of generation is in the form of dispersed and (often) small units a new connection pattern emerges whereby the dispersed units are embedded in the reticulation infrastructure. Now, the flow of power is no longer the same as in the aforementioned case since the dispersed generating plants contribute with generation also at the distribution grids level. The latter lose their semantic connotation since they partly serve for distribution and partly for carrying contributions to generation, hence the term “mixtribution” coined by a friend an Cigrean fellow of mine Mr. Stig Göthe, member of the Cigré Executive Committee.

The one or the other scenario may thus be applicable at the level of a country or a region. Consequently, large geographical regions may exhibit both scenarios in different constellations. Understanding the specifics of each scenario is therefore a necessary step in order to see the bigger picture.

4.1 The “distribution” scenario

As mentioned earlier, a centralised generation structure prevails in this scenario. Consequently, the morphology and task of power systems will not differ much from what we have today. However, the qualities, performance and the operational features will be somewhat different. It is safe to say that the power systems of tomorrow will strive to feature the following qualities: They will be

- Clean and sustainable, *with low environmental impact*.

In electric power engineering, the use of environmentally sound materials is a prerequisite in this context and it must be accompanied by a strategy for their disposal at the end of the equipment life.

In the generation field, in addition to the efforts to introduce flue-gas cleaning and renewables, the increased share of gas in the total fuel mix will contribute to a lesser impact on the environment thanks to the lower emission levels of gas-fired plants compared to coal or oil-fired plants.

In the transmission field, the power density of existing overhead line corridors will be increased with little visual, electromagnetic and audible impact and new lines will feature environmentally attractive designs. Cables will play a key role in mitigating the environmental impact of the electricity delivery infrastructure particularly in cities and their neighbourhood, thus becoming the natural complement to overhead lines.

- Sufficient, i.e. *supplying enough power to maintain a good quality of life on this planet.*
 This implies investments in fuel supply/handling facilities, power system capacity and adequate maintenance programs to guarantee high availability of power plants as well as a reticulation infrastructure that reaches deep into the remotest regions of the world. Transmission will thus continue to play a key role in helping to level off regional and temporal imbalances in supply and demand. Obviously, bulk-power transmission will still be in demand. Interconnection between regional and national grids will grow in importance and capacity. For example, some regions of the world may exhibit interconnection capacities amounting to 10-20% of their installed generation capacity.
- Affordable, so that *all people around the world can have access to electricity.*
 The combined effect of economies of scale and scope coupled to new solutions using modular approaches and designs requiring a minimum of maintenance will all contribute to reduce the investment, operation and maintenance costs of equipment and plants. In many Developing Countries the traditional approach to electricity infrastructure development is financing based on the national balance sheet, i.e. either cash or by sovereign guarantees for the repayment of loans. This often stretches the financial capabilities to the limit. In the next twenty years we will increasingly see a shift in political paradigm and acceptance of foreign ownership. From being everything from the buyer of equipment to the provider of services, the host government’s primary function will then be to provide satisfactory legal and regulatory framework and political and economic stability. The reward for the host government will be to have the services efficiently provided without any negative impact on the state budget. Naturally, this affects not only the role of governments but also the role of other participants in a project, such as banks, equipment suppliers etc.
- Tailored, so that *the supply of electricity will have the reliability and quality needed by the consumers.*
 Presently, the reliability and quality of most transmission grids is adequate. However, the distribution grids are not always able to respond to the availability and quality requirements of all consumer categories. In the next twenty years we will see substantial improvements in this respect. Distribution infrastructures less prone to atmospheric disturbance (storms, lightning, etc.) and fitted with “intelligent” equipment will increase the reliability of supply. Power conditioners supplemented with energy storage capabilities will make it possible to meet the individual quality requirements of different categories of electricity consumers. Commercial agreements between electricity supplier and consumer will relate requirements to prices in a transparent way.
- Smart, *making use of information technology (IT) to provide meaningful criteria and manage large systems.*
 Information technology permeates all fields of engineering and power engineering benefits strongly from IT. The primary HV equipment will increasingly become “intelligent” in the next decades, featuring advanced sensors and actuators designed to minimise electrical and mechanical stresses on the equipment. Monitoring and diagnostics of HV equipment will be an integral part of asset management systems and of usage optimisation systems, providing real-time data (including environmental data) in order to maximise the

availability and use of existing resources. For example, dynamic rating of power system components will be commonplace. Communication between HV apparatus, their field devices and data processing and information extraction functions hosted in a network of portable and stationary computers will automate and improve the performance of power systems. We will see a shift from handling huge amounts of data yielding limited or vague information to a situation where refined and adequate information is extracted from a multitude of sources and condensed to support the operators or the concerned decision makers. This comprehensive information integration will cover multiple aspects of a power system, ranging from planning and scheduling, plant and process engineering to operations and maintenance. It will support asset owners and operators throughout the entire lifecycle of their assets and optimise operations by extending information availability all the way from business systems with relatively moderate transaction times to very quick real time data from field devices.

- Efficient in the supply and use of electricity

First and foremost, the focus will be on reducing wasted energy. We will therefore see a trend towards generating units with higher conversion efficiencies and grids with lower delivery losses. Obviously, new technology and new materials will play a key role in achieving these objectives. One aspect of efficiency that I particularly wish to highlight is the possibility offered by Information Technology to design power systems with reusable solutions and intelligent products. Modular approaches using “copy-and-paste” engineering coupled to a plant engineering philosophy of “plug-and-operate” will contribute to reducing design and application risks and to boosting the economic performance of the power system assets. All stakeholders will benefit from high productivity in electricity supply provided this is also coupled to an efficient use of electricity. The potential here is still largely untapped and I believe that the next twenty years will bring substantial improvements in this domain, among others thanks to process enhancements and advances in materials engineering. Again, some of the “smart” solutions hinted above will also contribute to increased efficiency.

- Flexible and Controllable, to enable quick and accurate power supply in response to market demand.

On the generation side, hydropower will continue to provide flexibility and control. The relatively smaller capacity of gas-fuelled plants anticipated for the next two decades will also add to flexibility in meeting variation in demand. The transmission system and particularly interconnections will be equipped with a growing number of power flow control devices (FACTS and HVDC). The controllability will improve both the steady state and the dynamic response of associated power systems. It will also adapt the transmission system to the requirements set by dynamic electricity markets, thus solving some of the limitations we see presently with transmission systems developed long ago for given purposes, but subjected nowadays to other constraints. The high voltage – high power semiconductor devices will by virtue of their inherent controls assume a local protection role as well. Advanced wide-area protection schemes

will anticipate trouble and initiate suitable counter measures to safeguard the integrity of the power system.

On the demand-side, we will see the emergence of economically affordable intelligent devices and communication means allowing the consumers as well as the suppliers and operators to obtain greater flexibility during peak and/or valley hours.

Finally, it is probably safe to say that mobile telephony and the Internet will surprise all of us with a host of new functions and applications for added flexibility and control in the power systems of 2020!

4.2 The "Mixtribution" scenario.

This scenario describes power systems with a 20-30% share of dispersed generation, the remainder being based on centralised generation. The dispersed generation units produce electricity and/or heat close to the load centre and by virtue of their lower economic size they can be connected to sub-transmission and distribution grids. This results in major changes particularly at the distribution level, in respect of planning, design and operation.

From a power systems point of view, I can see implications on the following aspects of our work:

- ◆ **Flexibility:** Most distribution systems today, including those hosting dispersed generation, lack real-time remote control facilities. This is because they were originally conceived for a unidirectional flow of power along radial paths. At the same time many distributed generating resources have a controllable power output, which makes them suitable for power exchange with the grid under a variety of operating conditions. This results in bi-directional power flows. Changing power flow patterns require increased distribution grid flexibility compared to present conditions. This calls for fully automated real-time remote control systems and power flow control devices in such grids, in order to manage the dynamics of the new power system. Consequently, the distribution grid management and control philosophy currently applied will be fundamentally revised. An enabling factor that comes into play in this context is the tremendous development in telecommunications engineering and the massive spread of Internet usage.
- ◆ **Operability:** In light of the above, one can foresee that the dispersed generation units will be adequately orchestrated through real-time information and controls systems. For example, clusters of such units will collaborate to offer network services such as reactive power management, frequency response, reserves etc. in a similar fashion to what is currently being done at the transmission grid level. In fact, a virtual utility operation can be of greater value than the sum of the individual generating resources. Furthermore, security benefits will be derived under outage conditions by reverting to the operation of dispersed generating units in so-called island mode. Obviously, operation of this kind of network will be more complex than traditional distribution networks. Thus the need for a thorough revision of the existing planning practices and operational procedures. The competitive pressures on dispersed generation resources will put stringent requirements on technologies and designs in respect of availability and low maintenance needs. Dispersed generating facilities based on intermittent resources are not schedulable (e.g. wind power, solar power), thus the need in this scenario to adequately guarantee the availability of schedulable generation reserves. This implies the existence of a liquid

market for reserves with low transaction costs.

- ◆ **Quality:** Generation based on intermittent energy resources have an impact on the voltage quality of networks to which they are connected. Wind power is a good example of this, since the output power level varies with the wind conditions. The reactive power demand fluctuates as well. Whenever a substantial capacity addition is made using wind power connected to a distribution grid, the issue of rapid active and reactive power control becomes important. Power control devices will therefore be commonplace in this scenario of the power systems 2020. For example, in my country, a fully controllable High Voltage Direct Current link rated 50 MW at ± 80 kV has been in operation since 1999, connecting a wind power park to the load centre some 70 km away. Operational records show an improved voltage quality in spite of a doubling in wind power generation. This improvement in quality of supply would be impossible to achieve without the control features inherent in the HVDC converter scheme.
- ◆ **Safety:** Increasing the aggregated capacity of dispersed generation connected to distribution grids, leads in the short-term to an increase in short-circuit current levels. Network reinforcement may become necessary in order to ensure that the fault levels are within the capability of the installed equipment. The safety aspect related to the general public and to the equipment itself must remain in focus. In the long run, I believe that this issue will be solved using innovative connection technologies that have intrinsic fault level control.

The relatively large portion of centralised generation assumed to be part of this scenario will naturally have the same general traits as described in the previous scenario. However, demand for bulk-power long-distance transmission will be reduced compared to that scenario, due to the siting of generation closer to the consumption centres. The new dimension here lies in the planning, design and operation of distribution grids and in their interaction with embedded generation.

5. CONCLUSIONS

Ladies and Gentlemen, I will now wrap up, and submit to you a few thoughts for further discussion.

In every economic sector, we find electricity to be an indispensable and convenient form of energy. The historical evolution of electric power systems over the past century is characterised by a series of moves from local to regional to national power systems. In the past few decades, many interconnection projects, particularly in Europe, have extended the boundaries of electric power systems beyond the national borders into an international arena.

Looking into the next two decades, it is clear in my mind that this trend will continue particularly in those regions of the world hosting Developing Countries. Concurrently with this development, and particularly in the OECD countries, we will see the establishment of a new power generation structure featuring a mix of dispersed units as a complement to the traditional centralised generation. Hence the two scenarios I described earlier. I do not believe that these scenarios present insurmountable technical

challenges. Technology is indeed available or under rapid development both in terms of innovative power generation devices and in terms of Information Technology based equipment and systems.

The two most important changes we will see henceforth are related to a change in global fuel-mix favouring gas for electricity generation and to electricity market environment with stable and clear regulatory framework supporting a favourable investment climate. As you know, understanding the technical system implications of the scenarios described earlier is indeed important but not sufficient. For the overall picture to become clear, one also needs to address the impact of legal, regulatory and market arrangements as well. I have tried to do that in my analysis.

The share of electricity in the world's total energy consumption continues to rise. Transmission and distribution will continue play a key role in making electricity available to everyone. I therefore believe that the work of Cigré will continue to be important to electricians around the world.

I wish to conclude these few reflections with a word of advice to policymakers, investors, engineers and all other stakeholders in the electricity sector: Please be prepared for changes because the future is no longer what it used to be! Ladies and Gentlemen, I hope this speech will inspire you in your endeavours to serve your communities by ensuring that electricity contributes to a better quality of life. As electrical engineers I trust that we will be able to develop and manage the power systems of the year 2020 imaginatively and efficiently, so as to better satisfy the World's electricity needs.

Thank you for your attention.

V

**Contribution to panel on Electrical Power Systems 2020
August 27th, 2002**

Discussion

led by

Dr. Graeme Burt

Strathclyde University

Discussion
Graeme Burt

- 1.0. Walt Patterson has given a global view of the changing Electrical Power Industry. He argues that what is needed is a 'services system' not an 'electricity system'. Such a services system is unlikely to be provided by a traditional electricity power network. It will probably comprise local on-site modern generation technologies connected to a wider network. The latter including old hydro plants, modern micro-hydro units, large cogeneration technologies, off shore wind plants and possibly village scale biomass plants. The wider network would operate as synchronised AC but include many AC-DC-AC links to local networks.

Question 1.1

Do you agree with this scenario, if not what are the alternatives?

Question 1.2

To what extent do you believe the electrical power industry will have changed by 2020?

- 2.0. In his presentation Dr. Zomers summarized the findings of a recent study on rural electrification. It is now generally accepted that the availability of reliable and affordable energy, including electricity, is an important component of the rural development process. However in the modern business world, investors require quick returns on investment, long term investment is no longer likely to be underwritten by governments. As a result projects in underdeveloped countries will need to be of smaller scale, using newer technologies giving quicker access to services and quicker payback periods. Dr. Zomers focused on the need of such rural electrification projects. Renewables can offer opportunities for the electrification of rural areas, albeit the centralized grid remains of major importance with a changed role.

Question 2.1

Although most of the rural dwellers in the developing countries belong to the poorest people, many of them are prepared to pay a significant share of their income to reliable energy services. What would be the most appropriate approach, technically and financially, for the "green field" electrification of their areas?

Question 2.2

Will the Global Village Energy Partnership Initiative provide all the services required for some two billion people currently without electricity? Which are the critical success factors for this and similar initiatives?

- 3.0. In the third presentation we have heard about the emerging technologies and material challenges. If the scenarios described prove to be correct, then many of the emerging technologies will be required

to provide the 'services system' but much R&D effort will still be required to bring these to fruition.

Question 3.1

How do we coordinate R&D efforts to allow quicker application of the newer technologies bearing in mind that the traditional 15 year gestation period will not be acceptable in today's world, and how can future investment in R&D be encouraged?

Question 3.2

How should we encourage younger people to show that the Electrical Power Industry will be a worthwhile career?

- 4.0. Mr Chamia, in his presentation has also described the two possible scenarios, the modified traditional approach with the 'distribution' scenario and the evolving dispersed generation or 'mixtribution' scenario. This theme follows in all contributions and precise developments are difficult to predict even within the coming 20 years.

Perhaps Mr Chamias concluding comment to all electricity stakeholders is the most important : -

"Please be prepared for changes because the future is no longer what it used to be"!

Question 4.1.

How can CIGRE prepare itself to meet the evolving challenges and how could it best interface with other stakeholders, i.e. policy makers, investors, environmentalists etc.?

Question 4.2.

What possible further organisational or procedural changes could be introduced to allow greater flexibility to adapt as the scenarios unfold?

VI

Contribution to panel on Electrical Power Systems 2020
August 27th, 2002

Conclusion

Special Reporter

Bernard M. Pryor

CIGRE Panel on Electrical Power Systems 2020

Held on the 27 August 2002

Report of Special Reporter

B M Pryor

Four presentations were given at the Session these were : -

- 'A Global View of the Changing Electrical Power Industry' by Walt Patterson – Associate Fellow of the Royal Institute of International Affairs UK.
- 'The Challenge of Rural Electrification' by Adriaan Zomers – Advisor to the Dutch Ministry of Foreign Affairs.
- 'Emerging Technologies and Material Challenges' by Bernard Pryor – Independent Consultant, on behalf of SC15.
- 'Electrical Power Systems 2020. A prospective View' by Michael Chamia – Immediate Past President of Cigre.
- Discussion – Led by Graeme Burt, Strathclyde University.

Walt Patterson pointed out in his presentation that the changes in the Electrical Power Industry (EPI) over the last 18 years have been extremely rapid and that this trend will continue at even a greater and more rapid pace over the coming 18 years to 2020. The trend will be for greater application of decentralised units more readily able to achieve environmental, quality and financial requirements and at the same time provide facilities for giving supplies to the one third of the worlds population who currently have no access to electricity.

The changes ahead will be turbulent and will require resolution of many problems for which we currently have no solutions.

Adriaan Zomers highlighted the challenges of rural electrification, re-emphasising some of the issues raised by Walt, in particular, the fact that we can no longer ignore one third of the world's population who have no electrical supplies. The question is not 'if' but 'when and how' these can be provided. Centralised systems have been traditionally unable to provide needs at reasonable costs, the newer technologies will offer enhanced opportunities. An integrated global strategy will be needed to ensure that appropriate supplies can be made available. The Global Village Energy Partnership has been initiated and it is hoped that, with cooperation of all parties, programmes for the provision of electrical supplies in rural areas of developing countries can be initiated.

The SC15 Paper comprised a compilation of contributions of many international experts in the various fields of emerging technologies. The major 'drivers' are also highlighted as are the needs for more appropriate materials. The Paper was intended to give an up to date review of the current state of art. The main conclusions are a need for : -

- coordinated R&D
- improved R&D funding
- improved training of younger engineers to meet the challenges ahead
- need for all to work together to bring the technologies to fruition

Finally, Michael Chamia attempted to take a prospective view of a 2020 power system. After discussing drivers he put forward perhaps a little more conservative view than others suggesting two possible scenarios. The 'distribution' scenario which assumes that the centralised generation systems still prevail, and the 'mixtribution' scenario which he suggests is a centralised system but with a 20 – 30% share of embedded generation.

However the centralised system would not be as it is present, the 'distribution' system would need to be : -

- clean, sustainable
- sufficient
- affordable
- tailored
- smart
- efficient
- flexible and controllable

Similarly the 'mixtribution' system would additionally need to have : -

- flexibility
- operability
- quality
- safety

With this scenario the demand for bulk-power long transmission systems will be reduced with generation closer to the load.

Discussion

An interesting and open discussion was led by Dr Graeme Burt from Strathclyde University. Many topics were raised during the short discussion period : -

- A question was raised on reliability of supply and the comment was made that, at present, in the UK, there was no current problem with reliability. The Panel speakers did not agree and suggested that stringent pricing was forcing closure of uneconomic power stations, this would encourage more embedded generation which would further reduce system security and system reliability.
- The next questioner asked about the advantages of dc in evolving systems. Mr Chamia commented that modern dc technologies would allow greater flexibility and control of ac systems. Mr Patterson commented that most appliances operated on dc and there would be no problems for dc generation technologies to directly feed these. It was illogical to generate dc, convert back to ac, and then back to dc.
- In response to a question on the role of storage devices it was commented that local storage devices would be required but the need for large storage devices would probably reduce.
- Whilst networks for the supply of gas had evolved in developed countries, a question was raised about such supplies in developing countries. Mr Pryor commented that development of fuel supply infrastructures was critical to the

application of emerging technologies. Such fuels included hydrogen and methanol for which there were currently no delivery infrastructures.

- The next questioner raised the role of superconductivity in the evolving technologies. It was commented that by 2010 there would be a large market for superconductivity technologies and that by 2020 their application would be commonplace.
- Environmental 'pricing' was raised by a further speaker. It was commented that costing for environmental issues had not evolved.
- A final question was raised on competitive markets for the future. Mr Chamia commented that new actors and investors would emerge as the technologies developed. Mr Patterson, on the other hand, commented that current markets were false because electricity was not a commodity that could be marketed. We needed to move away from kWhrs to energy services including conservation.

The Future

Clearly the Panel has generated considerable interest, all authors foresee major changes ahead. We are very clearly entering a very turbulent period over the next 18 years and beyond. No one can yet give a clear picture of the EPI of 2020 but it is believed that the directions in which we are moving can be readily foreseen although the extent to which any of the emerging technologies will predominate is as yet unclear. Many of the issues likely to arise have as yet no solutions and the industry will be facing very challenging times ahead. We will need highly motivated well-trained engineers to move the technologies forward and there is a challenge for universities to provide appropriate training courses.

How does Cigré now carry the initiative forward? Within SC15 we propose the formation of a new WG to monitor the emerging technologies. It is suggested that perhaps a higher level group within Cigré would be necessary, perhaps an interdisciplinary group with representatives from all SC reporting to the TC. Similarly, liaison with outside 'stakeholders' will also be necessary and procedures for such liaison would need to be formulated.

Cigré has always had a major role to play in the development of the EPI and this will continue in the coming years at a greater pace than we have traditionally been used to.

To use Mr Chamias phrase 'Please be prepared for changes because the future is not what it used to be'.

Appendix

Panel on Electrical power systems 2020
August 27th, 2002

Biographical notes

Johan J. Smit

Johan J. Smit graduated in 1974 in Experimental Physics and in 1979 he received his Ph.D. at the State University of Leiden for his research in electro-magnetism on behalf of the National Science Foundation. He was employed in different research/management functions during two decades at KEMA's testing, consultancy and engineering company, Arnhem NL. In 1996 he became professor at the Delft University of Technology in High Voltage Technology & Management. He is also member of the supervisory board of TZH, the power grid company of South Holland. Furthermore he represents the Netherlands in the Technical Committee of IEC 98 on Electrical Insulation Systems and he is the chairman of CIGRE Study Committee 15-D1, Materials and Emerging Technologies.

Walt Patterson

Walt Patterson is Associate Fellow in the Sustainable Development Programme, Royal Institute of International Affairs, London. He is Canadian, resident in Britain since 1960. A nuclear physicist by training, he has been actively involved in energy and environmental issues for more than three decades. He is the author of twelve books and hundreds of papers, articles and reviews, on topics including nuclear power, advanced coal technology, renewable energy, energy efficiency, energy policy and electricity. He has acted as specialist advisor to two Select Committees of the House of Commons, and served as an expert witness at official hearings in the UK and abroad. He has been a frequent broadcaster and advisor to television and radio, and participates as speaker or chair in many conferences around the world. His most recent book, *Transforming Electricity*, was published by RIIA and Earthscan in 1999. His next book, now under way, a sequel to *Transforming Electricity*, will be called *Keeping The Lights On*.

Adriaan N. Zomers

Adriaan Zomers has been educated as an electrical power engineer and was admitted to the degree of Doctor by the University of Twente, the Netherlands on the basis of his research on the electricity supply of rural and remote areas. He worked for over 30 years in senior engineering and management positions in the power manufacturing industry and in the electric utility sector in the Netherlands. He is a core member of the Dutch Government Support Group for Energy and Environment (SEM) and acts since 1987 as an advisor to the Dutch Ministry of Foreign Affairs (International Development Co-operation) on energy supply and related environmental, institutional and management issues. He has been chairman or member of international and national committees and working groups of CIGRE. In 1995, he was awarded the CIGRE Technical Committee Award and in 1996 he was honoured with the distinguished membership of this international organisation.

Bernard Pryor, DipEE CEng FIEE MIMgt

Bernard's career started with a Student Apprenticeship with an electrical manufacturer where experience was gained on design, manufacture and type testing of switchgear, fuses, instrument transformers, power transformers, cables and capacitors; ultimately he was appointed Chief Switchgear Development Engineer. After 14 years he moved to the Utility Industry where he joined the then CEGB working within their switchgear group on all classes of switchgear. After 10 years with CEGB he moved to Scottish Power as Chief Switchgear Engineer responsible for all switchgear equipments from 240V-420kV. He was also instigational in the development of the GIS UHF partial discharge monitoring system and was responsible for the first 420kV GIS installation of the system in 1985. During latter years Bernard took on the role of Technology Development Manager, which involved assessment of evolving technologies. Throughout his career he has worked on many IEC and CIGRE committees and was honoured with the CIGRE TC award in recognition of his outstanding contribution to the work of SC23 – Substations. Over the last 5 years he has been UK representative on SC15. Bernard has written, and contributed to many International papers and has lectured to audiences in the UK and overseas. Since retiring Bernard continues to undertake Consultancy assignments for both manufacturers and Utilities in different parts of the world.

Michel Chamia

"Mr. Chamia is Vice President and Company Senior Specialist at ABB Utilities AB, Power Systems in Västerås, Sweden. His area of responsibility is Business Development in the field of electric power transmission. Mr. Chamia joined ABB (ASEA at that time) at an early stage of his professional career. He has held various key technical and managerial positions and worked in the field of Relay Protection, Power Systems Engineering, Plant Engineering, and Electric Power Transmission. Mr. Chamia has also served as Head of the Electric Power Engineering Department, Chalmers University of Technology in Gothenburg Sweden. Mr. Michel Chamia is the Immediate Past President of CIGRE (International Council on Large Electrical Systems), one of the very few international organisations bringing electric utilities, high voltage equipment manufacturers, consultants and educational bodies together under one banner. Mr. Chamia is member of the Administrative Council and former Chairman of the Technical Committee of CIGRE. Mr. Chamia has a wide International experience, serving on numerous International Steering Committees and Boards. He has participated in many business missions around the world and published over 70 articles at international conferences as well as in various professional magazines."

Graeme Burt

Dr Burt is currently a Senior Lecturer within the Institute for Energy and Environment, which forms part of the Department of Electronic and Electrical Engineering, at the University of Strathclyde. He was initially appointed as the SWEB Lecturer in Power Systems in 1992, and is now the Associate Director of the Rolls-Royce University Technology Centre in Power Engineering and Manager of the CEPE Utility Programme. His current research interests lie in the areas of assessing the impact of embedded generation on networks, power system modelling and simulation, energy market modelling, intelligent system applications. These interests are being pursued through a number of industrial and government funded programmes, including ScottishPower Research Fellowships, National Grid Scholars Programme, and EU Framework V projects OMASES¹ and DISPOWER². Dr Burt also conducts a number of short post-experience training courses both in the UK and in Asia concerning power systems operation and technology