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Centrifugal Electricity

When I read the programme for this conference, and saw the title the conference organizers had given to my presentation today, my eyes glazed over and my heart sank. I can't believe anyone wants to hear me 'assessing the critical impact of localized generation on power market structure – how will a fragmented electricity market affect base load demand and distribution'. I need a much snappier title than that. So let's talk about 'Centrifugal Electricity'. Those of you who remember your Latin will know that 'centrifugal' means 'fleeing from the centre'. That's what electricity is now beginning to do. As this trend away from the centre develops, it will have major implications not only for market structure, base load demand and distribution, but also for the very nature of the business you are in. Over time it is going to change the role and function of electricity in human society. Today I'll try to explain why.

The traditional electricity system, dating back to Thomas Edison's Pearl Street installation in lower Manhattan in the early 1880s, came about for one overriding reason: the economies of scale associated with generators driven by steam power or water power. Until the time of Edison, anyone fortunate and wealthy enough to boast electric light had the entire system - generator, cables and lamps - all on the same site. Edison's great idea was to scale up the process. Making individual generators larger reduced their capital cost per unit of output capacity; for steam power, increasing the size of the boiler also increased fuel efficiency, thereby also lowering unit operating costs. To be sure, some capital savings were offset by the additional cost of ever larger and more complex networks to subdivide and deliver the electricity output to users; and running cables across many properties and through public space raised other issues. But the overall effect of increasing scale of electricity generation and interconnected systems steadily reduced the cost of electric light and motive power. By the 1980s electricity was ubiquitous and indeed essential throughout modern industrial society. Moreover, although electricity systems were arguably the most complex industrial activity on earth, most people in modern industrial society took electricity and its many applications completely for granted.

In a traditional electricity system, electricity in the form of synchronized alternating current is generated by rotating machines in large, remotely sited central generating stations, and delivered to users over elaborate networks including long high-voltage transmission lines and lower-voltage distribution networks. Throughout the twentieth century this configuration became the common technical model of electricity system, replicated all over the world. Because the network is an inherent part of the system, system operators argued that an electricity system is a natural monopoly. Politicians agreed. From the 1920s onwards, whether 'natural' or not, an electricity system was almost invariably granted a monopoly franchise in its service area, with a corresponding obligation to supply all the electricity that its users required, everywhere within the area, throughout the day and throughout the year. Either implicitly or explicitly the relevant government supervised or 'regulated' the monopoly, to ensure that it did not take unfair advantage of its captive customers.

The monopoly franchise proved to be crucial for the expansion of electricity systems, especially once most people in the franchise area had come to rely on electricity from the system. Captive customers buying an essential good guarantee a revenue stream. System planners were therefore able to order and finance ever-larger generating units, always pursuing purported economies of scale. Such enormous units might take up to ten years to construct and commission, and might have to operate for another thirty years or more to earn an adequate return on investment; but the captive customers bore the risk. From the 1960s onwards, in many places, this risk proved substantial; many power stations suffered serious and costly delays and budget overruns. The consequent financial burden - thousands of millions of dollars, in many currencies - fell on electricity users and taxpayers. Nevertheless the traditional electricity system continued to prevail. In the early 1980s, as it celebrated its first century, its adherents little imagined what lay in store.

The first signs of the impending upheaval emerged in Chile and the UK in the late 1980s. The governments of Augusto Pinochet in Chile and Margaret Thatcher in the UK, ideologically committed to 'free markets', decided to sell off their government-owned electricity systems to private investors. So-called 'privatization' of electricity was not of itself at all novel; electricity systems in the US, Germany and Japan, for instance, had long been privately-owned. In the UK, however, the free-market theorists did not want the powerful Central Electricity Generating Board to become a private monopoly. Almost as an afterthought, therefore, as well as privatizing the country's electricity system, the Thatcher government broke it up into a collection of separate companies for generation, transmission and distribution - 'restructured' it; and announced that henceforth the different generating companies would have to compete to sell their output. Customers would no longer be captive; they would be free to choose between competing suppliers.

The introduction of competition had a number of unexpected consequences. One in particular stands out. Electricity liberalization in the UK coincided with the sudden emergence of gas-turbine generation for baseload operation, and cheap and abundant natural gas to fuel it. Within less than five years, gas-turbine generation became the technology of choice for new power stations not only in the UK but essentially wherever natural gas was available. Gas-turbine generation marks a sharp break with the historical trend, in which the ruling assumption has long held that a better power station is always a bigger power station, probably farther away. A gas-turbine generator can be efficient and economic at much smaller scale than traditional generators. It can be ordered, constructed and commissioned in less than three years, often substantially less. It is modular, allowing incremental investment timed to correspond to the growth of demand. Firing natural gas it does not require a fuel store. It produces no solid waste, and its emissions to atmosphere can be very low. It is therefore easier to site; it can be located closer to users, and indeed even on the same site as its major load. It is therefore ideally suited to cogeneration, producing electricity, heat and possibly cooling, boosting fuel efficiency above 80 per cent, improving both its economics and its environmental performance.

The most attractive feature of gas-turbine generation, however, is financial. In a liberalized competitive context, tradition electricity investments, large-scale and long-term, become acutely risky - and the risks must be borne not by captive customers but by shareholders and bankers. Minimizing exposure to such risks leads to a fundamental shift in the choice of electricity technologies. Instead of traditional technologies, centralized, capital-intensive and inflexible, liberalized competitive electricity favours more decentralized technologies. A portfolio of smaller-scale, more numerous, more diverse and more flexible assets yields more rapid returns; it is also less vulnerable to the vagaries of an electricity scene beset by intensifying uncertainties - financial, technical, institutional and environmental.

Liberalization and gas-turbine generation are, however, only the beginning. A whole range of innovative small-scale modular generating technologies is coming to market, dramatically widening the options available. Major international companies are devoting substantial budgets to developing microturbines, fuel cells and renewable energy technologies including wind power, biomass power and photovoltaics. The attributes of these technologies are very different from those of traditional generation. Their economics benefit not from increasing unit scale but from series manufacture and a rapid learning curve. The options they offer for ownership, siting, operation, new network functions and system configurations are far removed from those of traditional generation. The implications for electricity systems are profound, and as yet far from fully appreciated.

In particular, the evolution of electricity generation toward smaller, more numerous and more decentralized units presents a growing challenge for electricity networks - and vice versa. If electricity networks fail to evolve appropriately, they will become a serious if not insuperable obstacle to realizing the benefits of innovative generation. In a traditional electricity system, the roles and functions of transmission and distribution are clear and unambiguous. Systems all over the world are structured and configured accordingly. The generators are large, remotely sited and synchronized, so that all their output can be pooled into a high-voltage transmission grid and delivered over long distances. When the electricity reaches a cluster of loads, it passes through transformers to step its voltage down, and flows into a low-voltage distribution network that carries it to users. The whole network effectively constitutes a radial, one-way delivery system, from generators to users. The network also serves to subdivide the very large output from individual generators into smaller flows, to match loads that are usually much smaller than the generators. The presumption is that individual loads connect to and disconnect from the system at will, and independently. The rest of the system has to respond accordingly, almost instantaneously, in real time. Because the system is synchronized, the inertia of the large generators helps to keep it in stable operation. The generators and network must nevertheless be subject to a central controller, to coordinate the necessary responses as users connect and disconnect and the inevitable faults occur.

On a traditional system this arrangement works fine, as long as the system has enough generation and network capacity to match peak loads, and a margin of redundant capacity to cope with faults and other contingencies. The planners of a traditional system therefore order substations, transformers, switchgear, transmission lines and towers, distribution cables, circuit-breakers and other protective equipment, everything they consider necessary, including redundant capacity; and captive customers pick up the bills. Since a blackout is much more embarrassing than a tariff increase, system planners on traditional systems have historically equipped themselves with ample redundancy, to keep the lights on.

Liberalization, however, changes the ground-rules. The impact of liberalization on networks is less obvious than its impact on generation, and at the moment differs markedly depending on where you look. But over time, liberalization will affect networks at least as dramatically as it has already affected generation. We now have to consider a market FOR networks, and a market BY networks. In the market FOR networks, that is for new network technologies, applications and services, who are the buyers in a liberalized market context, and what do they want to buy? In the market BY networks, the so-called ‘electricity market’ now being established across Europe, North America and elsewhere, networks are the essential infrastructure without which this electricity market cannot function. But the existing traditional networks were never intended to be used this way, as an infrastructure for competition between generators supplying users who are free to choose among different generators and other suppliers. Accordingly, both the market FOR networks and the market BY networks are already giving rise to serious uncertainties. Major problems loom.

Where electricity is being liberalized, the status of traditional transmission and distribution is changing, almost month by month. High-voltage transmission networks are usually separated from lower-voltage distribution networks. Different parts of the same interconnected network often have different owners; but now these owners may be competing with each other. All the different parts must still operate together, in real time, to keep the whole system stable; but the different owners have different agendas - especially corporate and financial. Who is to have access to which parts of the network, and on what basis? The ground-rules and charges for access to and use of the network are already hotly controversial, and will become more so. Systems that used to have ample redundancy under the traditional monopoly franchise are now often facing capacity constraints, even within traditional franchise areas. Systems that used to be interconnected on a cooperative basis, for load-levelling and backup, are now supposed to operate in a market context, delivering electricity from competing generators over interties whose limited capacity exacerbates questions of access and charges.

At the same time, however, expanding traditional transmission capacity is usually difficult, if not impossible. Political and environmental objections pose daunting obstacles to any proposal for new overhead lines. Even if these obstacles can be overcome, the pervading uncertainties about the future status and financial prospects of new transmission capacity are a severe deterrent. Shareholders and bankers are reluctant to finance major projects that may not recover their investment costs. Until quite recently, manufacturers of traditional transmission technologies have been able to console themselves with thoughts of the market in parts of the world where liberalization has yet to take hold - where transmission business remains business as usual. Now, however, even those parts of the world - for instance China - are showing unmistakable signs of change toward liberalization. This is bad news for traditional transmission technologies and their manufacturers. In OECD, transition and emerging countries alike, a huge question mark looms over future investment in traditional transmission technologies. Who will place the orders? Who will put up the money, and take the risks?

In traditional systems, transmission and distribution have historically gone together, planned, financed and operated as complementary parts of a coherent network configuration. In a liberalized market context, however, the status, role and function of low-voltage distribution networks are beginning to diverge from those of high-voltage transmission networks. One crucial difference arises as a result of the advent of small-scale generation. Small-scale generation is often most appropriately connected to a network at moderate voltages, well below transmission voltage. Moreover small-scale generation is often sited at locations far from transmission lines, but close to users and the distribution network linking them. The resulting configuration has come to be called 'embedded generation'. I dislike this term, because it immediately raises the question 'embedded in what?' The implicit answer is 'embedded at an unexpected place in an otherwise traditional electricity system'. The corollary implication is that this generation does not fit traditional system criteria, and is therefore less satisfactory.

Electricity networks are therefore emerging as the battleground between tradition and innovation in electricity systems. Innovative generation does not fit comfortably into traditional networks. As yet, however, innovation in networks is lagging far behind innovation in generation. The stage is set for what may become a battle royal.

Nevertheless, as micro-turbines, fuel cells and other small-scale generating technologies mature, more and more places with ever smaller loads will become candidates for on-site generation - not only industrial sites but office buildings, shopping malls, airports, railway stations, hotels, hospitals, schools, blocks of flats and perhaps even individual residences. Small-scale generation will have to overcome the inertia of traditional networks, and the obstacles they will raise; but I remain confident that the advantages of small-scale local generation will eventually prevail.

What this will do to the rest of the electricity system over time, however, is still an open question. It depends on how the networks themselves evolve; but even at best the consequences may still be progressively disruptive. In due course it may even put those without access to on-site generation at a severe disadvantage, a corollary as yet inadequately considered. With an abundance of options to choose from, major players will be able to take care of themselves. But who will ensure that poor neighbourhoods and rural areas still have access to electricity services? Will industrial countries, like too many developing countries, divide into electricity 'haves' and 'have-nots'? No matter who owns what on a liberalized system, if the lights start going off, the government will be in the front line.

That, of course, is a key reason why governments and regulators persist in maintaining the traditional role and function for networks. They are afraid that otherwise they will lose control of the system - that the lights will go off. But the tension between traditional networks and innovative generation is not going to abate. On the contrary, it will become ever more acute. The changing structure and performance of nodes and interfaces, where generators and loads meet networks, and where one part of a network meets another, are going to be crucial if networks are to evolve as I believe they must.

Innovative network technologies are indeed emerging rapidly, for example, Flexible AC Transmission Systems or FACTS technologies; compact high-voltage DC; and power electronics of rapidly expanding capabilities and versatility, including transformers based on entirely new concepts. Innovative technologies such as these will greatly facilitate the evolution to new roles for electricity networks. Transmission networks will have to deliver not only hydro but also offshore wind from remote sites, and enable market-based trading in large quantities of electrical energy, including trading between different local networks. Distribution networks will have to evolve from radial one-way configurations into meshed multiply-interconnected two-way systems, linking local generation and local loads, with system monitoring and control technologies to match.

Some commentators call this configuration a ‘virtual utility’. I must say, however, that I myself have long since stopped using the word ‘utility’, because in the emerging liberal context no one can tell me what ‘utility’ means. It used to mean ‘public service’ - by implication provided either directly by governments, or indirectly by companies given a franchise by governments. In a liberal competitive market context, however, traditional ‘public service’ disappears, and along with it the ‘utility’. The critical question is what is to take its place, and how? How do we get all this innovative network technology into service? Who is to pay for it, and who decide? As yet I don’t know the answers; but we’d better find them, and quickly.

Let me explain why I think these opportunities are so important, and so pressing. In November last year I wrote a short paper exploring these issues. I read it through and found myself wondering ‘Do I really mean this?’ Then I read the paper again, and thought ‘Yes - I do’. I called the paper ‘Full Circle’. As the title indicates, its central premise is that after more than 120 years, electricity may be starting to come full circle, back to where it began. Until the time of Thomas Edison, at the beginning of the 1880s, anyone wanting electric light had the entire system on the same site - generator, cables, switches and lamps. The arrangement was dauntingly expensive. Edison’s great idea was to scale up the whole process, to reduce its unit costs. That in turn meant finding customers willing to pay for electric light on many different premises, all connected by cables to Edison’s central generating station on Pearl Street in lower Manhattan. At the outset Edison charged his customers according to how many lamps they used; he was selling electric light, not electricity. In order to keep costs as low as possible, he had to optimize the entire system, to deliver what customers wanted - electric light - at a price they could afford.

Then - and this is the point I’d like you to think hard about - it all began to go wrong. Shortly after the Pearl Street system started up, along came the electricity meter. From that time on, Edison, and his many contemporaries in the US, Europe and elsewhere, were no longer in the business of selling electric light. They were in the business of selling electricity, by the unit. Think about what that implies. If you are selling electric light, you want to make the whole system as efficient as possible, to deliver what the customer wants - the light - as cheaply as possible. If, however, you are in the business of selling electricity by the unit, you the seller actually benefit by having your customer use less efficient lamps. To get the same level of illumination, your customer has to purchase, and pay you for, more units of electricity. Inefficiency on the customer’s premises is good for your business. This perverse incentive has underpinned the electricity business for more than a century -

because the electricity business has been based on selling users electricity by the unit.

And what's wrong with that?, you may ask. Electricity, you may say, is just a commodity like natural gas or water, delivered to a customer's premises for the customer to use as desired. The meter just measures the flow of the commodity; the customer is billed accordingly. Throughout the twentieth century the economies of scale of ever-larger steam-turbine and water-turbine generators have steadily reduced the cost of a unit of electricity, so much so that electricity is now ubiquitous in modern industrial society, indeed taken completely for granted. Throughout the past decade, liberalization and the introduction of competition have underlined the view that electricity is a commodity. The vast infrastructure of 'electricity markets' now being laboriously erected in Europe, the US and elsewhere is predicated on the assumption that electricity can be treated as a commodity, and sold by the unit in a competitive market. The assumption may be tenable for a transition period; but it is already throwing up problems, and they will intensify.

This is because electricity is not a commodity. A commodity can be stored and held back from the market until the seller gets the price desired. Electricity cannot be stored. Nor, despite frequent usage to the contrary, is electricity a fuel. A fuel such as coal, oil or natural gas is a physical substance. It comes out of a hole in the ground at a particular 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 the entire interconnected system, including all the end-use equipment connected at any given moment. The whole system, the whole vast array of physical assets, has to be in place and in stable operation, all the time. You can't stockpile electricity for contingencies. On the other hand, electricity can be generated anywhere, at a price. Just ask the person with the hissing headphones sitting next to you on the bus.

The key word here is 'price'. The whole remarkable infrastructure of electricity systems we've put in place in the past century is there for one reason only: to keep down the price of using electricity. In the first decade of electricity liberalization, politicians have laid heavy stress on the price of a unit of electricity, to measure the success of the policy. The argument is shallow, to put it mildly. Tax regimes, depreciation rates and other asset accountancy, subsidies and cross-subsidies, and the regulatory treatment of monopoly networks mean that, in the words of Patrick Moriarty, respected one-time chairman of Ireland's Electricity Supply Board, 'The price of electricity is what the government wants it to be'.

For natural gas and other fuels, a delivery system of some kind is essential; the fuel itself has to be transported from its source to where it is to be used. Electricity is different. An oil well, a gas well or a coal mine has to be sited where the oil, gas or coal is. In principle, however, an electricity generator can be sited anywhere. I now believe that after nearly 120 years, the emergence of cheap, clean local generation brings with it the promise of overcoming at last the pernicious effect of the electricity meter. If you generate your own electricity on site, no one benefits by having you use inefficient buildings and equipment. Instead, like Edison on Pearl Street but with technical options that would astonish him, you can seek to optimize the whole local system.

Nor must you do it yourself. In a liberal context, electricity companies are already learning that competing to sell anonymous units of electricity at a customer's meter is a precarious business. They can compete only on price; their margins become vanishingly small. If, at the same time, customers can switch suppliers more or less at will, this form of business is a good way to go bankrupt. Accordingly, enlightened companies are already seeking different ways to win customers and retain their loyalty.

I am increasing convinced that before long, while the big players may participate in markets and trade electricity among themselves, final customers will no longer be buying electricity by the unit.

Instead enlightened companies will contract with customers to design, install, operate and maintain integrated local systems, generating electricity where it is to be used, and ensuring that the buildings and other end-use equipment make optimal use of the electricity to deliver the services customers actually desire - comfort, illumination, motive power, refrigeration, information handling and so on - at fixed prices over time, in continuous business relationships between company and customer. Some major companies are already offering such contract packages; more will undoubtedly follow. After years of frustration the age of the genuine ‘energy service company’ may be dawning at last.

Local electricity systems with on-site generation – so-called ‘microgrids’ - may prove a potent manifestation of the new business now emerging. If you are generating and using your own electricity, in your own economic interest you and your energy service company will want to ensure that your loads - your buildings, lighting, motors, and electronics - use this electricity as efficiently as possible. Optimizing the whole local system makes economic sense; and economics and environment point in the same direction.

How this will all work out in practice no one yet knows; and it won’t happen over night. But after 120 years electricity may eventually come full circle, back to where it belongs: on site. To take maximum advantage of this potential, networks too will have to take on dramatically altered forms and functions; and they will have to do so without interrupting the essential functions they already provide - a major challenge in itself.

If we were starting now to electrify society, with the technologies now available, electricity systems would look very different. As matters stand, however, modern industrial society already has a vast legacy of traditional electricity technologies, institutions and mind-sets that will impede and complicate the transition. In my book *Transforming Electricity* (RIIA/Earthscan 1999) I declared that ‘Electricity systems may be the most spectacularly successful technology of the twentieth century’. In this twenty-first century, nevertheless, traditional electricity systems are doomed. They have failed to reach two billion people - one-third of humanity - and the proportion of those without access to electricity is increasing, not decreasing. Moreover, the key technologies of traditional electricity, for large-scale generation and high-voltage transmission, all face financial, social and environmental problems that may become insuperable. The clash between tradition and innovation in electricity is likely to be protracted and messy; but my money is on the innovators.

Earlier this year, at the Planetarium in London, I gave the annual Melchett Medal Lecture for Britain’s Institute of Energy. I called the lecture ‘Energy 21 - Making The World Work’. It put forward the premise that we are now starting to see an accelerating evolution, gradual but inexorable, of the entire energy infrastructure of human society. One of the key determinants of this evolution will be electricity - how we produce, deliver and use it. Decentralizing electricity will be a crucial key to making the world work better, for everyone, everywhere.