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Future Electricity Systems

What will future electricity systems look like, and why? For the moment let's not be TOO radical. Let's assume that future electricity systems will still consist of the same three main components that make up the traditional electricity systems we all know so well - that is, generators, networks and loads. We then have to ask what future generators, networks and loads will look like, and why.

In the traditional electricity systems that spread across the world throughout the past century, we knew the answers to these questions almost without thinking about them. In this new century, however, electricity liberalization and technical innovation are forcing us back to first principles. We have to re-examine these basic questions, and ask them all over again. In the emerging world of innovative electricity, what are generators for? What are networks for? Come to that, what are loads for? Who decides, and what do they do about it?

Let me put this in context. Some of you will know that last year I published a book entitled *Transforming Electricity*, the result of some five years of research into what is happening to world electricity. When I wrote the book I thought I was writing it for general readers. To be honest, it hasn't sold many copies to the general public, or attracted much attention. However, I've been astonished and delighted that the book has been purchased and read in quantity not by general readers but by people actually active in electricity - in companies and governments caught up in the whirlwind of change now engulfing us all.

The central argument of the book is that the traditional electricity system is doomed. Liberalization and technical innovation are changing the ground rules, the guiding premises that shaped world electricity for a century. You all know the common technical model, taken for granted all over the world for at least half a century. It's based on generating electricity in very large, remotely-sited stations, and delivering it to users in the form of synchronized alternating current, through a network including long high-voltage transmission lines and extensive low-voltage distribution cables. In the newly liberal context, however, financial pressures and technical innovation are interacting to change the technical configuration of electricity systems, and the institutional organization of responsibilities, risks and decision-making. In *Transforming Electricity* I declared that the changes would be more more fundamental, more far-reaching and faster than most people yet realized. In the nineteen months since the book appeared, that has proved, if anything, to be an understatement.

The gist of the argument is probably familiar to you all by now. Because the traditional system was a franchised monopoly, system planners could pursue the economies of scale offered by generators using steam or water turbines, up to enormous size - single units of a gigawatt or more, taking six or more years to build, as well as the long transmission lines such remotely-sited stations necessitated. Planners could order these enormous assets, because the captive customers of the monopoly bore all the risks - and they were substantial, as many ill-advised

investments duly demonstrated. But captive customers had no recourse. If they wanted to use electricity from the system, they had to pay whatever the system was allowed to charge them, including the cost of bad investments, overpriced fuel contracts and underperforming technology. System planners and managers were completely insulated from the costs of their mistakes.

In a liberal competitive market system, however, the owners of generators, and their shareholders and bankers, bear the risks. As liberalization shifts the balance of risk, those investing in generation are eager for less risky alternatives. One in particular has seized their imagination. Liberalization happened to coincide with the emergence of gas turbine generation for continuous use, and cheap abundant natural gas to fuel it. Throughout the past decade, wherever electricity is being liberalized and natural gas is available, gas turbine generation has dominated investment in new generation.

Gas turbine generation marks a sharp break with the previous trend, in which a better generating unit was always expected to be a bigger unit, probably farther away. Gas turbine generation can be economic at much smaller size. It can be ordered, installed and brought on stream, generating both electricity and revenue, in two years or less. It is easy to site. It emits no particulates or sulphur oxides, and its nitrogen oxide emissions can be very low. It can therefore be sited close to users, or even on site. That in turn means that it can also be used conveniently for cogeneration of electricity, heat and also cooling, almost doubling overall fuel efficiency and further improving its economics.

The advent of gas turbine generation has initiated a new and fascinating trend, toward much more small-scale generation, much closer to users - a gradual change away from the traditional centralized system configuration toward a much more decentralized configuration. Much of the most exciting innovation in generating technology is now not at the large end of the scale but at the small end - microturbines, fuel cells and a variety of small-scale modular renewables - windpower, biomass power, photovoltaics - with unit outputs ranging from 10 megawatts down to a kilowatt or less. As the costs of these technologies go down and their performance goes up, the potential for on-site and local generation of electricity has shot up the agenda, bringing with it a number of promising corollaries, as I'll describe shortly.

However, 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. This issue is only beginning to emerge, but it lies at the heart of the question I posed earlier: in a future electricity system, what are networks for?

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.

Let me give you an example. To the outside world, Britain often presents itself as the leading example of electricity liberalization. The British government and British electricity companies are proclaimed as enthusiastic proponents of the advantages of competition, opening the market to all electricity users, and so on and so forth. Well, maybe. But you should know that in England and Wales the electricity networks for transmission and distribution are still subject to so-called ‘Standards of Performance’ set down in 1977, under the old Central Electricity Generating Board, and now administered by the new Office of Gas and Electricity Markets, or OFGEM. Despite its name, one of OFGEM’s key roles is to oversee the monopoly networks for transmission and distribution, and to set down the charges that must be paid by customers who are still, in this context, captive customers just as they were under the old franchised monopoly structure.

Before privatization, at the end of the 1980s, CEGB engineers referred routinely to the system as ‘gold-plated’. Since 1990, nevertheless, it is now claimed to be 25 per cent more reliable. Is that good? Understand what it means. As far as the networks are concerned, Britain’s electricity system is still a centrally-planned monopoly paid for by captive customers who have no choice and no say in the matter, just as it was before liberalization. Moreover, its structure and function are still determined by the same traditional criteria: it is a network to deliver electricity from large, remotely-sited central stations to users - a radial one-way system completely inappropriate for the

varieties of decentralized local generation that would otherwise be increasingly competitive options.

The British government is now engaged in a long-running process, in Parliament and outside it, to establish so-called 'New Electricity Trading Arrangements', or NETA. But advocates of small-scale generation, including cogeneration and renewables, are alarmed that the entire process appears to be predicated on traditional large-scale generation. They cite a long litany of lop-sided imbalances that will work to the disadvantage of innovative generation, many of which relate to the role and status of the networks, and to network connection costs and protocols - the old monopoly system again.

Official planners in Britain argue that the networks cannot readily accommodate small-scale generation. It would, however, be truer to say that the networks do not want to. The official argument is that expanding smaller-scale local generation, connected at lower voltages, will make network management difficult, and jeopardize reliability. Innovative generators hotly dispute this; but at the moment they appear to be losing the battle to the traditionalists. Unless the innovative generators can get comparable innovation for the networks, British electricity liberalization will stumble feebly to a standstill long before it can realize the true opportunities available.

Elsewhere, too, in the US, and in other parts of the European Union, network issues loom large, with no obvious solutions readily apparent. In the US, for instance, this summer has seen another rash of blackouts and system collapses, as air-conditioning loads bring down overloaded networks. Since I published my book *Transforming Electricity*, I have been working on my next book, which will be called *Keeping The Lights On*. At an early stage of work on the new book I speculated that reliability issues could prove to be potent drivers of the move toward on-site generation. At the time, however, I did not fully appreciate the converse: that electricity traditionalists would use reliability arguments to defend the status quo. That is only one aspect of a controversy that is going to become ever more intense - the controversy over the future shape, function and role of electricity networks.

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 such as those in Britain 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. Somebody has to show the way, to demonstrate that networks too can evolve, to take advantage of the opportunities of liberal markets.

Innovative network technologies are indeed emerging rapidly, not least from ABB, for example, Flexible AC Transmission Systems or FACTS technologies; high-voltage DC, especially ABB's HVDC Light; 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.

ABB calls this configuration the '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 whole market apparatus now being laboriously erected across Europe, North America and elsewhere is based on this presumption.

Unfortunately, however, 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. 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 am convinced 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 companies will contract to deliver the services customers actually want - comfort, illumination, refrigeration, motive power, information handling and so on - at fixed prices over time, in continuous business relationships between company and customer. Some companies have already begun to offer some customers this kind of business relationship; I think the trend will accelerate. After years of frustration the age of the genuine 'energy service company' may be dawning at last.

Local electricity systems with on-site generation - what ABB calls '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.

The most difficult part, however, will be getting there from here, with our cumbersome legacy of traditional technologies, institutions and mind-sets. On 22 June, 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. Getting electricity right will be a crucial key to making the world work better, for everyone, everywhere.

ABB's far-sighted and innovative new corporate strategy for its electricity business makes clear that ABB is accepting this challenge. It deserves an enthusiastic response from business partners all over the world. I wish you all every success.