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By

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*Dedicated to the memory of Ron Quartermaine*

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# AUTHOR'S PREFACE

Communicating a technical topic, is not straightforward. No treatise can adequately explain every statement without some level of assumed knowledge and the skill of the author rests upon striking that balance to inform, interest and communicate a message so that understanding may be given. In our modern world, energy is essential to our daily lives but central with all its use is the pivotal role of electrical power to secure the living standards we currently enjoy.

Understanding the characteristics of the various generation technologies and their accommodation is an essential foundation. Since privatisation of electrical supply, the industry has seen increasing political interference and failure to address structural weaknesses. The author has spent a lifetime working hands-on in electrical supply on disciplines within the varied generation technologies. A decade on coal-fired and hydro operations, a decade on coal and nuclear projects with installation and commissioning, culminating in grid system control over two decades. This latter period employed at the apex of the electrical supply pyramid, experienced shift operations under both nationalisation and privatisation. On having a University degree and chartered status, my view for the most critical competence in an operational environment, is not intelligence or academic qualification but experience.

In life we must all relate to our neighbours. Generating electricity is no different. Most of the varied technologies employed are mutually dependant, certainly for renewable resource, as singly they cannot be relied upon to give a secure, continuous and economic supply. This accommodation comes at a cost where consequences remain hidden and only fully understood by a small technical minority. The failure by politicians and their advisors to recognise these limitations is why our power supply situation has become so critical.

In my previous book "When will the Lights Go Out?" published by Stacey International, the attempt to communicate a message to a targeted audience was of necessity restricted and the need to communicate widely has since become more pressing. In a general sense the media is woefully lacking in basic understanding of electricity supply. This deficiency should come as no surprise, as its practitioners in their education and upbringing are based upon the humanities. Even for those with a scientific or technical background such understanding is not assured, nevertheless bridging that divide becomes so much easier. Information is vital but so is understanding.

This book does not set out to provide detailed statistics or mathematical formulae, the usual framework for any engineering treatise, neither have extensive footnotes been included. Instead, strategic analysis and observation will be supported by charts and diagrams. If required, reference to my previous book provides more information and some historical perspective. A conscious attempt has been made to avoid duplication and to treat this narrative as a stand-alone publication for a wider readership.

Appreciation and thanks are due to many friends and colleagues who over the years have been unstinting with information and support. No publication could have been contemplated without their contributions and whose knowledge and experience have guided my thoughts. As power engineers we all share a profound concern with the direction of energy policy over this last decade. In preparing this book Dave Bruce has given much assistance with illustrations and computer support, stretching back over many years and Mike Travers for incisive guidance with preparation. Permission has been given by National Grid to publish a number of illustrations for which I am most grateful. A debt of gratitude is due to the late Ron Quartermaine whose influence and encouragement over this past decade has provided so much inspiration towards the many submissions, reports and presentations being produced, a necessary foundation for this project. In large measure this book is their achievement although responsibility for what has been written is mine alone.

Throughout this book, the increasing cost of renewable accommodation has been highlighted leading towards the political tensions now arising. However, real problems rest upon the policy of mitigation to reduce carbon emissions. Any practical approach should recognise adaptation as the basis for accommodation with climate change. The present policy undermines wealth creation, the necessary means to provide those financial resources to contain the consequences of climate change. The role of climate science is essentially one of uncertain prediction, largely based upon computer modelling.

# INTRODUCTION

**National reliance upon energy. Nature of electrical supply and its vulnerability. Removal of market disciplines prompted by AGW. Evolution of wind resource. Consequences of “fracking” gas. Forthcoming chapters. Basic definition of technical terms**

## National reliance upon energy

To the popular mind energy is like the air we breathe. We take it so much for granted it becomes ingrained into our lifestyles. Our living standards are directly affected by the cost of energy, refined by technology to give ever increasing benefit to mankind. When we see a change to its cost we are reminded of the link with our prosperity but it is only when availability is threatened do we realise just how vulnerable our lives would become without this brittle commodity. As a nation our dependence on energy decides the opportunities for wealth creation, trade and the treaties we make, so it is inevitable for the state to become involved with its provision.

Political developments have handed power to super-national institutions in the form of regulation. This has been exercised to implement EU policy through the nation state and has led to a situation where the consumer and not the public purse pays for its execution. Unlike taxation where procedures are subject to public scrutiny through the Public Accounts Committee of the House of Commons, this expenditure is not open to challenge and even though administered by a public body, is immune from detailed scrutiny.

Currently most domestic households have three strands of energy security. A reliable means of transportation, home heating and cooking by the use of gas and oil products with the option of electrical heating as a backup within the home. The use of home appliances and communication are reliant upon electrical supply as is control with many forms of central heating. Any extended loss of supply can become life threatening and in large cities the risk of social disorder. To mitigate these effects there is the option of personal mobility with family and friends and for many households, gas supply is available for heating and cooking. What has become evident is the intent over the longer term to restrict the use of gas and confine mobility to electric cars thereby making all households entirely reliant upon a supply of electricity. Adding to this circumstance is the developing technology of "smart metering" that would then give the state an ultimate means of control over its citizens.

## Nature of electrical supply and its vulnerability

Electrical power provides a versatile and reliable means for all manner of uses in the home, factory, shops and offices. The ease of transmission allows production to be concentrated at few locations, enabling economies of scale to be realised and the economic delivery of fuel supplies. Its convenience and cleanliness has provided the greatest advance in health and longevity since the Victorian age. So versatile are its uses, other forms of heating rely on its use for control. Ultimately communications depend upon its use. The widespread benefit of computer technology across all fields of economic activity, to include retail and banking, would rapidly cease to function without power supplies. Electrical power is literally the lifeblood of the nation.

Electricity is the most important service industry that everybody relies upon at the flick of a switch. Its greatest vulnerability lies with its inability to be stored on any scale as can be done with water, oil and coal and is entirely governed by demand. It is important to relate electrical supply with the various fuels that power conventional generation. Unlike electricity, oil, gas and in particular coal can be stored in considerable quantities. Oil for transportation is ideally suited as its various component parts of petrol, diesel, and aviation fuel allow delivery by road tankers, coastal shipping and pipeline. Oil extraction is closely related to gas with methane, butane, propane and ethane which as natural gas liquids can be easily transported for specialised industrial purposes. Around four-fifths of gas is methane transported by pipeline to heat over two-thirds of our domestic needs. The exploitation of renewable resource is largely by electrical means that cannot be stored on any scale.

The scale of subsidy introduced to promote renewable development has not only distorted the market for essential backup capacity but has also restricted the running of these fossil-fired generation services to the point where power utilities lack the confidence to invest with such uncertainty. Lower world prices for coal prompted by the US "fracking" revolution, had at one stage seen gas turbine capacity mothballed. More recently, capacity margins to meet maximum winter demands have almost disappeared. This scenario coincides with increasing concern for the reliability of ageing infrastructure. The investment needed for the UK to meet the challenge of power supply is daunting, not experienced since the sixties and seventies of the last century.

The versatile nature of electrical power disguises its vulnerabilities. Most consumption is derived from heating, lighting and driving electric motors that provide the bulk of revenue for utilities. With rising renewable production, receipts from fossil-fired sources have declined as renewables always have priority to generate. **The increasing cost from carbon taxes levied on fossil-fired generation together with subsidised renewable promotion will compromise future thermal investment**. As profitable coal power stations are rapidly ageing, new dispatchable generation capacity is desperately needed. Given the convenience of use, peak annual demands can be expected to remain but thermal generation production will fall with higher charges and where competition from other sources will intensify. This effect is already happening in Germany where renewable development is advanced. Spiralling subsidies, higher tariffs and weakened utilities are having political repercussions.

Electrical Supply in the UK faces a perfect storm. The obsession with renewable energy for well over a decade has obscured a looming crisis where events have come together to present a very real risk of power disruption. Since privatisation, the UK investment in power generation has been limited to gas and wind turbines, both being short term technologies. The previous portfolios, constructed under nationalisation of longer term nuclear and coal-fired technologies are reaching the end of their working lives and in 2015 provided half of supply capacity. Generation is already being taken out of service from the initial post-privatisation investment together with the premature withdrawal of coal-fired capacity under EU environmental regulation. The increasing intermittence from renewable sources stresses ageing fossil-fired generation capacity, being the only sufficiently responsive means for National Grid to balance demand with supply. The failure to meet this essential requirement leads to grid instability and power disruption. Generation connected to the distribution system is uncontrolled and destabilising for the grid system. What should be clear is that National Grid does not have responsibility for generation supply, only for its accommodation.

## Removal of market disciplines prompted by AGW

The skill and far-sightedness of engineers from previous generations has created a basic confidence in our power supplies. This confidence has led to an attitude of mind, certainly amongst politicians, where technology can expect to give an assurance of viability across many areas of innovation. **The perceived threat of anthropogenic global warming (AGW) has removed market discipline to be replaced by arbitrary targets thereby fostering a range of untried and uneconomic technologies**. The scale of subsidies introduced to promote these technologies open the door for commercial exploitation and rent-seeking.

What is meant by anthropogenic global warming? It is with the activities of mankind in burning fossil fuels that raises the proportion of carbon dioxide in the atmosphere to stimulate rising world temperatures, leading to climate change and melting glaciers thereby raising sea levels. Public and political concern over this issue has prompted significant funding into climate science, a relatively new discipline, heavily embroiled into computer modelling. As the very nature of the problem was global, international conferences held at Kyoto, Japan initiated targets to reduce global emissions. A body known as the IPCC would issue reports and monitor progress. Subsequent conferences held at Copenhagen, Mexico, South Africa and latterly Paris have all failed to reach binding agreement. The EU acting independently, obliged its members to reduce carbon emissions by 20% overall, based upon 1990 levels within which the UK negotiated a 15% target.

The scientific basis for justifying carbon reduction targets has increasingly been questioned amongst the academic community. Already the reality of global warming has not been squared with forecast, heavily reliant on computer prediction that in itself has been discredited with financial instruments during the 2008 financial crisis. The obsession with levels of carbon dioxide pale in comparison to water vapour, represented by cloud cover as a mechanism for retaining heat on the planet. Furthermore, the contribution of man-made carbon emissions represents a twentieth of that produced by natural processes, notwithstanding the significant level of plant growth stimulated by such minute increases.

There has been a curious co-operation between three prominent national public institutions advancing the cause of AGW. The Meteorological Office, the BBC and the University of East Anglia Climate

Research Unit have over time become embarrassed with that involvement. Common funding directs suspicion towards the state promoting an international purpose and where mistrust over international politics with AGW suggests the issue is being used as a vehicle rather than a cause.

## Evolution of wind resource

The innovations mentioned above came from political direction at an international level, seeking to limit carbon emissions under the Kyoto international treaty, latterly replaced by the Paris accord. Whilst the targets chosen were EU inspired, implementation was based upon the nation state, placing emphasis on renewable forms of energy. This has led to a disproportionate burden being placed upon electrical supply in the UK where wind resource became the dominant technology. Whilst technically impressive, this technology is uncontrollable and intermittent, leading to severe problems absorbing such power into the electrical power network.

## Consequences of "fracking" gas

Another factor encouraging the promotion of renewable energy has been its role as an indigenous resource, promoting energy security in an uncertain world where oil and gas resources had been considered finite. The developing technology of drilling into rock strata in specific directions and shale bed hydraulic fracturing (fracking) has transformed the international situation with the US becoming the first nation to exploit this technology. The scale of this transition has significantly reduced gas prices and by 2017 had attained national self-sufficiency in energy. This has led to the US having lower carbon emissions through reduced coal burn from power stations where coal had always been the dominant fuel for power supplies. The displacement of US coal onto world markets, thereby lowering its price, had promoted a significant increase of coal burn across Europe, in contrast with measures within the EU to limit carbon emissions.

The position of the environmental lobby has been perplexing. By resisting the development of promising "fracking" technology, an underlying purpose has been to deflect the threat to any programme of renewable investment. As the nominal objective of EU energy directives is to limit carbon emissions, the suspicion remains that vested interests connected to renewable exploitation (with generous levels of subsidy) would be disadvantaged by this new "fracking" technology. As for wind resource, this technology has to be seen in perspective, not just as an inadequate and intermittent energy resource but also with regards to its costly accommodation on the electricity network. With no technical body having overriding responsibility for electricity supply, utilities can only react to their best financial interest. Imposed subsidy only encourages inappropriate investment. With most renewable technologies, intermittence is endemic where measures to mitigate its limitations allow the opportunity for lucrative recompense amongst power utilities.

Electrical supply provides a revealing example of how wealth creation has been subverted. When energy costs are the bedrock of living standards there can be no surprise these have fallen over the past decade for the greater majority of its citizens. Any serious attempt to meet such arbitrary targets would have to include a reduction of air transport movements that at over a hundred thousand a day worldwide contaminate the fragile troposphere. Whilst improved efficiency has been achieved with new aircraft, the fuel is not taxed internationally nor are any targets imposed. The absence of restrictions with the transport of unseasonal foods and international tourism is seen to be politically necessary. This position is reflected with electric car transport where generous subsidies are made available. As for electrical supply, restrictions on coal use and a disproportionate share of burden within mandated targets, induce rising costs. (One wonders how the CEGB would have responded to these conditions had they still been in existence. Parliament decreed the lowest cost of electricity to be provided for consumers. Private electricity supply companies have no such remit). Given this perspective political direction cannot be questioned, allowing the enormous cost of supporting subsidy to continue its destructive process.

## Forthcoming chapters

In the following chapters the nature of electricity supply is explained together with some background perspective over international targets, where their expected contribution is out of all proportion to its share of energy end use in the national economy. To gain some understanding of the problems arising from implementing both targets and regulation on electricity supply, initial chapters explain the characteristics of various technologies in producing power and crucially their accommodation upon a dynamic grid system. The chapters then progress to explain how the profound consequences arising from privatisation have allowed free reign subsidy to develop without any long term institutional perspective that is the basis of electrical supply. Engineers became subservient to accountants, politicians and civil servants. Political direction since the millennium has seen energy ministers passing through a revolving door on an annual basis with seven ministers over this decade. Their departments were under constant reorganisation with various titles over this period, being pressured from Brussels over energy assimilation. At one stage energy and climate change, both situations being incompatible, were linked in the same department.

Some caution with international comparisons are explored followed by scrutiny of information sources and reliability of statistics, all to provide some background for outlining the consequences of renewable policy where their exorbitant cost is shunted onto the captive long-suffering consumer, a cynical imposition avoiding parliamentary scrutiny. Any explanation of falling living standards all too often fail to mention rising energy costs as a fundamental multiplier, inflicting its burden disproportionately on the disadvantaged.

So much for the past, need is to the future. Electric transport can expect to have widespread implications across society. Some lessons can be learnt from German "energiewende" where very real political consequences have arisen. Europe has been responsible for excessive regulation and their consequences for the UK is outlined. Investment priorities mould a national blueprint whose structural means remain elusive, turning away from an historic perspective of coal technology. Grid instability is set to become a serious problem, created by government policy that cannot be understood, let alone addressed by them. Structural issues lie at the heart of reform to curb the present direction and finally some suggestions are made to point the way forward.

## Basic definition of technical terms

A conscious attempt has been made to avoid technical phrases throughout this book. Some basic grounding of terms however is essential. One of the most common pitfalls is the confusion between capacity and energy. The term "*capacity*" (or size to the layman) is defined as the ability to do work. The term "*energy*" (or output) is the length of time that capacity is exercised. A bar on an electric fire is usually rated at a capacity of one kilowatt (kW) that if run for one hour would consume energy of one kilowatt-hour (kWh) or a unit of electricity. The kilo can be substituted for Mega, Giga and Tera in ascending multiples of one thousand.

- A generator of 1kW installed capacity if run for one hour would produce 1kWh of energy (a unit)
- A typical 2kW generator as used with caravans run for an hour gives 2 units
- A generator of 1kW when run for a year would produce 8760kWh (units) or 8.76MWh
- A generator of 1MW (megawatt) run for a year would produce 8.76GWh or 8.76 million units
- One thousand generators of 1MW or 1GW (gigawatt) run for one year would produce 8.76TWh (terawatt-hours)

To give some perspective:

- A typical large onshore wind turbine would be rated at 1.5 to 3MW.
- A generator within a large coal-fired power station is often rated at 500MW. With four generators this would give a power station capacity of 2GW.
- Peak system demand for the GB grid system has been in the region of 60GW with an annual energy consumption of some 360TWh.
- National Grid operates at voltages of 400kV (kilovolts) and 275kV (or 275,000 volts). Scotland has dispersed lower rated hydro schemes extending the transmission grid to 132kV.

- Distribution is exercised at 132kV, 33kV and 11kV with domestic consumers connected at 230 volts.
- A typical electric kettle would be in the region of 2kW capacity.
- A Mercedes electric car on a single nine-hour charge can travel 124 miles on a 28kWh lithium-ion battery.

What can be confusing is describing the cost of electricity in different terms as is often used in the media. £20 per MWh is exactly the same as 2p per kWh (or 2p per unit). The former is normal for commercial use whilst the latter has more domestic application. Appendix D provides more detailed costings on an historical basis.

# ADDENDUM

# RECENT DEVELOPMENTS

## Policy Changes, System Inertia, Structural Reform

Over the past year since publication of the hardback version there have been a number of significant policy changes by government. A major grid incident of 9th August 2019 has revealed a serious problem known as system inertia that affects the security of the GB grid system. Prediction of this problem was made on page 42 and 92 of the original text.

## Policy Changes

A succession of announcements by DBEIS over late 2018 and 2019 began when it became apparent the long-awaited report by Professor Dieter Helm would largely not be acted upon. A range of recommendations included a 'legacy bank' to ring fence subsidy payments as well as reducing the scale of state intervention into the electricity market. Energy prices for the consumer were far too high. The one positive outcome was closing down the subsidy scheme for Feed-in-Tariffs.

The widely expected exploitation of hydraulic fracturing has never really materialised, largely due to seismic regulation levels being unrealistically restrictive. The resignation of a government advisor failed to influence change and nothing was done when the Scottish administration prevented any exploratory drilling in Scotland. The consequence of failing to exploit an indigenous resource only increases reliance on imported LNG supplies, a position compounded by the refusal to subsidise gas storage that is now at a 4% level of annual national consumption.

The position of storage also becomes critical with the announcement to discontinue the technology of coal resource by 2025. This policy also removes any prospect to refurbish existing plant and denies an alternative option to the essential dispatchable role of gas for grid balancing. Of the 20GW of CCGT capacity installed in the first decade of privatisation, already 5GW has been withdrawn with the remainder due for replacement by 2025. Since 2013 plant margins to cover winter peak demands have been inadequate, as recognised by Ofgem, with reliance being placed on continental interconnection capacity.

To compound the provision of dispatchable capacity is the decision to promote 30GW of offshore wind by 2030. This policy overturns the purpose of a generation mix, not just by a disproportionate reliance on the single technology of wind resource, in itself inherently intermittent, but the exorbitant cost with grid connection and reinforcement. To this circumstance can be added the additional CCGT capacity needed where nationalised investment is now due for replacement, all above the target demand to become carbon neutral before 2050. The promise of nuclear capacity at Wylfa and Cumbria from two Japanese consortia has failed to materialise.

A decision was made by the May government not to support the Swansea tidal barrage. This would have been a precursor to the development of tidal lagoon storage on both the Severn and at Cumbria. Events now place this development in a much more favourable position with the requirement for system inertia.

The summation of all these consequences would be to place reliance upon continental interconnection that although currently at 4GW is planned to rise to over 10GW by 2022. A considerable investment, only necessary because of the scale of intended wind resource.

What is encouraging in the short time of the new government, are three new initiatives:

- Promotion of nuclear SMR technology by announcing plans for factory erection in Yorkshire
- Delaying approval for Hornsea 3 offshore wind farm
- Promoting gas turbine development at Drax power station.

## System Inertia

The initiation by a lightning strike of the major Grid incident on Friday 9th August involved three separate grid failures that together, overwhelmed the contingency arrangements in place, leading to automatic disconnection of over a million consumers. A fundamental cause that has been recognised is insufficient system inertia. Efforts are in progress to monitor improved measuring for this problem that derives from the technologies of wind, solar and interconnection sources that are only connected through power electronics. All other conventional generation is connected through synchronous alternators whose rotating mass of hundreds of tons at 3,000 rpm provide an essential stiffening to the grid system, making it resilient against system faults. It would appear the excess of renewable generation diluted this stiffening, allowing voltage fluctuations to operate protection systems at will, a source of grid instability.

The nature of this problem has a continuous and variable condition, requiring constant vigilance. The suggestion of synthetic inertia would only be relevant for frequency response. There are a number of solutions having considerable ramifications. One approach is to establish a cost in providing system inertia that whilst fitting in with current practice is essentially an imperfect second hand solution. Without renewable generation there would not be a problem and even conventional generation has a varying contribution with steam sourced and hydro plant being more prominent. Expectation has interconnection and wind resource becoming casualties. Constraint payments can only increase significantly. A review of previous decisions taken with coal and tidal lagoon storage would seem appropriate, especially with the critical need for inertia and storage capacity. Such an approach can only relate to the GB grid system as further interconnection is not only inadequate but would aggravate the problem. The reasons are explained on page 51 and 93 of the original text.

## Structural Reform

A fundamental reappraisal of government policy is inevitable. The scale of this transition demands structural changes both with government and the electrical supply industry. The timescale for necessary investment is insufficient for the scale of power generation to be made available and severe pruning of the existing direction of expenditure a necessity. Transmission does not produce a single unit of electricity. EU policy in promoting renewable power generation has severe penalties due in 2020 for any failure in meeting climate targets. This policy has distracted attention from the essential provision of conventional power sources across Europe. This neglect can only confine EU resources to itself, placing the security of continental interconnection in question with any assessment of firm power criteria.

It must now become obvious from the many incidents from overseas that the policy of renewable investment has serious shortcomings. Sound technical advice has not been listened to. In desperation, media agitation has followed a drop of renewable investment to half that was made from a decade ago. More seriously, grid instability is becoming a serious threat to several nations where once confidence in security of supply is broken, many adverse consequences arise. The policy of flexible pricing, otherwise known as ‘smart metering’, currently estimated at £15 billion, has the potential to destroy this confidence. Another serious consequence has been the excessive cost inflicted upon the consumer, reducing living standards. This burden has not been shared equitably being funded through the consumer and not through taxation, falling disproportionally onto the disadvantaged.

The disruption following the grid incident of $9^{th}$ August has been a timely reminder of the essential role that electricity supply has in society. Had the number of consumers affected been translated away from London, media reaction would have been much less. These consequences should come as no surprise to those who are technically informed. There are other issues such as Crossrail and HS2 where government policy being promoted had unforeseen results that technical opinion was only too aware of. Until technical scrutiny can enmesh itself into the process of decision making, dissipation of wealth creation can only continue from our political masters.

DGB 22nd October 2019

# CHAPTER ONE

# THE NATURE OF ELECTRICAL SUPPLY

**State intervention with EU carbon targets. Characteristics of electrical supply. Generation mix and embedded generation. Grid instability. Continental comparison. Security of supply. Financial pressures.**

The public perception of electricity is that of a product always available at the flick of a switch. Sources of energy are prolific and why cannot natural forces be harnessed to provide all our needs for energy when its fuel is free and availability inexhaustible? A simple question that even our politicians would endorse. With such limited understanding, legislation was enacted for the Climate Change Act of 2008 requiring 80% of our energy needs to come from renewable sources by 2050. By 2017 reductions of about 35% had been recorded. A non-binding target by a parliamentary committee has recommended reductions of 57% by 2030. Many people are now aware that all is not well with that ideal and issues are just not that simple. For those who have knowledge of energy supply by qualification and working experience, this is only the beginning of a prolonged ordeal that will seriously reduce our standard of living in years to come.

## State intervention with EU carbon targets

Historically the aim of government energy policy was to achieve security of supply at the lowest possible cost. With concerns over this last decade from man-made global warming, these objectives have changed to that of being competitive, secure and of low carbon supply. In the market place this last requirement is incompatible with normal competition unless proper and effective legislation is enacted. The imposition by the UK government to achieve carbon reduction targets set by the EU (nominally at 20 percent but negotiated to 15 percent for the UK, based upon emission levels from 1990) has fallen disproportionately on electrical supply whose durable technologies take decades to develop. **The limited timescale of 2020 has given rise to "quick fix" solutions, with an utterly**

**inappropriate and costly technology of wind power being promoted**. Not only is excessive subsidy required to ensure rapid take up, intermittence becomes a source of instability. It is hard to imagine a worse means of producing economic electrical power, even with the employment of such impressive design technology. A basic understanding of physics reveals its limitations.

Most other renewable technologies have intermittence as a basic characteristic of their operation. **Being small scale and widely dispersed, many technical complications arise and therefore increased costs**. This is a reversal of an historic trend towards large generating units located close to centres of demand, bringing lower unit costs and cheaper electricity. The recent contribution of installed renewable power is mostly short-lived, uncontrollable, uneconomic and destabilising. However, by good fortune tidal resource has impressive potential that whilst intermittent is predictable and reliable. Conventional hydro power with storage has been a most successful technology but with limited scale and potential.

## Characteristics of Electricity Supply

An important characteristic of electrical supply is its inability to be stored to any appreciable extent. If the storage of generated power could realistically be provided on an appropriate scale and at reasonable cost, the accommodation of generation from renewable sources could become manageable. Such promise has eluded the supply industry for generations. Within a supply system, production has to balance demand instantaneously. To a very limited extent variation of system frequency can be tolerated but outside defined statutory limits, automatic disconnection sheds consumer load on a cascading basis to correct any frequency imbalance. (1) Pre-selected consumers become disconnected in order to save the whole grid system from instability. When generation is in deficit, frequency falls below a standard target of 50 cycles per second. With demand load falling, frequency then rises. This is why electric clocks can be a few seconds adrift from GMT. *(refer to fig 6-3)*

## Generation mix and embedded generation

On any integrated high voltage AC Grid system, the means to mitigate such an inherent vulnerability is to enlarge the grid system or diversify generation sources. The latter is known as the *generation mix* where the varied characteristics of each technology become mutually supporting. These alternatives are necessary to secure operational flexibility, diversify fuel sources and prevent over-reliance upon any single generation technology. There is a significant economic dimension to the mix and inevitably major political considerations at the strategic level.

The *electricity network* has two quite distinct divisions between distribution on the one hand and transmission on the other. The characteristics of each are profoundly different. As the name suggests, the former distributes power to consumers in what until recently has been an essentially static system, whereas transmission connects major generation plant to points of bulk supply for distribution. Ideally this power should be produced where demand is needed but the economy of scale and security of supply have established transmission in bulk as standard practice. The transmission grid is a dynamic entity, inherently unstable. To maintain grid stability, not only must generation and consumer demand be kept in constant balance, frequent adjustments are needed to maintain voltage levels across the grid system to sustain power flows. Both these functions are essential for system stability but are compromised by intermittent power and the increasing scale of small generation (or microgeneration) being introduced on the distribution network. This is known as *embedded generation*.

## Grid Instability

The national grid system has always been susceptible to disruption from a variety of causes that can endanger grid stability. The loss of major generation capacity, the tripping of transmission circuits and the loss of communication channels are the principal concerns, countered by having sufficient standby reserve to cope with potential losses. Adverse weather conditions increase this risk, as does intermittence where the overall level of risk rises to an intangible assessment, given the scale of innovation being introduced. It is the combination of unexpected events rather than any single event where the assessment of risk is most critical. Certain measures can mitigate the raw imposition of these destabilising forces at additional cost and technical complexity. **Whilst awareness of blackouts is a problem, the real concern is the cost of mitigating measures to ensure disconnection does not happen.**

## Continental comparison

Comparisons between national grid systems are sometimes made but caution is needed. Every national grid system has different features where characteristics of size, climate, interconnection and generation portfolio, all combine to influence any comparison. The UK, or more accurately Greater Britain (GB), is a high voltage alternating current (HVAC) entity with limited high voltage direct current (HVDC) subsea cable interconnection to adjacent nations (for technical reasons HVAC connection is not feasible). The GB generation portfolio is mainly thermal with time constraints that affect load changing response. On the continent many EU nations are interconnected by high voltage transmission lines, creating a single HVAC entity about six to seven times the size of the GB grid system. There is also a significant hydro generation component with fast acting response. These conditions make the continental grid system much more robust when dealing with intermittence although there is an increasing problem with destabilising power flows crossing national borders.

## Security of supply

Security of supply has many facets. Its scope ranges from securing fuel supplies to adequate controllable generation plant and secure grid transmission. Security can expand to safeguarding communication links and the many essential services and specialised products needed to maintain power supplies. Its meaning has taken on a new dimension with the growing scale of intermittence from renewable generation, in particular with wind resource, spread across both transmission and distribution networks. From a grid perspective, embedded generation is not monitored in real time, least of all controlled.

The appeal of "small is beautiful" has resonated in the public mind to accept microgeneration as a practical way of producing power. When self-contained, expense and security are a deterrent but when interconnected this perspective changes. The problems of maintaining power supplies on remote Scottish islands are severe, in spite of abundant renewable resources being to hand. It can be done and is done but given the practical realities, even with "free fuel", cannot be sustained indefinitely. A typical island supply, not connected to the distribution system and having all equipment provided free, has costs of supply one and a half times the normal electricity price. The problems of access, parts replacement, skilled