Stability in Smart Grids

Stability in a smart grid is generally influenced by the balance between power supply and demand, the responsiveness of the grid's participants to changes (such as price or frequency), and the physical and economic structures supporting these dynamics.

Mechanical Power (P)

Stable: Power generation matches consumption, maintaining frequency stability.

Unstable: Discrepancies between generation and consumption lead to frequency fluctuations, causing instabilities.

Detailed Explanation: Stable mechanical power ensures that the generated energy precisely meets the consumption needs without causing excessive frequency rises or drops, which can destabilize grid operations.

Damping Constant (D)

Stable: Higher damping helps in quickly settling any fluctuations arising due to sudden changes in load or generation.

Unstable: Low damping constants make the system prone to persistent oscillations after disturbances.

Detailed Explanation: Adequate damping absorbs the kinetic energy generated from grid disturbances, thereby stabilizing the grid more rapidly.

Line Capacity (J)

Stable: Transmission lines have the capacity to handle maximum expected loads with some margin for unexpected surges.

Unstable: Exceeding the transmission capacity can lead to overloads and failures, contributing to cascading failures in severe cases.

Detailed Explanation: Ensuring that line capacities are not exceeded is crucial for maintaining the physical integrity of the grid and its ability to transmit power reliably from producers to consumers.

Price Elasticity Coefficient (K)

Stable: High elasticity indicates that small changes in price significantly influence demand, aiding in quick demand response adjustments.

Unstable: Low elasticity suggests that demand is unresponsive to price changes, hindering effective demand management.

Detailed Explanation: Effective use of price elasticity through real-time pricing helps in managing demand dynamically, aligning it closer to the supply conditions, which stabilizes the grid.

Reaction Time (T)

Stable: Short reaction times to pricing signals enable quick adjustments in power consumption or generation in response to grid conditions.

Unstable: Longer reaction times delay the adjustments necessary to stabilize the grid after disturbances.

Detailed Explanation: Fast response times are critical in dynamic grid environments, especially with high penetration of renewable energies where power output can be volatile.

Averaging Time (A)

Stable: Longer averaging times smooth out the measurement of frequency changes, providing a more stable basis for operational decisions.

Unstable: Short averaging times might lead to responses to normal frequency variations as if they were significant fluctuations.

Detailed Explanation: By averaging frequency measurements over a longer period, the grid can avoid unnecessary and potentially destabilizing adjustments based on transient changes.

Additional Insights for Grid Stability:

Coordination and Control: Advanced control strategies, such as decentralized smart grid control, can significantly enhance stability by allowing a more adaptive response to real-time changes.

Infrastructure Upgrades: Modernizing grid infrastructure to handle new types of loads and generation sources, like electric vehicles and renewables, is crucial for maintaining stability.

Regulatory and Policy Support: Policies that encourage balanced grid management, including incentives for demand response participation and renewable integration, can foster a more resilient grid.

Strategies to Mitigate Instability:

Enhanced Forecasting and Monitoring: Utilizing better forecasting methods for renewable outputs and consumption patterns can prepare the grid for fluctuations.

Dynamic Pricing: Implementing dynamic pricing that reflects real-time grid conditions can help manage consumer behavior more effectively.

Investment in Storage Technologies: Energy storage systems can buffer the variability of renewables and provide additional stability by quickly responding to grid demands.

Model Definition

The model used is an artificial neural network (ANN). It reflects a sequential structure with:

- one input layer (12 input nodes)
- three hidden layers (24, 24 and 12 nodes, respectively)
- one single-node output layer.

As features are numerical real numbers within ranges, ReLU is used as the activation function for hidden layers. Similarly, as this is a logistic classification exercise, where the output is binary ('0' for 'unstable', '1' for 'stable'), sigmoid is used as activation for the output layer.

Compilation with 'adam' as optimizer and 'binary_crossentropy' as the loss function follow the same logic.

Model Statistics

The predictive model exhibits a high degree of accuracy and reliability in distinguishing between stable and unstable states in the smart grid, as evidenced by a detailed analysis of its performance metrics. The model successfully predicted 'unstable' states with 3739 true positives and only 88 false negatives, indicating a robust capability to recognize and accurately classify actual instances of grid instability. This corresponds to a high recall of 98%, demonstrating the model's effectiveness in capturing nearly all true unstable cases.

Conversely, for 'stable' states, the model identified 2128 true positives with only 45 false negatives, further attesting to its strong performance with a recall of 98% for this class as well. This indicates that the model is equally proficient in recognizing true stable conditions, ensuring minimal oversight of actual stable instances.

Precision metrics are similarly impressive, with the model achieving a precision of 99% for unstable states, thereby confirming its accuracy in labeling detected instabilities as true, with minimal false alarms. For stable states, the model achieved a precision of 96%, showcasing a high level of accuracy in classifying grid conditions as stable when they are indeed so.

The Area Under the Receiver Operating Characteristic Curve (AUC-ROC) score is 0.978, indicating an excellent ability of the model to discriminate between stable and unstable states. This high AUC-ROC score suggests that the model can effectively differentiate between the conditions with a high degree of accuracy and is particularly adept at managing the trade-off between sensitivity and specificity across various thresholds.

Cohen's Kappa, which measures the agreement between the predicted and actual classifications adjusted for chance, stands at 0.952. This reflects almost perfect agreement, indicating that the model's predictions align closely with the true data labels. Such a high kappa value is indicative of the model's robustness and its reliability in operational settings, where accurate detection of grid instability is crucial.

The Matthews Correlation Coefficient (MCC) is also very high at 0.952, confirming the model's strong performance. MCC is a more reliable statistical rate as it considers true and false positives and negatives and is generally regarded as a balanced measure that can be used even with unbalanced datasets. The high MCC value affirms that the model is effective across all categories of the confusion matrix, underscoring its capacity to predict stable and unstable states accurately without bias.

Overall, the model's accuracy stands at 98%, complemented by a macro average F1-score of 0.98 across both classes. This reflects not only the balanced performance in detecting both stable and unstable states but also the model's effectiveness in handling the different volumes of class instances, as confirmed by the weighted average metrics with precision, recall, and F1-score each standing at 0.98.

The consistency and reliability demonstrated by these results underscore the model's potential as a crucial tool for monitoring and managing smart grid stability.

Introduction

'Smart' is the new 'e'. A decade ago, a small 'e' in front of something showed that it was new and exciting – email, eCommerce, eHealth, eVoting . . . . Now, you read about smart – smart phones, smart cities, smart transport . . . even smart water!

If you believe the newspapers, *smart* grids are the solution to our future energy problems and, possibly, the panacea to global warming. But what is a smart grid and what makes it so much cleverer than what we've got now? Are all smart grids equally smart? How do you recognise one and what does it mean to the average consumer?

This book tries to answer these questions and more. For those of you familiar with *Smart Metering For Dummies*, you'll know what to expect, namely a concise primer to get you rapidly up to speed with the business context, terminology, impacts and issues surrounding smart grids.

Foolish Assumptions

In writing this book, we've made some assumptions about you. We assume that:

- You work in the utilities sector and understand the basics of how electricity markets work.
- You want to know more about smart grids and how they will affect distributors, suppliers, consumers and others.

- You understand some utilities jargon (but don't worry – we include a glossary at the back of the book, just in case).

How This Book is Organised

Smart Grids For Dummies is divided into six concise and informative sections:

- **Part I: Explaining Smart Grids:** We explain what makes a grid smart and how it differs from existing distribution grids.
- **Part II: Making the Case for Smart Grids:** We discuss the business drivers that are forcing the move from conventional to smart grids.
- **Part III: The Anatomy of a Smart Grid:** We describe some of the technologies that go into making a grid smart and try to demystify smart grid jargon.
- **Part IV: Implementing a Smart Grid:** We discuss some of the challenges faced when implementing a smart grid.
- **Part V: The Impact of Smart Grids:** We look at the effect that smart grids will have on distributors, suppliers, consumers and others.
- **Part VI: Top Ten Smart Grid Tips:** If you read nothing else, this section lists the essential things to bear in mind when discussing smart grids.

Icons Used in This Book

To make navigation to particular information even easier, these icons highlight key text:

The knotted string highlights important information to bear in mind.

This icon points to information that helps you implement smart technologies.

This rarely used icon points out practices and situations to beware of.

Dummies man indicates a real-life example to illustrate a point.

Where To Go From Here

As with all *For Dummies* books, you can dip in and out of this book as you like, or read it from cover to cover – it won't take you long!

Use the headings to guide you to the information you need. If you require any more information, feel free to contact us at `energyandutilities.uk@logica.com`.

Part I

Explaining Smart Grids

In This Part

- Examining the smart grid concept
- Comparing smart grids to their conventional cousins

Type 'smart grid' into any search engine and you'll get an indication of the breadth of opinion on what constitutes a smart grid and what one can do. In this chapter, we look at some of the characteristics that make a grid smart. But for now, we'll go with the following definition:

> A *smart grid* is an electricity distribution network that can monitor electricity flowing within itself and, based on this self awareness, adjust to changing conditions. It does this by automatically reconfiguring the network and/or exerting a level of control over connected demand and generation.

Phew! A bit of a mouthful . . . let's explore what we mean by this.

Looking at the 'Uneducated' Grid

Traditionally, power has been generated by a small number of large power stations. It is then transported at very high voltages to areas of demand on a transmission system and delivered at lower voltages to end users via a distribution network. Flows on the distribution network are generally one way only with power taken off the high voltage transmission network and supplied to the end consumer. Transmission systems have always been relatively smart but, on leaving the transmission network, things dumb down rapidly.

Conventional distribution grids are built on a *build and connect* principle. When new housing is built, the network is sized for the likely maximum anticipated load by applying tried and trusted design principles. The infrastructure is then built, homes connected and little more needs to be done for the lifetime of the network.

However, the global warming-induced pressure for countries to move towards low-carbon economies is now challenging this traditional 'build and connect' culture. We discuss the business drivers for smart grids in Part II but, suffice to say, electricity distributors are now being forced to move from a 'build and connect' to a 'connect and manage' culture. Distribution networks can no longer be left to their own devices but need to be actively managed, along with the consumers they serve, to cope with rapidly changing demands on the network.

Getting to a Smarter System

Smart grids don't usually start out smart. The vast majority of the electricity distribution network has been around for some time now and pre-dates the 'smart' era by several decades.

How a smart grid develops

A new network can be designed to be smart from the outset but the majority of grids need to become smart by adding information and communications technologies (ICT) to the existing 'dumb' network. So a smart grid is an electricity distribution network with some added ICT. Glad we cleared that up.

But, technology is only part of what enables a smart grid. A massive cultural change in the way distribution grids are planned, operated and managed is also required.

REMEMBER

Depending on the market, a fully functioning smart grid is likely to require a radical overhaul of existing commercial and regulatory relationships between distribution, supply, generation and transmission companies. And let's not forget the consumer who's an integral part of the transition to a low-carbon economy that smart grids are supposed to enable.

What a smart grid can do

A smart grid can provide better visibility of the electricity being distributed and can proactively manage both demand and generation connected to the network along with the network itself.

A smart grid helps deliver electricity more efficiently and reliably by:

- Automatically re-routing power, shifting loads and/or controlling embedded generation to manage constraints and outages on the network.
- Monitoring the condition of network assets and predicting failures, thus reducing maintenance costs.
- Intelligently managing the network to maximise the electricity distributed.

A smart grid can help 'sweat the assets', defer the need for reinforcement and thus, reduce investment costs.

However, with great power comes great responsibility . . . with so much automation and dependence on ICT, a smart grid must also be secure from malicious attack by incorporating cyber security at its heart.

Part II

Making the Case for Smart Grids

In This Part

- Exploring some of the drivers behind the need to make grids smarter
- How smart grids will benefit the consumer and the distributor

To understand why smart grids are necessary, you need to understand a bit more about how we currently consume electricity. Today, we use electricity when we want to and as electricity is difficult to store, the flexibility to meet this changing demand is provided by a small number of large generators that change their output to match our needs.

For most of us, the lights stay on most of the time and the system works pretty well. So why the need for change? Well, there are a number of reasons, most rooted in climate change and the need to move to more sustainable sources of energy.

Reducing Carbon Emissions

Most electricity today is produced from carbon-rich energy sources such as coal and gas. But, to tackle global warming, there's a general acceptance that we need to move to lower carbon energy sources. This presents a challenge since low carbon generation such as nuclear and renewables tends to be inherently less flexible than, say, a gas-fired plant that can increase or decrease output at relatively short notice. In the case of renewables, the challenge is even greater since they're often not only inflexible but also unpredictable. (Who knows when the wind's going to blow or the sun's going to shine?)

Living with sustainable generation

Moving to low-carbon energy sources will require a fundamental shift in the way we use and store power. The unpredictability and inflexible nature of power generated from sustainable sources means that we've either got to get better at storing electricity or at using it when it's available – in truth, we're going to have to get better at both.

TIP

Energy storage technology still has some way to go. So, in the short term, we need to be able to shape energy demand to match available generation. For demand to align to low-carbon generation, consumers need to:

- Be aware of when power's available.
- Be able to schedule their consumption accordingly.

In short, consumers need to become a lot more engaged with the electricity industry than they have been to date.

Managing growth in electricity consumption

At the same time as facing a fundamental change to the way we consume electricity, we're also set to start using a lot more of it. The World Energy Council envisages that by 2050 energy will come from at least eight different sources: coal, oil, gas, nuclear, hydro, biomass, wind and solar.

Electricity is set to play an important role in integrating this diverse supply portfolio, and the International Energy Agency predict electricity's share of the total energy market to grow from 24 per cent in 1970 to 40 per cent in 2020.

The largest growth in electricity usage is likely to occur in residential heating/cooling and in transportation, two heavy users of carbon-rich energy sources. Whilst low-carbon alternatives such as bio-methane, hydrogen, fuel cells and bio-diesel are all possibilities, these have some way to go before becoming commercially viable and in the meantime, electricity is likely to be the most practical alternative. We need to substitute our gas central heating for electric heat pumps and our 'gas guzzlers' for electric vehicles (often referred to as '*EVs*').

To reduce carbon, we need to electrify transportation and residential heating/cooling which means we need to generate even more electricity than we do today (from low carbon sources, naturally). That, in turn, means more electricity to distribute and more pressure on our distribution grids.

If new electricity demand is to be met, it must be flexible enough to adapt to the increasingly inflexible and unpredictable sources of sustainable generation.

Decentralising Energy Generation

Renewable generation comes in all sizes, from massive offshore wind farms and community hydro electric schemes right down to the wind turbine in your back garden or the solar panel on your roof (the small scale stuff being what's commonly referred to as '*microgeneration*').

Going local

Locating electricity generation close to where the electricity is consumed makes a lot of sense. Doing so reduces the inevitable energy loss that occurs when power is moved around, both in transmission and distribution. Recognising this, many governments are now encouraging *microgeneration* (generation in your home or backyard) through financial incentives such as feed-in tariffs aimed at producing a new breed of 'prosumers'.

Creating your own

Prosumers, consumers who can also generate electricity, benefit in a couple of ways:

- They meet some of their own electricity requirements and, thus, avoid the cost of purchasing it.
- They get paid for every kilowatt hour they produce and any excess that they put back onto the grid.

Experts have estimated that one in five of homes could put up a small wind turbine or solar panel without significantly impacting the distribution network (so long as they didn't all live in the same area!) But here's the dilemma. This amount of microgeneration won't be enough for us to achieve the CO_2 reductions that governments are striving for and yet any more is likely to cause distributors serious problems.

Prosumers represent a significant challenge to distributors whose networks have been designed for a one-way flow of electricity from transmission grid to end consumer. Power flows can now be two-way and are likely to be less predictable. This has huge implications for the distribution network, not least health and safety issues during network maintenance, and creates the requirement for more real-time information to manage the network.

Prosumers may also take the form of communities who share the energy produced by a mid-sized combined heat and power (CHP), wind turbine or hydro plant. These communities may form *distribution islands* on the network that are at least partially self-sufficient but also trade with the larger network to top-up their demand requirements or sell surplus generation.

Offering Better Consumer Service

Aside from saving the world (or at least doing their part), smart grids offer additional benefits to consumers.

Smart grids offer good visibility of the network, which allows distributors to pinpoint and resolve outages more quickly, thus, reducing the time consumers are without power.

Better network management via smart grids also offers the prospect of better quality of supply:

- Fewer brown outs.
- Less flickering.
- Less interference with communication systems and other electronics.

TIP

The ability to maximise use of the existing network capacity can reduce the time required to connect new customers.

Optimising Distribution

From a more parochial view, smart grids can offer a compelling business case to distribution companies. The improved asset monitoring and network optimisation of smart grids allows a distributor to 'sweat its assets' (maximise the investment it's made in its existing network).

Distributors can move towards *condition-based maintenance* in which assets are maintained when required rather than according to fixed schedules. This form of maintenance can reduce both operating expenditure (OPEX) through less unnecessary maintenance, and capital expenditure (CAPEX) by extending the life of assets.

Smart grids also enable smart investment strategies. Better visibility of power flows on the network gives distributors a better understanding of where losses occur, allowing them to target investment accordingly. And the ability to add more customers to the network without digging up the street and laying new cables means more revenue for less investment.

Part III

The Anatomy of a Smart Grid

In This Part

- Focusing on the technology that makes a grid smart
- Looking at other helpful technologies

Network engineers are a strange bunch. Get one onto the subject of smart grids and, unless you've an electrical engineering degree under your belt, they might as well be talking Swahili. Still, we'll try to keep the discussion in English to give you a brief overview of some of the technologies that can contribute to a smart grid. This chapter gives you a fighting chance of holding your own at the coffee machine when the topic turns to smart grids (and don't be surprised when it does with increasing regularity).

Most smart grids are created by adding information and communication technology (ICT) to existing power networks. Given the lack of a universally accepted definition of what constitutes a smart grid, it's difficult to say exactly where a smart grid stops. One view is to base its scope on who owns the assets, so that a smart grid extends only as far as the assets owned by the distributor. However, this simplistic definition may exclude many items that are key contributors to, or drivers for, a smart grid. So we split this chapter into two sections: the first covers those technologies that sit on the network and the second covers those that are more peripheral but play an important role in any smart grid.

Core Smart Grid Technologies

The following sections explain the technological stuff that's likely to be on the shopping list of a distributor looking to implement a smart grid.

Active Network Management (ANM)

Active network management (ANM) is a collective term for the technologies that put enhanced network monitoring and intelligence into the network to automatically manage functions such as voltage control, fault levels and network restoration.

TIP

Optimising the network through ANM also offers a smart grid distributor the ability to connect more *distributed generation (DG)*, potentially a relatively inexpensive way to reinforce the network.

REMEMBER

An essential part of ANM is a fast and reliable communication infrastructure between substations on the network and the central *distribution management system (DMS),* a suite of application software that supports the operation of electric systems.

EXAMPLE

From chips to grids

Imagine a factory that produces a million dollars of product every *hour!* Welcome to the world of semi-conductor manufacturing. Japan's largest global semi-conductor manufacturer has a factory that produces a billion semi-conductor chips per month. At a million dollars per hour, even modest process improvements deliver significant returns on investment.

With 2,000 pieces of equipment generating over 1,000 state transitions per second, optimising such a complex manufacturing process is no mean feat, but it was achieved by implementing Starview Technology's Analytical Event Processing (AEP) software.

AEP, an advanced form of Complex Event Processing, is able to monitor and modify the factory's production schedule in real time to minimise equipment downtime and maximise throughput. At every one of the 1,000 steps in the manufacturing cycle, each production lot can be allocated to the optimal piece of manufacturing equipment based on the equipment's current condition and state. Plant problems can be rapidly identified and product re-routed accordingly.

This massive optimisation exercise is achieved through a hierarchical set of business rules deployed across the factory. There are rules for managing individual pieces of equipment, individual workflows and the running of the overall factory, each functioning autonomously but able to interact with other rule sets when required. New rules can be deployed and tuned in a simulation environment to prior to being released into production.

Now substitute production lines with a distribution network, manufacturing equipment with distribution assets and product throughout with energy flows and you can see why Starview is looking to use AEP as a smart grid enabler. AEP offers the potential for self-balancing sub-stations, self-healing networks and near real time distribution system optimisation.

Automatic Voltage Control

The voltage across an electrical network changes depending on where consumers are connected and how much electricity they use. The higher the consumption, the greater the voltage drop between substation and consumer.

Distribution systems are typically designed to let voltage levels vary within acceptable limits as consumer load varies – voltage levels approach the statutory minimum when loads are greatest and statutory maximum when loads are at a minimum.

Consumers complain when they don't get enough voltage whilst high voltage levels can result in unnecessary energy losses. *Automatic voltage control (AVC)* is about putting intelligence into the substations to monitor voltage levels within the Low Voltage (LV) network and automatically adjust controls to maintain the voltage level within preset limits. AVC can improve both the efficiency and power quality of the distribution network.

AVCs are going to have to get smarter as not all cope well with the reverse power flow conditions that can arise when distributed generation (see below) is connected to the network.

Dynamic Line Rating (DLR)

The conventional approach to network planning and operation is to operate distribution lines within static or, at best, seasonal rating limits. But, in truth, the maximum current an overhead line can carry safely is an ever-changing value affected by prevailing weather conditions.

Dynamic line rating (DLR) is about squeezing more capacity out of existing network infrastructure through real-time monitoring. For example, strong winds provide cooling that increases line capacity. By measuring line parameters and weather conditions, DLR can determine the capacity of a section of the network at any given moment and use that information to help the network function at peak performance.

Intelligent Electronic Device (IED)

Smart grids need smart tools, and an intelligent electronic device (IED) combines substation protection, control, power quality recording and measurement capability in a single device.

Phasor Measurement Unit (PMU)

Referred to as a power system's 'health meter', a *phasor measurement unit (PMU)* samples voltage and current many times a second at a given location on the network, giving the distributor a near real time view of the power system's behaviour. If traditional Supervisory Control And Data Acquisition (SCADA) systems can be said to provide an X-ray of the network, PMUs provide an MRI scan.

Reactive Power Compensation

Reactive power is one of those concepts that non-electrical engineers struggle with, but in a nutshell it can be described like this: Some connections to the network just consume power; some, such as a large motor, have the annoying habit of storing up energy supplied to them for a part of the energy cycle, then letting go of it later in the cycle. This reactive power cycle means more power on the network, requiring greater capacity in the cables and increased losses.

Reactive power compensation is the injection or absorption of this reactive power to control voltage and increase available capacity.

Peripheral Smart Grid Technologies

The stuff we talk about in the next section is a bit more peripheral to a distributor's network than the technologies described above, but is just as important in the creation of a truly smart grid. Some may already be part of the distributor's responsibility; others are unlikely to be and represent both a threat and an opportunity as we'll discuss later.

Distributed Generation (DG)

Distributed generation (DG) is typically a small-scale source of electric power embedded in the distribution network. In contrast to the traditional model in which energy generation and delivery originates at a central plant, DG is situated close to the consumers it supplies. Thus, a DG system cuts down on transmission and distribution losses. The associated cost savings typically run to more than 30 per cent of the total cost of electricity.

Making room for renewables

The Orkney Isles in the north of Scotland have fantastic potential for renewables, restricted only by the capacity of the island's network and the submarine cables connecting it to the mainland. According to conventional approaches to network planning and operation, there was no capacity available for new renewable generators.

However, by implementing an Active Network Management (ANM) scheme, it was possible to connect several additional wind farms to the existing network, avoiding expensive and time consuming network reinforcement.

The power output of the new wind farms is managed in real-time to ensure that the network isn't overloaded. This provides a quicker and cheaper means of connecting renewables to a congested network.

The ANM scheme, SGi, was deployed by Smarter Grid Solutions and Scottish and Southern Energy in 2009. Colin Hood, Chief Operating Officer at SSE said. 'This deployment provides a blueprint for how smart grids can be used to connect high penetrations of renewable generation in a cost effective way and resolve grid congestion as a result. The connection of similar levels of renewable generation on Orkney by the conventional means of network reinforcement would have cost around £30 million.'

DG includes a broad range of technologies including renewables (wind, solar, hydro) and combined heat and power (CHP) plants. At its smallest scale, DG can include microgeneration (see below).

DG presents distributors with both a challenge and an opportunity. If unharnessed, it can cause huge problems with voltage levels, voltage fluctuations, thermal ratings and power flows, but if controlled, it can provide an invaluable tool for balancing the network. A key benefit of smart grids is the ability to master distributed generation and, therefore, encourage more of it.

Dynamic Demand (DD)

Using *dynamic demand (DD),* electronic appliances (such as the refrigerator in your home) that don't make time-specific demands on the power system, can play a role in keeping the system in balance.

System balancing is essentially the art of keeping the lights on and is the responsibility of the *transmission system operator (TSO)*. The TSO ensures that there's enough electricity at the right place at the right time and a key indicator used by the TSO in performing this role is the voltage on the network (called *system frequency*) which must be kept within acceptable boundaries.

To continue with the fridge example, DD automatically adjusts the refrigerator's *duty cycle* (the amount of time it consumes power) in response to changes in system frequency on the network. The response is automatic and immediate, providing *TSOs* the potential of a valuable, if uncontrollable, balancing tool.

Freezing the cost of system balancing

Currently, transmission system operators (TSOs) have to call on large power stations, often running in an inefficient stand-by mode, to keep the lights on in the event of a major loss of generation. Making these power stations available is expensive, both in terms of cost and carbon.

A study in the UK in 2008 suggested that 40 million refrigerators fitted with dynamic demand (DD) could provide over 1,000 megawatts of frequency response – the equivalent of a large power station. This represents a total CO_2 saving of over 1.7 million tonnes per annum. So, if new fridges were required to include DD as standard (along the lines of the EU directive that will phase out incandescent light bulbs), we have the potential to reduce our reliance on reserves based on expensive, carbon-rich generation plant.

Grid energy storage

An age-old problem for the electricity industry is that storing electricity in large volumes is very difficult, so generation and demand need to be matched in real time. And, with an anticipated increase in generation from unpredictable renewable sources such as wind and solar, the problem is exacerbated. What can you do with all the electricity generated from a wind farm during a storm at 3am? And how do you provide enough electricity to boil the kettles during half-time on a still, overcast World Cup final day?

One solution used for some time is *pump storage* in which water is pumped up to a holding reservoir when electricity is abundant and released through turbines to generate electricity at times of high demand. Trouble is, pump storage facilities are expensive to build and require a suitable location, typically in the mountains – away from areas of high demand.

Research is on-going into new grid energy storage technologies including:

- **Batteries,** which are expensive to produce, costly to maintain and have a limited lifespan.
- **Compressed air,** which requires similar large scale facilities as pump storage.
- **Flywheels,** only good for small scale storage.
- **Hydrogen,** manufactured using off-peak electricity and then combined with oxygen to produce electricity at peak time but with lower efficiency than pumped storage or batteries.
- **Superconducting magnetic energy storage (SMES),** a means of storing energy in the magnetic field created by a direct current flow in a cryogenically-cooled superconducting coil. It works only for small amounts of energy and is expensive to boot.

It's fair to say that there's still a long way to go when it comes to grid energy storage.

Microgeneration

As with most *smart* jargon, there's no single definition of what constitutes *microgeneration,* but it's generally accepted to mean very small scale generation, typically serving a single home. Examples of microgeneration are solar panels (also referred to as *photo voltaic* or *'PV'* panels), wind turbines and micro CHP (small boiler-like units that generate heat for home heating from gas and produce electricity as a by-product).

It’s debatable whether microgeneration is part of the smart grid or one of the emerging factors that smart grids need to accommodate but, either way, it is set to influence future smart grids and is worthy of mention.

Microgeneration presents a new set of challenges to distributors. In the case of three phase distribution systems (in which electricity is carried as three alternating currents in three circuit conductors), microgeneration can cause voltage imbalance if not evenly distributed across all three phases. It can also cause localised interference with communication systems. At volume, microgeneration could also result in reverse power flows (for example electricity flowing from the distribution grid back onto the transmission system).

Smart appliances

We’re not talking fashion here, although many smart appliances are sleek and smart looking, and they, too, have a role to play in enabling smart grids.

Smart appliances are your traditional domestic white goods but with some added ICT cleverness. That cleverness comes in different forms – some smart appliances can be controlled remotely by you, the owner, by your smart home (see the next section) or by a third party (an energy services company, for example) so as to run when power is at its cheapest or shut down when peaks occur. Smart appliances can, therefore, help flatten demand by moving consumption from peak periods to off-peak periods – a process known as *peak shaving.*

Smart homes

A *smart home* is another of those unspecified terms that means different things to different people. In this context, it means a residence fitted with a smart hub that can communicate with and co-ordinate a number of *smart appliances* so as to optimise energy consumption within the home. A smart home helps to take some of the burden of sustainable living off the shoulders of the home owner.

As they become more prevalent, distributors will need to engage with smart homes instead of with individual smart appliances or individual, perhaps not-so-smart, consumers.

Smart meters

Whilst most people would agree that smart meters are an integral component of any smart grid, they aren't the same thing. *Smart meters* can provide distributors with an in-depth view of what's going on in their networks. Where previously a distributor's view of power flows stopped at substations, smart meters provide the potential for extending visibility right down to the end consumer.

Depending on its IQ, a smart meter can also help the distributor adjust loads remotely, thus providing a powerful tool for managing the network (for more, see the next section).

In most countries, where metering is still the responsibility of the distributor, establishing a smart grid is often the driver behind smart meter rollouts. However, in countries where competition has been introduced in the energy sector resulting in unbundling of different roles and functions, new smart meter deployment models, such as the supplier-led deployment in Great Britain, have emerged.

REMEMBER

Truth be told, many stakeholders have an interest in the data and functionality on offer from smart meters:

- Suppliers see smart meters as an opportunity to win more customers through enhanced products and services whilst at the same time reducing their operating costs.
- Distributors see smart meters as the means of extending the smart grid down to the very end of the low voltage network.

For more information on smart meters, take a look at *Smart Metering For Dummies* published by John Wiley & Sons and available online at `www.logica.co.uk/we-are-logica/media-centre/articles/smart-metering-for-dummies/`.

EXAMPLE

From reactive to pre-emptive

For one of the world's largest power grid transmission operators, making sense of low-level energy events taking place in the grid was a huge challenge. While the majority of these events are harmless, others are indicators of upcoming problems and potential failures.

The operator deployed complex event processing technology from TIBCO that continuously monitors all low-level energy events and correlates these into meaningful information. This makes it possible to rapidly identify important events, understand how these events are inter-related and thus spot issues with the power grid before any major disruption occurs.

As a result, grid operation can focus on pre-emptive rather than reactive actions. With large transformers costing millions of Euros and requiring weeks, if not months, to replace, this has a huge impact both on the overall reliability of the network as well as operational costs.

Virtual power plants (VPPs)

To understand virtual power plants (or 'VPPs', for short), you need to first know what a distributed energy resource (or 'DER') is. A DER can be small-scale distributed generation (DG), a power storage facility or a flexible, controllable load. A *VPP* is an aggregation of DERs that can be remotely monitored and collectively controlled in a similar way to a conventional large-scale power plant.

REMEMBER

DGs that do their own thing are a problem for a distributor due to their unpredictability. However, herd them together and take control of them via a VPP and they become a powerful tool for managing the distribution network.

You can think of a VPP as a means by which lots of little players can gain the market visibility they need to play with the big boys – it's good for the VPP members and it's also good for the system. DER with no exposure to market signals tends to behave inefficiently, whereas, a VPP integrates DER into the market place.

VPPs come in two flavours:

- Commercial VPPs (or 'CVPPs'): The prime objective of a CVPP is to maximise the financial outcome for the participating DERs.
- Technical VPPs (or 'TVPPs'): The prime objective of a TVPP is to help optimise management of the distribution grid.

Put crudely, CVPPs serve the suppliers whereas TVPPs serve the distributor. Given that a VPP can take on either guise, the big question is: Who should have control? In an unbundled energy market, control of demand-side flexibility is likely to fall to suppliers. Research such as Project FENIX (see the sidebar 'Threat to opportunity') suggests that suppliers can make more money through commercial aggregations of DER in the form of CVPPs than offering distribution optimisation services via TVPPs.

VPPs are a major component of any smart grid. However, there are significant challenges in balancing the needs of distributors and suppliers, these challenges being more commercial than technological.

Threat to opportunity

In even moderately deregulated energy markets, large distributed energy resources (DERs) are able to sell their energy on the open market even though their production still flows through the distribution network. In some instances, the transmission system operator (TSO) may be aware of their intended production schedule, but this is rarely the case for the distributor. The lack of visibility and controllability of DER makes DNOs reluctant to include DER in their networks.

FENIX, a €14.7m European collaborative project partly funded by the European Commission, set out to demonstrate how DERs could be 'tamed' by distributors and harnessed to help manage the distribution network. The 4-year project, which kicked off in 2005, involved 8 countries and a consortium of 20 companies. Focusing on CVPP (Commercial Virtual Power Plant) applications, FENIX attempted to quantify the value of DER under conditions prevailing in the UK (the 'northern scenario') and Spain (the 'southern scenario'). The project found that DER, aggregated and controlled in the form of a CVPP, could offer substantial benefit to suppliers, distributors and TSOs alike. However, equitable access to these benefits will require substantial changes to current regulatory frameworks.

Part IV

Implementing a Smart Grid

In This Part

- Enabling smart grids with smart meters
- Looking at the effects of regulation on smart grid implementation
- Comparing the technical and business challenges of implementing a smart grid
- Balancing the needs of distributors and consumers

Building a smart grid is not as easy as it may first appear as not all of the components are under the control of the distributor. For example, putting enhanced monitoring within substations may well be at the distributor's discretion but installing smart meters in residential homes may fall to the suppliers. Similarly, in an unbundled market, any flexibility at the consumer end – embedded generation and/or flexible demand, for example – is likely to be under the control of suppliers. The commercial mechanisms that would allow the distributors access to this flexibility in order to better manage their networks may not be in place.

REMEMBER

Truth be told, implementing a truly smart grid is likely to be as much a commercial and regulatory revolution as a technological one.

Smart Meters versus Smart Grids

In an ideal world, smart meters and smart grids go hand-in-hand. Smart meters extend the distributor's view of its network right down to the end consumer whilst, at the same time, providing customers with the real time information they need to become energy savvy. In this ideal world, smart meters are an integral component of a smart grid implementation. Unfortunately, we don't all live in an ideal world.

In Britain's deregulated energy market, the government has allocated the responsibility for installing smart meters to the suppliers and the responsibility for implementing smart grids to the distributors. The integration between these two programmes is not as great as many industry experts would like. Although suppliers have been trialling smart meters for some time now, joint supply/distribution trials are only just being considered.

Having a single party responsible for both smart meters and smart grids doesn't necessarily guarantee an equitable balance between the needs of consumers and the needs of the distributors. In Italy, energy provider ENEL completed the world's largest rollout of smart meters to its 27 million customers in 2006. However, this impressive undertaking gave consumers no real-time access to their consumption – an oversight only now being addressed.

Perhaps Portugal will provide a better model for a balanced implementation – see the sidebar describing EDPD's efforts.

From AMR to InovGrid . . . The evolution of a smart grid

EDP Distribution (EDPD), the national Portuguese distributor, faces all the usual challenges of a distribution company in the twenty-first century including dealing with the liberalisation of the European and Iberian electricity markets, meeting European energy efficiency targets, managing large-scale integration of microgeneration and accommodating increasing quantities of unpredictable renewable energy.

EDPD's answer is InovGrid, an ambitious evolution of Portugal's distribution network towards a truly smart grid. Developed in partnership with Logica, Janz, EFACEC and the scientific research institution INESC Porto, InovGrid is a multi-hierarchical network comprising energy boxes (EBs - essentially enhanced smart meters) at producer and consumer premises, distribution transformer concentrators (DTCs) at LV sub-station level and a central management and control capability.

In addition to providing customers with detailed consumption information, the EBs also provide microgeneration and active load management. The DTCs can use this flexibility for local energy balancing along with transformer control and automation functions. The central management and control systems then utilise the data and functionality of the DTCs and EBs to enhance existing network organisational processes such as planning, maintenance, quality of supply, outage management and commercial strategies more focused on the customer.

InovGrid, which has now being deployed to 50,000 customers, is set to bring significant benefits to both EDPD's 6 million customers and the Portuguese economy during subsequent stages of rollout.

Smart Grids versus Unbundling

Implementing smart grids as a step towards a low carbon economy is taking place against a backdrop of increased deregulation in global energy markets. In Europe, directives have been put in place that require keeping generation and supply separate from the natural monopolies of transmission and distribution.

The number of discrete players involved in the production and delivery of electricity has a significant impact on the implementation of smart grids. In countries which retain a single, dominant player in the electricity sector, smart grid implementation tends to be easier as responsibility lies with a single body. In more deregulated markets, responsibility tends to be split across a larger number of stakeholders which places more importance on the regulator to ensure a coordinated, coherent smart grid strategy.

And it's not just responsibility for delivering the smart grid that gets fragmented in a deregulated, unbundled market. In Great Britain, where deregulation has moved on apace and unbundling has extended to metering and metering services, a study by Logica revealed that *distribution network operators* (*DNOs*) shared an overwhelming belief that there was no credible business case to encourage DNOs to invest in smart grids. (See the sidebar, 'No incentives, no smart grid' for more on this topic.)

No incentives, no smart grid

A smart grid maturity survey completed by Logica in 2010 offers a useful insight into the state of preparedness for smart grids in Great Britain. Interviews were carried out with key executives in the distribution companies to survey distribution network operators' (DNOs') attitudes towards smart grids and their state of readiness to implement them.

A key finding was the considerable importance regulatory incentives play in developing smart grids. The study highlighted an overwhelming belief that there was no credible business case yet to encourage DNOs to invest in smart grid technology. Although initiatives such as *Ofgem's* (*Office of Gas and Electricity Markets*) *Low Carbon Network Fund* (*LCNF*) were welcomed, these were not seen as substitutes for ongoing, effective incentives to invest.

The survey also suggested that, whilst DNOs were keen to take advantage of LCNF, most put smart grid development into the timeframe of the next *Distribution Price Control Review* (*DPCR6*) since little, if any, allocation had been made for smart grids in the previous price review (DPCR5). This strong alignment to regulatory control cycles emphasises the responsibility of the regulator in making smart grids happen.

Perhaps the most significant finding of the survey was the widely held belief that, for smart grids to truly flourish, DNOs need the freedom to interact with suppliers, generators and others and that this will require a root-and-branch reform of the existing regulatory regime. Ofgem suggest that their proposed reform of the DNO price regulation (RPI-X@20) will be this root-and-branch review and will be in place for DPCR6.

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Clearly, there's a lot for Ofgem to do if smart grids are to become a reality in Great Britain.

Where deregulation has been around for a while, there's evidence that the remaining regulated monopolies have become slaves to regulation and respond only to regulatory incentives. The responsibility for enabling smart grids then falls to the regulator who must articulate the various goals of a smart grid in the form of clear and measurable incentives – incentives which have a knock-on effect for de-regulated participants.

Technology versus Transformation

The start of this book describes smart grids as the application of ICT to an existing distribution network. But, there's more to smart grids that just some whizzy technology. Building a smart grid is one thing but using it is another.

The smart grid is a catalyst for a business transformation that affects all parts of the energy distribution organisation, from long-term network planning to real-time network operation.

And the transformation isn't confined to the distribution business. It extends to users of the network such as consumers, their suppliers, energy service companies and transmission system operators (TSOs).

Consumer versus Network

Perhaps the most overlooked component of a smart grid implementation is the consumer. One of the primary tools available to the smart grid to optimise the network is to influence consumers' behaviour, and one of the key drivers for smart grids is to enable the consumer to make the transition to a low-carbon lifestyle. It's not unreasonable, therefore, to expect consumers to be at the heart of any smart grid programme.

Failing to get consumers onboard can doom the implementation of a smart grid programme. In 2009, vigorous campaigning by consumer groups in the Netherlands resulted in the government backing away from a mandatory rollout of smart meters in favour of voluntary adoption. Opponents to the mandatory rollout successfully claimed that the introduction of smart meters would constitute a violation of the consumers' rights to privacy and, consequently, would be a breach of the European Convention of Human Rights.

Part V

The Impact of Smart Grids

In This Part

- Looking at the effects of smart grids on distributors
- Looking at the effects of smart grids on others
- Predicting the future

Smart grids are a catalyst for a fundamental re-think about how we generate, deliver and use electricity. Some people look at smart grids as simply a layer of ICT (information and communication technology) added to the existing underlying network equipment, but most recognise that smart grids change not only the way electricity distributors operate but also their relationships with others in the electricity supply chain.

As stated in *Future Network Architectures: Department of Business Enterprise and Regulatory Reform UK, 2007:*

> 'Ofgem should consider reviewing the functional and licensed roles of supply, distribution and transmission under a low carbon, high DG (*distributed generation*) future. This should ideally extend to examine the licence restriction on DNOs owning and operating generation and storage, and the respective roles of the distributor and supplier in

relation to commercial treatment of demand side management and storage.'

In this chapter, we examine the likely impacts of smart grids on the key industry participants and speculate on how this impact will change over time.

Changing How Distributors Operate

Smart grids represent a major transformation to the way that distributors have operated in the past. Moving from a 'build and connect' to a 'connect and manage' culture is no small change. The switch to smart grid technology permeates all aspects of the distribution function including long-term investment planning, asset maintenance, connections and real-time operation. Distributors need to get smarter in the way they use their networks in order to carry more electricity through their existing infrastructure without digging up the street to lay new cables. Only by maximising the use of their existing network, will distributors be able to respond quickly to the changes in consumer behaviour that accompany a transition to a low carbon lifestyle.

REMEMBER

Perhaps the most challenging change facing distribution companies is the move from 'passive' to 'active' network operation and all that it entails (see 'Getting closer to consumers', below). Controlling consumer demand in preference to building new network capacity will require a new set of skills and, most probably, a new set of market mechanisms.

Moving from pooling to trading

On the 27th March 2001, the New Electricity Trading Arrangements came into force in England and Wales, radically changing the electricity wholesale market.

The old pool-based trading arrangements, in which virtually all electricity was sold directly through a centrally-administered pool, were replaced with more competitive, market-based trading arrangements similar to other commodities such as coal and oil.

The impact on both supply and generation companies was immense and created the need for a whole new skillset and culture.

Getting closer to consumers

Distributors currently don't tend to actively manage the consumers connected to their networks. Instead, the traditional 'fit and forget' approach means that the distributor makes sure that sufficient capacity is in place to accommodate any consumer behaviour under most network conditions and has little to do with the consumers, themselves. This is all set to change as conventional network reinforcement is supplemented by active network management (ANM), a concept we talk about in more depth in Part 3.

Distributors in a smart grid system will need to become distribution system operators (DSOs), actively managing consumers' behaviour via a range of mechanisms such as:

- Distribution tariffs that encourage consumers to use less energy at times of peak demand.
- Ancillary contracts which reward consumers for switching off when asked to do so by the DSO.
- Short term commodity markets where the DSO can buy flexibility in consumer demand as required from the consumer's supplier or other authorised representative.

There has even been speculation that distributors should be allowed to own and operate their own distributed generation (DG) and/or storage.

Embracing new payment schemes

Distributors currently charge consumers for use of their networks, most typically via the consumer's supplier. Although they vary across countries and networks, charges to consumers are usually based on some combination of the maximum power that they use at any one time and the total volume of energy that they consume.

With an anticipated growth in partially self-sufficient prosumers who generate some of their own electricity, existing ways of charging for power may need to change to provide more equitable cost recovery for suppliers and distributors. At the same time, in order to maximise the use of their existing networks, distributors will want to encourage consumers to use less power at peak times.

TIP

Without a direct commercial relationship with the consumer, the distributor's only financial tool for influencing consumer behaviour is likely to be the distribution charges they impose on the consumer's supplier. A major shake-up of distribution charging, such as a move towards time of use (TOU) distribution tariffs, in which energy costs vary with time of day, day of the week, season of the year etc., is on the cards.

Looking after the network

A smart grid gives a distributor better visibility of the state of the physical equipment that goes to make up the distribution network. So instead of a fixed maintenance schedule in which bits of the network get attention at set times, the distributor can move to preventative maintenance based on the actual condition of equipment, as monitored by the smart grid.

This radical change offers a win-win outcome. Not only does it reduce unnecessary maintenance by only taking action when it's required, it also extends equipment life expectancy by fixing small problems as soon as they occur and before they have a chance to develop into big, expensive problems. This combination helps reduce both the distributor's operating and capital expenditures.

Managing more data

Having better visibility of your network comes with a price – lots more data! All the smart decision making that goes with a smart grid – the investment planning, asset maintenance, network operation and so on – is based on having timely access to large volumes of data. And extending the smart grid to the end consumer increases this volume by orders of magnitude.

A successful smart grid not only needs to manage this vast quantity of data but also needs to be able to get hold of this data quickly.

EXAMPLE

Moving metered data from billing to operations

As grids get smarter, data volumes are set to explode. In a traditional network, visibility of energy flows rapidly diminishes with the descent through the network but smart grids raise the potential of monitoring right down to the end consumer. Metered data previously only used for monthly billing can now play a key role in optimising the grid. However, the challenge is to present this wealth of data to grid operations staff in an accessible and meaningful way.

Xcel Energy addressed this challenge by implementing OSIsoft's PI meter data management solution to combine information from domestic customers' meters and Home Area Networks (HANs) with its existing operational data set. Near real time aggregation was used to summarise high volumes of low level data in 'roll up' metrics that could be used to enhance existing sub-station views of the network. The result is a seamless 'at a glance' view of the network based on a single, common set of data that enables the utility to effectively manage the network.

The Impact of Smart Grids on Others

Smart grids will have a wide impact.

Rewriting regulations

You can bet on the fact that existing regulations will need to change to keep up with smart grid evolution.

Rules that spell out quality of supply standards and describe how power outages should be handled are likely to change to reflect the distributor's improving view of every aspect of its network. Similarly, price controls may need to be reviewed to ensure that appropriate incentives are in place to encourage distributors to develop an investment deferral strategy that produces smarter and smarter grids (this incentive system could be modeled on those currently imposed on transmission system operators). Licence conditions may also need to change to allow distributors to access embedded generation and electricity storage.

Training the new workforce

New technology on the network will require new skills within the distribution workforce. But the changes that a smart grid will bring to a distributor are more fundamental than just the technology. Becoming a distribution system operator in the age of the smart grid will require a new way of operating.

Other aspects of the business such as investment planning and asset maintenance are likely to change dramatically as well. Distribution companies are likely to face a period of significant up-skilling and recruitment.

Shifting the role of suppliers

If not already delivered by smart metering programmes, smart grids are set to provide suppliers with a hitherto unheard of level of consumer engagement. This can take the form of passive engagement such as influencing consumer behaviour with time of use (TOU) tariffs, in which energy costs more when used at peak times. It can also take the form of more active engagement such as demand side management (DSM) in which the supplier actively controls energy use within consumers' homes.

Flexibility in demand, previously only associated with large industrial and commercial consumers, is now set to become more prevalent across the wider consumer base. This new-found flexibility is likely to create new markets and commercial opportunities.

Changing the consumer experience

For smart grids to work, consumers need to become much more engaged in the electricity industry than they are today. They need to be aware of their own energy use and its associated cost. The smart grid can provide this awareness and information as well as the means to better manage consumption, so that they can save money through more efficient energy use.

Consumers can expect better service from a smart grid – fewer interruptions, quicker restorations, better quality of service – and large customers who generate their own electricity (DGs) can expect less of a wait for connection to the distribution network.

More importantly, the smart grid should enable the consumer to make the transition to a low-carbon lifestyle – to install their heat pumps, erect their wind turbines and plug in their electric cars. Just how many will choose to make this transition remains to be seen.

Including transmission system operators

Although peripheral to the distribution network, the transmission system operator (TSO) is not immune to the impact of smart grids. In many places, control of any DSM belongs to suppliers who can use this flexibility to balance their wholesale portfolios and/or sell flexibility to the TSO.

Distributors are now likely to need a similar local balancing mechanism for managing their local smart networks and, depending on the emerging regulatory framework, may have first call on available DSM. Any unused DSM which can be accommodated on the distribution network could then be offered to the TSO, presenting them with a new tool for system balancing.

Predicting the Future

With new technology comes new regulations, new practices, and new roles for everyone in the energy sector. In this section, we speculate on the changing markets within which smart grids will be built.

Planning for the unknown

Distributors are being asked to implement smart grids to cater for the anticipated transition to a low-carbon economy. Trouble is, no one's quite sure what this low-carbon economy will look like or how quickly it will appear.

Distributors are only one set of participants in this transition. Delivering a fully functioning smart grid requires that distributors gain insight into the behaviour of consumers and suppliers as well as governments and regulators.

Fortunately, there are some obvious pointers as to where to start. Most distribution networks have *hot spots* – stressed areas of the network that are prone to problems. Focusing on these hot spots can give distributors a chance to introduce some smart grid technology improving both the network and the distributor's bottom line.

WARNING!

Predicting future scenarios is a difficult prospect and carries the risk of stranding your assets if you invest for growth in an area of network that fails to materialise. However, the IT equivalent of the crystal ball is at hand – in the form of Dynamics Modelling, explained in the sidebar, 'Predicting the future with Dynamics Modelling'.

Predicting the future with Dynamics Modelling

Predicting the future is never easy, but Logica has helped organisations do just this using an advanced business modelling technique called *Dynamics Modelling*. Dynamics Modelling identifies the underlying cause and effect relationships within an organisation's steady state business and then tests a wide variety of 'what if' scenarios. This allows the impact of potential changes, both inside and outside the business, to be quantified. Understanding the relative importance of these influences and their interdependencies allows the organisation to define a transformation programme that accommodates anticipated change whilst protecting continuity of service.

Logica used Dynamics Modelling to help a UK train operating company (TOC) decide how best to spend its asset management budget in order to minimise annual maintenance costs within regulatory constraints, the most important being safety. The TOC's most significant maintenance cost is replacement/refurbishment of the wheels and axles of its rolling stock.

Dynamics Modelling showed that the TOC's current policy to replace components only when the wheel/axle is failing actually costs the TOC more than a policy of replacing components as soon as they show any signs of wear. It also revealed a hitherto unrecognised relationship with Network Rail (the owner of the rail infrastructure) in that worn wheels/axles increase the rate of wear to the railway track which, in turn, has a reciprocal effect of causing wheels/axles to deteriorate faster. With the help of Dynamics Modelling, the TOC was able to identify a change in maintenance policy that delivers a commercially quantifiable win-win outcome for both itself and Network Rail.

Part VI

Top Ten Smart Grid Tips

This section is short but packs a punch! In it, we distill the key points you need to remember to survive and thrive in the world of smart grids.

Smart Grids and Culture Change Go Hand-in-Hand

Implementing a smart grid is a business transformation that affects all parts of a distribution company, including planning, investment, and operations. In moving to smart grids, you need to think about the people as much as the technology.

Technology is the Least of Your Worries

Technology is only one of the challenges in implementing smart grids. Smart grids frequently require a major review of existing commercial and regulatory arrangements, involving multiple stakeholders. Engage early with the regulator!

Incentives are Key

When implementing a smart grid in an unbundled energy market, get your incentives right! Regulated monopolies tend to respond better to regulatory incentives than innovative commercial opportunities.

Smart Meters don't make a Smart Grid

Giving everyone a smart meter won't deliver a smart grid. Although smart meters are an essential component of a truly smart grid, there's more to smart grids than just smart meters.

... But Smart Meters are an Essential Component of Smart Grids

Smart meters need to support smart grid implementation. If not implemented as part of the smart grid programme, be sure that smart meter functionality and data communications will serve the smart grid. Retrofitting millions of customer premises would be a financial and logistical disaster.

Get Ready for Data – and Lots of It!

Better visibility of the network comes with a mountain of data to manage. Make sure you have the systems and processes in place to cope.

Start with What You've Got

Many distribution companies could achieve a lot through better integration of their existing systems before adding new technology.

Fix Existing Hot Spots

Applying smart technology to solve existing problems improves your network and is more likely to provide an earlier return on investment.

Start Forecasting more than just New Connections

Low carbon interventions, such as electric vehicles (EVs), microgeneration and eHeating, can pop-up anywhere on the network and can rapidly cause problems. Start polishing the crystal ball!

Don't Forget the Consumers!

At least 30 per cent of smart grid benefits will come by getting consumers engaged in the process. No amount of technology will deliver a truly smart grid without having the consumers on board.

Glossary

ANM – active network management: Technologies that enable enhanced network monitoring and intelligence to automatically control voltage, manage fault levels and implement network restorations.

AMM – advanced meter management: Another term for *smart meters* and their supporting infrastructure.

AVC – automatic voltage control: Technology, installed within a substation, which monitors voltage levels within the *low voltage network* and automatically controls equipment within the substation to maintain voltage levels within preset limits.

brown out: A drop in voltage in an electrical power supply, so named because it typically causes lights to dim.

CAPEX – capital expenditure: Investment in a fixed asset.

CHP – combined heat and power: A heat engine or power generator used to simultaneously generate both electricity and useful heat.

CVPP – commercial virtual power plant: A *virtual power plant (VPP)* whose primary aim is to maximise the financial outcome for the participating *distributed energy resources (DERs)*.

DSM – demand side management: The control or influence of energy consumption by end users, typically at times of peak demand on the network.

DER – distributed energy resource: A small-scale *distributed generator (DG)*, a power storage facility or a flexible, controllable load connected to the distribution network.

DG – distributed generation: Typically small-scale generation, connected to the distribution network and sited close to where its output is used.

DMS – distribution management system: A suite of application software and systems that helps manage distribution assets and plays an important role in ensuring reliable and efficient power distribution.

distribution network: the network that carries electricity from the transmission system to the end consumer.

DNO – Distribution Network Operator: A company licensed to distribute electricity in Great Britain by the Office of Gas and Electricity Markets (*Ofgem*).

DPCR – Distribution Price Control Review: The regulatory price control regime imposed by *Ofgem* on licensed *DNO*s in Great Britain, currently applicable for a five-year period.

DSO – distribution system operator: A distributor with active, near-real time control of power flows across the distribution network, either through direct physical control or commercial mechanisms.

DD – dynamic demand: A technology that allows non time-critical electrical appliances, such as domestic refrigerators, to automatically alter power consumption and, thus, help in *system balancing*.

EV – electric vehicle: A vehicle that uses one or more electric motors for propulsion.

FCL – fault current limiter: A device that limits the excessively high current levels that can occur during a network fault.

HV – high voltage: The definition varies across countries, but the International Electrotechnical Commission considers HV to be any voltage over 1,000 volts alternate current.

ICT – information and communication technology: The clever bits that make grids smart.

IED – intelligent electronic device: A device providing substation protection, control, power quality recording and measurement capability.

LCNF – Low Carbon Network Fund: A £500 million fund established by the energy regulator, *Ofgem*, in Great Britain to encourage *Distribution Network Operators* to explore new technology, operating and commercial arrangements in order to understand how the DNOs can provide security of supply at value for money as Great Britain moves towards a low-carbon economy.

LV – low voltage: Definitions of LV vary by country. In the UK, LV runs at 230 volts to c 400 volts.

MW. Megawatts**.**

Ofgem – Office of the Gas and Electricity Markets: The government regulator for the electricity and downstream natural gas markets in Great Britain.

OPEX – operating expenditure: The ongoing cost of running a business or system.

PMU – phasor measurement unit: A device that samples voltage and current at a specific location on the network many times a second.

prosumer: A consumer of electricity who is also capable of generating electricity.

PV – photo voltaic: Another term for a solar cell or panel that converts energy from sunlight into electricity.

RES – renewable energy sources: Natural resources such as sunlight, wind, tides and geothermal heat, which are renewable sources of energy.

SCADA – Supervisory Control and Data Acquisition: Today's equivalent of smart grid technology, SCADA has been around for a long time but has typically only been deployed on transmission systems, water or gas networks.

smart meter: An advanced meter offering remote access to a rich source of consumption data and meter functionality via two-way communication between meter and utility.

smart grid: An electricity distribution network that can monitor electricity flowing within itself and, based on this self awareness, adjust to changing conditions by automatically reconfiguring the network and/or exerting a level of control over connected demand and generation.

SMES – superconducting magnetic energy storage: A means of storing energy in the magnetic field created by a direct current flow in a cryogenically-cooled superconducting coil.

supplier: A retailer of electricity who buys electricity on the wholesale market and sells this to end consumers.

system balancing: Real time actions performed by a *transmission system operator* to ensure that electricity is transferred across the *transmission system* to where it is required.

TVPP – technical virtual power plant: A *virtual power plant* (*VPP*) whose primary role is to help optimise management of the distribution grid.

TOU – time of use: A tariff that has different rates corresponding to different times of day, day type and season.

transmission system: The high voltage network used for bulk transfer of electricity from generators to substations located near areas where the electricity is consumed.

TSO – transmission system operator: An operator that transmits electrical power from generation plants to regional or local electricity *distribution networks* via a high voltage *transmission system*.

VAr – volt amperes reactive: A unit used to measure reactive power in an alternate current electric power system.

VPP – virtual power plant: An aggregation of *distributed energy resources* (*DERs*) that can be remotely monitored and operationally controlled in the same way as a conventional large-scale power plant.