Smart Meters and Losses: Best Practice Review

UK Power Networks
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Contents

1. Executive Summary

Smart meter rollout in Britain is already underway with a total of 53 million gas and electricity meters forecast for installation by the end of 2020. The availability of smart meter data, particularly when combined with in-house display units, will significantly increase consumers' awareness of their usage patterns. This is predicted to lead to overall energy savings across Britain.

Availability of smart meter data will enable electricity suppliers and DNOs to improve their efficiency. DNOs are increasingly becoming Distribution System Operators; a process that is heavily reliant on increased visibility of data. The dynamic behaviours of DSOs are typically more cost-efficient and flexible than traditional networks and it is anticipated that this is where the majority of benefits from smart meter data will lie for System Operators. Simultaneously, Suppliers' representatives will no longer need to visit customers' premises to obtain meter readings, and access to more accurate consumption data will help to avoid costly disputes about inaccurate bills.

This document provides a summary of the significant stakeholder engagement that UK Power Networks has undertaken to understand how smart meters are being used to better manage technical and non-technical[1] losses. By studying countries[2] which are ahead of Britain in their smart meter adoption we have been able to identify what is already being achieved.

Common trends include:

- Focus on non-technical losses is common across most countries. Predominantly two approaches are used to detect illegal consumption and meter failures. The first uses advanced statistical methods to compare recent consumption against historic profiles to identify irregularities. The second compares aggregated smart meter consumption data against recordings from an upstream metering device to highlight discrepancies (this arrangement is referred to as "differential metering" in this report)
- Consideration of technical losses is less common and appears to require a significant level of smart meter penetration. Losses caused by phase imbalance, poor power factor and high (or low) voltage levels can be managed through smart meter use. Demand Side Response is also being used effectively
- Smart meter data and network modelling can be useful to identify malfunctioning meters and illegal consumption
- Data isn't aggregated in most countries

[1] Non-technical losses refer to energy units that are delivered for consumption but which are not paid for due to of a wide variety of factors ranging from theft and non-registered consumptions to differences in billing and metering. Information retrieved from: https://www.ceer.eu/documents/104400/-/-/ef0719a0-2d70-924a-1957-fba8d815efec

[2]

Country Surveyed	Network Operator
Poland	Energa Operator
Italy	Enel
Portugal	EDP
Canada	BC Hydro
United States of America	Baltimore Gas and Electric Company

Discovering the common trends enabled us to identify barriers to the effective utilisation of smart meter data. This report details what these barriers are, and how we may tackle them. In summary, they include:

- Lack of smart meter penetration, which reduces the accuracy of both technical and non-technical loss calculations and their subsequent management.
- The outputs of some smaller embedded generators, when not metered, will exacerbate problems caused by incomplete smart meter penetration
- Longer sampling intervals reduce the accuracy of loss calculations
- Data aggregation potentially limits the effective use of smart meters to manage network losses
- Metering accuracy of +/-2% will limit the extent of network losses which can be effectively identified

In understanding these barriers we have been able to highlight specific opportunities that can be used to ensure that effective use of smart meters is still possible. Areas of opportunity include:

- Better understanding of customer's usage profiles, particularly Low Carbon Technologies (LCT) – many of which are currently unknown
- Using outputs from our work with Imperial College London we believe that we can more accurately target cost effective transformer size optimisation (section 4.2)
- More effective management and mitigation of specific network supply characteristics, such as power factor and phase imbalance, once visibility of these parameters has been established
- Improvement in our understanding of parts our HV network where visibility is currently lacking. For instance, by aggregating LV loads we expect to be able to better identify overloaded distribution transformers
- Better understanding of near-real time voltage levels, particularly those influenced by the embedded generation resources connected to them. This visibility will help us to actively manage our transformer tap changers ensuring that LCTs can continue to connect whilst networks remain within statutory voltage limits

The majority of benefits that have been identified are reliant on sufficient smart meter penetration being achieved. An exact figure is, at this stage, difficult to predict. Our work has shown that countries with 80% smart meter penetration are using their data to good effect. We will keep this value as our current 'trigger' point but will work to revise this in the interim through our proposed Losses Discretionary Reward activities.

2. Introduction and Overview

The UK Government has committed to reduce reliance on fossil fuels and improve energy efficiency. The commitment, known as the 'Three 20 targets' undertakes to:

- Reduce emissions of greenhouse gases by 20% by 2020, taking 1990 emissions as the reference
- Increase energy efficiency to save 20% of EU energy consumption by 2020, and
- Reach 20% of renewable energy in the total energy consumption in the EU by 2020

Photo 1: Example of a smart meter and a home display unit

Included in the Government's plan to bring our energy systems up to date is a commitment to undertake smart meter roll-out. This £11bn programme requires energy suppliers to offer smart meters to all homes and small businesses across Great Britain by 2020.

The installation of smart meters isn't compulsory and, whilst it is anticipated that by 2020 a large proportion of Great Britain will have adopted smart meters, there is a minority of people who have concerns about how their data will be held and whether the use of smart meters infringes their privacy. Therefore, it's unlikely that 100% coverage will be achieved in this timeframe.

Longer term, forces of supply and demand could eliminate the production of electromechanical meters leading to complete smart meter penetration.

To date, the benefit of the smart meter data has been promoted[3] as allowing in near real time:[4]

- Better matched supply and demand, which reduces the costs of generating and distributing energy
- Improved energy efficiency and reduced energy waste
- Helping unexpected power outages to be tackled faster

[3] Information taken from https://www.smartenergygb.org/smart-future/britains-smart-grid & https://www.gov.uk/government/publications/smart-meter-roll-out-gb-cost-benefit-analysis

[4] Near real time refers to a 30-second target response time. Power outage alerts may take up to 7 minutes, other alerts have up to a 24 hour response time

- To deliver improved customer service by energy suppliers, including easier switching between suppliers and enhanced price transparency, more accurate bills, new tariffs and payment options5;
- Where cost effective, to support development of smart grids.

Smart meters provide more functionality than simply conveying near real time consumption figures to the consumer. Recognising that the electricity networks are changing, moving from traditional unidirectional power flows to bi-directional flows, smart meters are capable of helping to match demand and generation. This may be done through time of use tariffs; making energy cheaper when there is an excess of wind generation, for example, or increasing costs when energy is in short supply.

Traditionally, network capacity has been determined based on peak usage. This usage may only reflect energy consumption during a few hours of the year; late afternoon in the middle of winter for instance. It is possible to avoid costly future network reinforcement if these energy consumption peaks can be shifted. This is starting to happen as energy generation patterns change and become increasingly dependent on renewable energy sources rather than traditional power stations. In addition, households have the potential to become more autonomous from the electricity grid with increased availability of domestic energy storage and generation. Given the lack of historic data, and hence limited current understanding of consumption and export patterns, it is anticipated that smart meters could help to match demand with generation and indicate where consumer behaviours can be influenced through price signals and certain levels of automation. This automation may include consumers' non-essential equipment being switched on, or off, dependent on what is happening within the wider network

It is expected that by providing consumers with information about their energy consumption they will be able to determine where opportunities exist to reduce their usage. Whilst their primary driver may be financial, it will indirectly help the government to meet their commitment to reduce energy consumption by 20%.

To maximise the portion of energy that is utilised from low carbon sources it is necessary to ensure that demand and generation are closely matched. This includes altering the level of demand as generation exports vary. When considering traditional energy usage it is hard to imagine how this would be possible, i.e. the consumer has to be at home to use their electrical appliances. However, as we move to a low carbon world where people wish to charge their electric vehicles or battery storage, it's possible to see how smart meters may help to match generation and load; irrespective of the time of day at which it occurs.

Smart meters are expected to have further benefits to those focussed on energy efficiency. Eliminating the need to visit a customer's property to take meter readings presents huge savings in time and resource requirements. Without frequent meter reads, bills are estimated. Inaccurate data and billing create significant costs for suppliers and consumers, causing disputes over bills and problems with the change of supplier process, thereby potentially hindering competition and hampering the overall customer experience.

Smart meters will notify network operators when supplies fail, which will help to improve service to customers. Rather than waiting for the first customer to notify them, DNOs will be able to respond once the first smart meter outage alert is received; this will typically be within 7 minutes of the supply interruption occurring. Smart meters will also notify network operators where supply quality, such as voltage level, falls outside predefined levels. This will help network operators to better understand the quality of their supply and address deficiencies.

[5] Department for Business, Energy and Industrial Strategy: Smart Meter Roll Out Cost-Benefit Analysis

Smart metering is hence an enabling technology that will help to address a number of challenges in the move towards smart energy systems. Smart grid developments are heavily reliant on data and information, and smart meters will provide consumption data from LV networks where previously, this data was very scarce.

3. International Benchmarking

3.1 Benchmarking to Prepare for Smart Meter Data

UK Power Networks undertook extensive benchmarking to assess peers' activities and opportunities that may exist once smart meter data is available. Table 2 below shows a summary of countries and network operators surveyed to compile this report. The primary objective of this study was to increase knowledge about economically feasible ways to reduce losses through the utilisation of smart meter data.

Table 1: Countries and Network Operators Surveyed

Country Surveyed	Network Operator
Poland	Energa Operator
Italy	Enel
Portugal	EDP
Canada	BC Hydro
United States of America	Baltimore Gas and Electric Company

3.2 Initial Impact on Energy Consumption

Smart meters will consume more energy than the older meters that they replace.[6] At the same time, customers who choose to install smart meters in the UK will be offered home display units as part of the transaction. Enel (section 7.2) attributed a 4% reduction in consumption to the influence of home display units. Locally, the Department of Energy and Climate Change assumed that smart meters would decrease domestic electricity consumption by 2.8%.[7] Hence, overall, there is an expectation that smart meters will marginally decrease losses in the short term.

3.3 Key Uses of Smart Meters and Lessons Learnt from the International Review

Based on our benchmarking we have identified the following ways in which smart meters are being used:

3.3.1 Reduction of Non-Technical Losses

Almost without exception, all network operators appear to be using smart meters to address non-technical losses. There are several different techniques to identify problems ranging from illegal consumption to faulty metering equipment. The most successful case study we observed was BC Hydro in Canada who suggested that they had reduced their non-technical loss figure by 50% within a three-year period.

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[6] Northern Powergrid Strategy for Losses, July 2015, indicates that smart meter energy consumption could increase demand by 8MW in the Yorkshire region alone.

[7] Information retrieved from https://publications.parliament.uk/pa/cm201617/cmselect/cmsctech/161/161.pdf

Multiple organisations cited differential metering as a useful technique to gain a better understanding of network losses (see section 7.4 for example). Differential metering consists of the network operator measuring the energy flowing into and out of their network and comparing the two sets of values. Work conducted at Aalto University in Finland[8] concluded that using statistical methods to reconcile the various data sets could become problematic when there are "major losses" on the network between the various meters. Their conclusions point towards a need to calculate energy losses between meters to balance measurements.

Photo 1: TGI Raptor meter used by B.C. Hydro to balance energy flows

3.3.2 Reduced Energy Usage by 'Informed' Consumers

Various organisations indicate that energy consumption reduces once consumers are presented with more visibility of their usage patterns. This reduction in consumption will lead to a reduction in upstream network losses. A study undertaken by Imperial College London, on behalf of UK Power Networks, estimated that a 2.8% reduction in energy consumption by our customers will lower associated network losses by 5.5%.

3.3.3 Demand Side Response (DSR)

In addition to general reductions in consumption, some network operators were also using smart meters to implement Demand Side Response[9] (DSR). In particular, Portugal's EDP assigned a value of 4% losses reduction owing to DSR and one international peer uses DSR to manage customers' load; particularly that of air conditioning

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[8] Retrieved from https://www.euramet.org/Media/docs/Repository/A169/ENG04_smart_grids/KorhonenAkseli.pdf

[9] Demand Side Response describe schemes that financially incentivize customers to lower or shift their electricity use at peak times. These help to manage load and voltage profiles on an electricity network.

equipment. This network operator took a novel approach in the sense that they incentivize customers to reduce load, rather than relying on tariff increases to discourage consumption.

3.3.4 Technical Losses

Surprisingly, not all network operators appeared to be considering technical losses following the roll out of smart meters. Those companies that are considering technical losses appear to be reliant on higher levels of penetration. Portugal's EDP used an area with circa 80% smart meter penetration and were able to estimate their technical loss improvement across three categories; DSR, phase imbalance improvement and Voltage Management. Overall they reported a 10% improvement, which splits across these categories as follows: DSR (4%), Phase Imbalance (2.6%) and Voltage Management (3.2%).

Adjusting network target voltage levels can have an impact on losses dependent upon the type of customer equipment connected to the network. Where predominantly resistive loads are connected, it makes sense to reduce the target voltage and hence reduce the current supplied to the consumer. Fixed power devices will draw more current as voltage reduces; thus worsening losses.

Embedded generation tends to increase voltage in the network to which it is connected. Therefore, to connect as much generation as possible, network operators tend to reduce target voltage levels. Some network operators are using smart meter voltage data to better understand their network voltages. Based on information received they are then able to determine how to operate their transformers' tap changers to minimise network losses.

The benchmarking exercise provided some useful conclusions to guide our plans and activities moving forward. In summary:

- Non-technical losses appear to be the area of focus common to most companies surveyed
- Consideration of technical losses appears to require a significant level of smart meter penetration
- Smart meter data and network modelling can be useful to identify malfunctioning meters and illegal consumption
- Data doesn't appear to be aggregated in the companies surveyed
- Smart meter data can help Network Operators to manage network voltages to reduce losses.

4. Possibilities Following Great Britain's Smart Meter Roll Out

From the information obtained during our benchmarking study we are better positioned to understand what we can achieve once the smart meter roll out is a) underway, and b) complete in the UK, and the challenges that we can expect to encounter while implementing smart meter-related activities. Section 4.1 elaborates on these challenges, and how they could undermine efforts to extract benefits. Following the focus on challenges, section 4.2 details how UK DNOs can use smart meter data to address losses.

4.1 Expected Challenges

1. Sampling intervals - Great Britain uses 30-minute average values, which is a significant improvement on the arrangement prior to smart meters. However, some of the countries that we have surveyed are using 15-minute sampling intervals. This difference in sampling rate is significant because the averaging process attenuates calculated network loss values for high loads that appear for intervals shorter than 30 minutes at a time.

   A study undertaken by Imperial College London, using smart meter data taken from UK Power Networks' Low Carbon London project, indicates that increasing the sampling rate from 30 minutes to 5 seconds leads to an increase of 190% on calculated network losses. Whilst a 5-second sampling rate isn't practical, it does demonstrate the loss in accuracy that reduced sampling causes.[10]

2. Lack of smart meter penetration – the uptake of smart meters isn't compulsory. There will be customers who opt out of installing smart meters due to personal preference. Premises not served by smart meters cause "gaps" in data available to stakeholders. These gaps in coverage may ultimately limit what DNOs can achieve. The timescale of roll out affects data gaps in the sense that it is unlikely that anything approaching 100% penetration will be achieved until after 2020.

   The challenges caused by data gaps could be overcome by substituting generic consumption patterns into the data gaps – work done under the auspices of Southern Electric Power Distribution Plc.[11] demonstrated how generic profiles could be generated and used for network simulation purposes . We hope to prove the usefulness of this approach in a future trial once smart meter penetration levels permit. We will however follow this approach with caution, as the value of the outcome heavily depends on the accuracy of profiles and assumptions used.

   Bi-directional energy flows accentuate the challenge caused by data gaps. It is understood that smart meters will provide import and export energy flows to DNOs. However, where G83 customers are present, the use of generic profiles to cover data gaps presents an additional complication due to the fact that G83 customers consume some of the energy produced by their own installation; the volume of energy exported into the network over each sampling interval is variable and unclear.

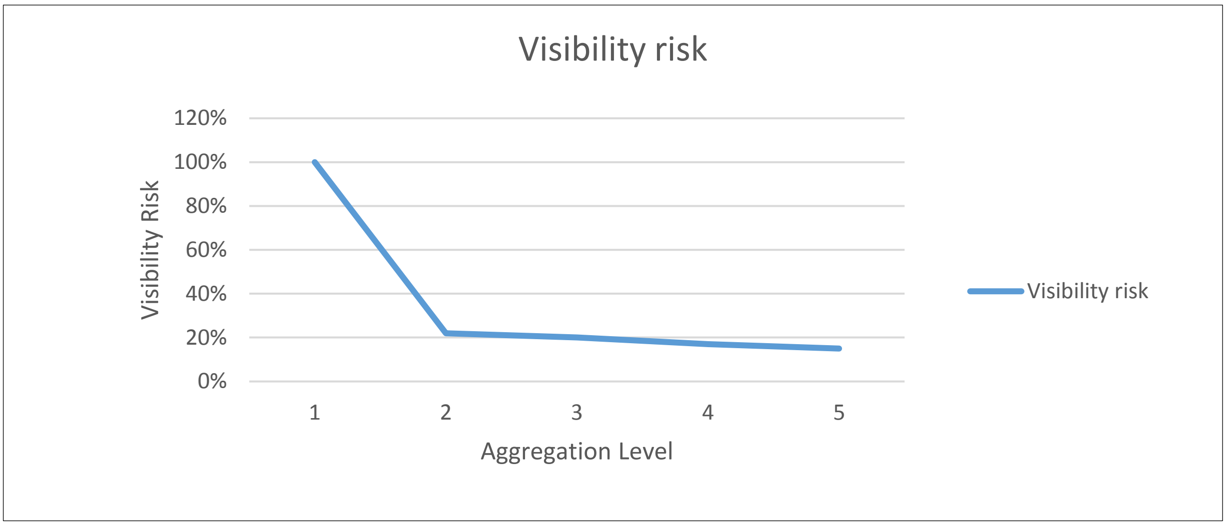
3. Adequate protection of customer privacy - data on a per-household basis will be required to enable accurate load flow calculations for LV networks. These calculations are required to balance energy flows through the network (section 3.3.1 refers) and to quantify losses attributable to specific network components. Where data is aggregated or anonymised, it may no longer be possible to quantify losses caused by high phase imbalance

[10] This finding was based on data from a single customer supply.

[11] Information retrieved from a report called "Losses Teams – Work Package 6". TNEI Services Limited and Element Energy contributed to this report.

either. Aggregated data from properties on the same phase will be more useful than aggregated data from properties that are only geographically close to one another.

A report produced by EA Technology Limited for the Electricity Networks Association indicated that the security benefit of data aggregation diminishes quickly when more than two customers' data is involved – Graph 1 below shows more detail. Further work is required to understand the impact of data aggregation on deriving losses benefits from smart meter data.



Graph 1: Visibility Risk – EA Technology Limited

4. Metering inaccuracies – smart meter specifications state an accuracy of ±/2%, which represents an improvement over the previous meter accuracy of +2.5%/-3.5% used in Great Britain. The usefulness of differential metering techniques is highly dependent on meter accuracy to uncover irregularities. For example, if illegal consumption in a network is less than 2%, it might be unclear to a network operator using differential metering whether an imbalance in energy measurements is caused by meter inaccuracy or illegal consumption[12].

4.2 Further Opportunities to Reduce Technical Losses

Whilst a number of barriers are anticipated to the use of smart meter data, there are still significant opportunities available to use this data to improve network visibility:

1. Refinement of customer demand/export profiles – The network is being increasingly used by new technologies which network operators know less about than previous technologies. Learning in this area is continually improving but technologies such as domestic storage, electric vehicles, electrification of heat and embedded generation still represent some unknowns. It is expected that smart meter data will help to accelerate the

[12] There are many secondary transformers serving 100 or more customers in urban networks. It hence follows that one of these customers' consumption amounts to circa 1% of the total energy delivered by the relevant secondary transformer. It is hence conceivable that metering inaccuracy of ±2% could totally obscure illegal consumption of circa 1% in magnitude.

understanding that network operators have regarding these technologies. This improvement in understanding is also likely to relate to how these technologies interact with each other and the time of use that is prevalent with each technology type. Improved learning in relation to all aspects is likely to enable the network operator to refine their forecasting and modelling capabilities in these areas, and install optimally efficient equipment as a result.

2. Transformer size optimisation – Ofgem's Cost Benefit Analysis (CBA) sheet is used to determine where it is economically justified to upgrade transformers to larger units solely based on the losses reductions that can be achieved. Using standard factors for utilisation and load loss, UK Power Networks have demonstrated that it's feasible to upgrade 315kVA transformers to 500kVA, and 800kVA transformers to 1,000kVA units.

   However, some of the work that Imperial College London has undertaken showed that upgrading more transformer sizes can be justified where higher load loss factors are experienced. Table 3 below shows some of the units considered and the instances at which upgrades can be considered:

Table 2: Break-even peak load for distribution transformer upgrades[13]

				Transformer Loss Load Factor[14]		
Type	Rating, kVA	Copper Losses, W	Iron Losses, W	15%	20%	25%
PMT	25	900	70	12kVA	10kVA	9kVA
	50	1100	90			
GMT	100	1750	145	81kVA	70kVA	63kVA
	200	2750	250			

   Given this insight, in addition to enhanced network visibility provided by smart meters, we expect to understand where different transformer sizes can be used to reduce losses.

3. Driving power factor optimisation – Domestic customers have historically been billed only for their real power consumption where whole current metering is used. Customers using CT metering have been billed for reactive power where their consumption is excessive; typically in excess of 33% of their active units; representing a power factor of 0.95.

   It isn't proposed to start charging domestic customers for their reactive energy consumption – this would reflect a significant change in existing charging methodologies. However, by gaining visibility of domestic customers'

[13] Table 3 shows the break-even load in kVA for various transformer sizes. For example, if the load on a 25kVA PMT, supplying a load with a LLF of 15% exceeds 12kVA, it is deemed economical to upsize to a 50kVA unit to limit losses.

[14] The Loss Load Factor is the ratio between the sum of losses over a year and losses incurred at the peak load. Data in table 3 was extracted from a report produced by Imperial College London.

reactive energy consumption, we could start to target installations with DNO-supplied solutions or education on how to improve power factor.

4. HV power factor optimisation – Two of our key LDR Tranche 1 activities have been the work that Imperial College London has undertaken and the extensive international benchmarking that we've undertaken. Both of these activities have highlighted a common element that is a major cause of network losses – excessive reactive power flow. During Tranche 2 we plan to undertake trials on our HV network to understand how, and where, to best tackle this issue. One of the problems that we face in approaching this matter is visibility of the HV network. Not all feeders have reactive power measurement capabilities and establishing these measurements can be costly; certainly, it can change the cost/benefit analysis from a positive outcome to a negative one. Through visibility of reactive power flows at LV we expect to be able to aggregate this information to provide a high-level understanding of where on the HV network power factors are likely to be poor. Based on this visibility we then expect to be able to better target our HV reactive power flow compensation work.

5. Section 7.5 discusses the use of smart meter data to enhance load profiles used in network planning activities. By extension, aggregated smart meter data could be used to highlight and upgrade overloaded equipment, which would decrease losses in addition to enhancing safety in general. At the same time, aggregated data could be used to form a robust picture of load distribution across networks, and highlight opportunities to redistribute load more evenly to decrease losses.

6. Smart meters will feature four-quadrant metering, which will help to understand the volume and timing of energy exported from customers' premises into the LV network. Once customer phase connections are known, this information can be used to aid voltage management to decrease losses, whilst it can also be applied to highlight parts of the network that can accommodate increased levels of distributed generation.

7. The impact that imbalance makes on network losses is often mitigated by the fact that loads tend to be highly variable in nature – large imbalances often do not persist for long periods. However, where distributed generation far exceeds customer demand on a single phase, imbalanced currents of a sustained nature will occur, leading to substantial increases in losses. Smart meter data can be used to identify such instances, and test the economic merit of mitigating measures.

8. Imperial College London indicates that substantial energy losses could be mitigated through 11kV feeder reconfigurations. Such feeder reconfigurations often carry a risk in the form of voltage excursions following switching operations. Having voltage excursions reported by smart meters could help DNOs to reconfigure feeders more often with more confidence.

Understanding the challenges and opportunities above enabled UK Power Networks to prioritise problems that require further attention in preparation for smart meter data. The next section further elaborates on the challenges.

5. Key Focus Areas and Actions

Given the understanding that has been developed during our international benchmarking exercise and the subsequent discussions that we've had with our peers within the electricity industry, we feel better positioned to prepare for the availability of smart meter data and to use this data to manage network losses.

We expect the work that we undertake over the coming years to be subtly different to the work that will be required once smart meter penetration is significant. It is however important to ensure that the work areas that we focus on next are compatible with those required longer term. Therefore, the main areas of focus that we plan to develop are as follows:

5.1 Data Privacy

DNOs need to clearly understand the potential to obtain detailed consumption data, particularly where realising benefits is hampered through the use of aggregated data. Additionally, DNOs also need to understand the level of aggregation that they have to deploy. Given that a trade-off exists between protecting customer privacy and the usefulness of the data to benefit customers, this area warrants dedicated attention in the immediate future. UK Power Networks will leverage work done by the Electricity Networks Association to inform our decisions in this regard.

5.2 Identifying Phase Connections

The second focal area relates to identifying the network phase that a smart meter is connected to. Irrespective of penetration levels, visibility of smart meter phase connectivity will only ever enhance what can be achieved through the use of the data that is provided. Certainly, if we wish to tackle phase imbalance in any meaningful way then identification of phase connection is essential.

Other work that we've undertaken during the first tranche of the LDR estimates that, along with poor power factor, large phase imbalances are a significant driver of losses in LV networks. Given that changing network usage will shift demand/generation profiles, we expect that phase imbalance will become more significant in future years. We also anticipate that establishing visibility of the phase connection will help us to improve the service offered to our customers. No longer will it be a case of targeting all customers that are supplied from a feeder which is known to have a supply interruption; we would be able to interact with those that are connected to the affected phase only.

5.3 Compensating for Gaps in Coverage and Meter Inaccuracy

The third area of focus relates to filling the data gaps that lower penetration levels will create. This focus will be particularly relevant during the smart meter roll out if we wish to use data from smart meters in the interim. The focus will also have value once penetration levels are significant as, with any gap, there will always be a level of assumption. At a future date, when the smart meter penetration level reaches 99%, the effectiveness of all the data associated with the 99% of customers being considered will still be affected by the validity of assumptions surrounding the 1% of customers for which smart meter data isn't available. Therefore, development and refinement of these gap-filling capabilities is imperative.

Once significant volumes of smart meter data are available, and we're confident that we can fill gaps through modelling or assumed profiles, it will become necessary to better understand the inaccuracies associated with the actual meters. Getting to an accuracy of ± 2% will be a significant improvement on our current position. Given that losses are estimated to sit within the range of 5-8% of energy distributed, an accuracy of ± 2% in this context is still significant. Therefore, to maximise the benefit delivered by smart meter data it will be necessary to understand whether it is possible to anticipate and compensate for metering errors.

UK Power Networks will continue to monitor smart meter penetration levels, and initiate a trial in a suitable area to address the challenges that were described in sections 5.1 to 5.3.

6. Conclusion

In undertaking our benchmarking exercise it became clear that other network operators have been using smart meter data to manage losses more effectively. We are confident that we will be able to apply the same principles to reduce losses; subject to comparable levels of data visibility being achieved.

Following the introduction, section 3 described international network operators' uses of smart meter data to reduce technical and non-technical losses. The evidence showed how aggregated smart meter consumption data can be compared to energy measurements from an upstream metering device to highlight irregularities

Section 3 next elaborated on international approaches to quantify and reduce technical losses. Other network operators primarily focused on DSR, Voltage Management and improving load imbalance. Following this, section 4 discussed our own proposals to decrease technical losses beyond international peers' proposals. In broad terms, our proposals focused on improved network design, mitigating load imbalance across phases and different network sections, addressing poor power factor, preventing overloads and better understanding the impact of low carbon technologies on our networks. This extension demonstrates UK Power Networks' commitment to drive smart meter benefits in support of the UK Government's "Three 20 Targets" commitment.

A number of challenges have been identified that need to be addressed to help realise smart meter benefits. In particular, the following items should receive focussed attention during the trials that UK Power Networks initiates:

- Finding ways to account for energy flows not registered by smart meters. Load flow calculations, based on detailed energy flows, will be required to attribute losses to specific network elements. Being able to quantify and attribute technical losses to specific network elements will aid engineering interventions to decrease technical losses, and enhance DNOs' abilities to detect causes of non-technical losses
- Using averaged consumption profiles to calculate technical losses with sufficient accuracy to locate causes of non-technical losses
- Understanding how data aggregation affects network loss calculations, and how to compensate for inaccuracies caused by aggregation
- Determining the extent to which smart meter inaccuracy affects DNOs' abilities to quantify technical and non-technical losses

UK Power Networks will continue to monitor smart meter installations across our networks, and we will invite interested organisations to participate in trials to address the challenges that we have identified.

7. Appendix 1: Benchmarking Results

7.1 Poland

Energa Operator[15]

Energa Operator conducted research to demonstrate the potential of smart grid solutions to reduce technical and “commercial” (i.e. non-technical) losses. Their work was conducted in Kalisz and Hel Peninsula. Reports in the public domain were somewhat vague in terms of specific technical details, but we were able to discern that:

- They were able to reduce losses in their project footprint by 10% on an annual basis
- That circa 90% of the cited loss reduction was attributed to network optimisation
- Circa 1% loss reduction was attributed to reductions in illegal energy consumption & energy consumption by metering equipment

Further information revealed that meters could help to balance networks, make consumption information visible to customers and detect (metering) errors[16].

Energa Operator started their smart meter implementation programme in 2012, and they had 109k meters in service at the time of reporting. Interestingly, they had access to smart meter data in 15-minute[17] intervals. A different source[18] revealed plans to cover 70% of energy transmitted to their customers with smart meters.

The overall project cost was estimated to be 1 billion PLN and would cover about three million customers within a time span of seven years, which indicated that smart meters only penetrated a portion of their overall network by the time that they began to publish findings.

Overall, they expect to decrease energy theft by 60%.

[15] Information retrieved from http://addgrup.com/news/energa-operator-data-from-smart-meters-helps-in-reduction-of-losses

[16] Information retrieved from http://addgrup.com/news/energa-operator-ami-and-smart-meters-a-closer-look

[17] Information retrieved from http://addgrup.com/news/case-study-ami-project-poland

[18] See http://yadda.icm.edu.pl/yadda/element/bwmeta1.element.baztech-32edacd8-de3c-42f8-80de-36403577a265/c/Zabkowski.pdf

7.2 Italy

Enel

Italy's large-scale smart meter installations began in 2006 and were completed in 2011. Enel installed 32 million smart meters in Italy during this time. Their strategy largely revolved around making customers aware of their own consumption patterns and thus motivating them to save money and energy.[19]

Having access to improved data related to consumers' habits enables Enel to run power plants more efficiently, while they are also motivated to address "rampant theft and other forms of fraud.[20] " Spiegel Online further noted that Enel made use of variable pricing to influence consumers' behaviour. Indications were that Enel would recoup their infrastructure investment in only four years.

Enel indicated that consumption in a test group fell by circa 4% compared to a control group[21] who had smart meters but no home display units (note that losses vary exponentially against consumption level). There were also indications that being able to "balance energy" for each transformer enabled them to detect fraud more accurately, and that their "success rate" had increased by 70%[22]. Commercial losses in their case referred to meter tampering, fraud, theft and meter reading errors.

7.3 Portugal

EDP and InovGrid

InovGrid is EDP Distribuição's "umbrella project" for smart grids. The project serves as a trial area to generate answers to several challenges, including the need for increased energy efficiency; the pressure to reduce costs and increase operational efficiency, the integration of dispersed generation and accommodation of growing electric vehicle loads.

Of particular interest amongst their work is smart meter trials conducted in Evora, where 80% of 37,000 smart meter installations were complete at the time of reporting[23]. EDP estimated, based on probabilistic representations of energy flows in their project footprint, that energy loss reductions of up to 10% are possible with the help of smart meter data.

Very importantly, there were indications that EDP had to validate data contained in their systems (such as customer phase connections) to realise the benefits that they claimed, (which adds cost and consequently, erodes the value of prospective business cases). Furthermore, they had access to 15-minute samples for LV feeders, 1-

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[19] See http://www.reuters.com/article/energy-efficiency-smartmeters-italy/europe-to-follow-italys-lead-on-smart-meters-idUSL5N0EA3HL20130530

[20] Retrieved from http://www.spiegel.de/international/business/energy-efficiency-how-italy-beat-the-world-to-a-smarter-grid-a-661744.html

[21] Information retrieved from a slideshow called "The Pilot Project for Enel Info +"

[22] Information retrieved from a report called "AMM Drivers in Italy or 'Why to become smart", published by Enel

[23] The report was dated 2011.

hour samples for individual residential customers, 15-minute samples for “other customers” and 15-minute samples for microgeneration plants.

EDP did not estimate loss reduction benefits for power factor improvement at LV, stating that this activity would require investment to install power factor correction equipment.

Table 3: Summary of calculated loss reduction benefits in EDP’s network

	MWh Loss / Loss Improvement	**% Loss improvement**
Total EDP losses in project footprint	225	
DSR-related loss reduction	9	4%
Loss reduction due to imbalance improvement	5.9	2.6%
Increased voltage to decrease losses	7.3	3.2%
Sum of loss reductions		9.9%

7.4 Canada

BC Hydro

BC Hydro indicated in 2013[24] that, before introducing smart meters, electricity theft amounted to about 7% of “residential load” in their networks. (This is substantially different to Sohn Associates’ estimate that circa 1% of energy distributed in the UK[25] is getting lost due to theft). BC Hydro further indicated that electricity theft led to about 100 premature transformer failures per annum amongst their ±300k transformers in service at the time. (Note that avoided repair costs strengthen any prospective business case).

From their footprint containing 1.9 million customers, they estimated that they could increase revenue by $802 million per annum due to smart meter information assisting in their theft detection efforts. From the sum total of theft discovered & quantified in one publication, they assigned 45% to only five cannabis growers, and the remaining to 34 individual homes.

They further used “feeder meters” to measure energy flows on overhead HV feeders, and they reconciled energy measurements from these meters to aggregated smart meter data beyond the point of measurement to detect discrepancies.

Another report[26] provided more detail about their success story: “With a combination of smart meters, existing SCADA devices, Awesense’s TGI sensors (i.e. feeder meters) and analytics software, BC Hydro went after the illegal grow operations. In three years, they reduced their losses due to theft by 50 %”. (It thus becomes clear that

[24] Information retrieved from an internet publication called “Insights into BC Hydro’s theft detection solution”

[25] Report retrieved from https://www.ofgem.gov.uk/ofgem-publications/43519/sohn-overview-losses-final-internet-version.pdf

[26] Report retrieved from https://www.awesense.com/blog/2017/1/23/bc-hydro-success-story

smart metering represents only a portion of the overall investment required in their case. Nonetheless, it is a critical and valuable enabler).

7.5 International Peer

UK Power Networks studied publications to compile this report, but one international peer agreed to share information directly. This organisation incentivizes customers to reduce load at specific times, rather than increasing prices to reduce demand. They have specific agreements in place to facilitate these interactions. Their incentives are useful to influence air conditioning load especially. Their approach is valuable, because customer acceptance of price increases to reduce demand could be challenging.

The second item discussed was Voltage Management. This Network Operator uses targeted smart meters to guide their control room operations when generation constraints appear on the network. To date, they have relied on manual intervention from their control room to manage voltage constraints.

The last item discussed was the use of smart meter data to enhance planning load estimates. This organisation uses smart meter data to enrich and extend the load profiles that feed into their network planning processes. They are able to tell if air conditioning is present in customers' loads, which aids their network modelling and planning.

7.6 USA

Baltimore Gas and Electric Company (BGE)

In 2014, Baltimore Gas and Electric Company[27] launched complex algorithms across two million sensors and devices in their territory to identify and reduce unbilled energy usage. In the first six months they have identified non-technical losses generating $2.8 million in economic benefit from verified fraud cases. During the same timeframe they were able to detect smart meter health issues with a 99% accuracy rate.

Further research revealed that the University of Illinois developed the statistical framework that others generally refer to as “complex algorithms to detect fraud”. They published a paper[28] called “F-DETA: A Framework for Detecting Electricity Theft Attacks in Smart Grids” to promote their theory and methodology. They used Kullback-Leibler (KL) Divergence[29] to test consumption patterns against established patterns to identify discrepancies. The key finding in this instance is that this technique, to date, has not been deployed in instances where data is aggregated.

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[27] Information obtained from https://c3iot.com/case-study/driving-grid-efficiency-and-revenue-protection-efforts/

[28] The publication was retrieved from https://www.perform.illinois.edu/Papers/USAN_papers/15BAD04.pdf

[29] http://web.engr.illinois.edu/~hanj/cs412/bk3/KL-divergence.pdf