Smart Meters to Monitor Power Quality at Consumer Premises

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Abstract

Power quality (PQ) in the low voltage (LV) network and consumer premises, especially homes, is largely unmonitored and, anecdotally, is not well understood. Specific monitoring typically takes place only after consumer complaints have been laid or abnormalities noticed. This paper investigates the possibilities, opportunities, and challenges around leveraging the advanced metering infrastructure already installed or being rolled out across New Zealand to monitor PQ in the LV network. The research summarised in this paper has been carried out as part of the GREEN Grid programme.

An introduction to smart meters and advanced metering infrastructure (AMI) and the potential benefits they bring to multiple sectors of the electricity industry is given. The progress of smart meter deployment in New Zealand reviewed, an overview of PQ parameters which may be of interest to electricity distribution businesses is presented, the features and capabilities of different models of smart meters presented, and discussion given to a number of potential issues around such usage. Alternative options for LV PQ monitoring are also identified.

It is found that while many of the over one million smart meters deployed in New Zealand have the ability to measure and log steady-state voltage, voltage sags/swells, and harmonics to a basic level, there is a range of other factors which need to be considered and challenges overcome before electricity distribution businesses (EDBs) are able to make effective use of PQ data from AMI.

1. Introduction

Power quality (PQ) in the low voltage (LV) network and consumer premises, especially homes, is largely unmonitored and, anecdotally, is not well understood. Specific monitoring typically takes place only after consumer complaints have been laid or abnormalities noticed. This paper investigates the possibilities, opportunities, and challenges around leveraging the advanced metering infrastructure already installed or being rolled out across New Zealand to monitor PQ in the LV network. The research summarised in this paper has been carried out as part of the GREEN Grid programme.

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2. Introduction to Smart Meters and AMI

The development of 'smart meters' or, perhaps more broadly, advanced metering infrastructure (AMI) holds a range of benefits for multiple facets of the electricity industry beyond the simple revenue metering role of traditional electro-mechanical meters. Of particular interest in this paper is the ability of AMI to provide power quality (PQ) information to both consumers and electricity distribution businesses (EDBs). It has been recognised by many, including parties involved in metering activities within the industry, as well as groups such as CIGRE, that "In the future networks, the Advanced Metering Infrastructure (AMI) will play a bigger role in PQ monitoring than it plays today" [1]. There are, however, a number of technical, regulatory, and economic hurdles which need to be overcome if these technologies are to be utilized on a widespread scale.

It is first necessary to define what is meant by the term 'smart meters'. Opinions around the definition of smart meters or advanced metering infrastructure differ, however there are three key reoccurring attributes. These are time-of-use (TOU) consumption recording, remote meter reading capabilities, and two-way communication[1] [2] [3]. In addition to this base functionality there are also a number of other capabilities which 'smart meters' may offer including [2]:

- Tamper and zero-reading reporting
- Display of real time consumption data to consumers with in-home displays
- Metering of both active and reactive, import and export, quantities
- Remote disconnection and reconnection of consumers
- Load control
- Outage reporting
- Power quality reporting

These functions all have the *potential* to deliver benefits to multiple parties in the electricity industry including retailers, distributors, and consumers. Benefits include the potential for consumers to reduce consumption, reduced metering costs, and the collection of data to allow smarter and more targeted network investment. The extent to which these potential benefits are actually realised is largely dependent on how AMI is actually implemented in New Zealand.

[1] Distinguishing AMI technology from advanced meter reading (AMR) technology which allows for the remote reading of meters but not the remote configuration and programming which the two-way communication of true AMI provides.

The deployment of AMI in New Zealand differs from the majority of overseas deployments in that it has been driven by market participants rather than a regulator, as has been observed overseas [3]. It should also be noted that New Zealand differs from many overseas jurisdictions in that the provisioning of metering services is driven by a competitive market as opposed to a monopolistic provision of metering services. Meridian's roll out of AMI initially as a trial in the Hawkes Bay, followed by Christchurch, by then subsidiary ARC Innovations appears to have been a catalyst for the development of AMI in New Zealand and is an example of innovation occurring when left to the market.

Being market driven rather than regulated, the reasons for installing AMI have varied from those overseas. In particular New Zealand has had an effective load control system (ripple control) since the 1950s [4], as such load control is not a large driver of AMI as it has been overseas where load control is desired in order to defer network investment. This limiting of peak demand can also reduce the need for thermal generation and reduce greenhouse gas emissions. Improved accuracy of meter readings and billing are also oft-cited drivers of AMI deployment overseas as well as a revenue protection measure by reducing electricity theft and fraud [5].

One driver of for AMI in New Zealand however has been the metering interim compliance deadline of April 2015 which was agreed upon by the industry in 1999. By this date all meters at residential and small commercial premises were to be fully certified. Many retailers and meter owners have taken this opportunity to install new fully certified advanced meters rather than certifying their existing traditional meters [5]. At the same time they have used recertification as an opportunity to install smart meters to reduce their cost to serve.

Retailers hold responsibility for metering and as such it has been argued that the AMI deployed to date has been deployed with only the interests of retailers accounted for. An unregulated roll out has the risk that it will only benefit the retailers which are driving the deployment. This is not is not necessarily the case however, and significant capabilities exist for additional benefits within New Zealand's deployed meter stock which are discussed later in this paper. This can at least in part be attributed to the fact that New Zealand makes up a very small portion of the global AMI market and as such cannot materially affect trends and developments in the technology, so New Zealand gets the same technology as in countries where regulation requires capabilities beyond those necessary for only revenue metering.

AMI has been recognised to hold potential for network companies, particularly when meters have power quality measuring capabilities. Halliday and Urqhuart [6] as well as the Electricity Commission [5] identify a number of benefits AMI can bring to EDBs:

- The network business can better understand what is happening on its network – areas of overloading or underutilization can be identified.
- It can prioritise remediation work with a great deal more certainty because it knows where the worst areas of supply are located;
- Overloading can be minimised by monitoring of voltage levels;
- The network business does not need to be purely reactive to customer complaints;
- Trends, such as increases in harmonics, can be identified as data is collected over several years.
- Faulty equipment, such as a defective voltage regulator, can be identified from the change in voltage levels from the norm;
- Even with SCADA, pockets of the network can remain unknowingly without power after a major event such as a storm. Comprehensive AMI can help to identify these areas;

- Comprehensive power quality indices could be provided to regulators to assure that power quality is being managed adequately.

Progress of roll out in NZ

As of 31 December 2014, data from the Electricity Authority's Electricity Market Information database reports AMI meters at 62.3% of the 1.75 million residential ICPs in New Zealand. October 2014 data shows a 6 month rising trend of approximately 17,000 AMI installations per month [7].

The penetration of smart meters shows significant geographic variation. Figure 1 presents the percentages of residential ICPs with Smart Meters as at 31 December 2014.

There are two significant players in the provision of AMI assets and services in the New Zealand market, though the EA registry data still recognises Arc Innovations as a separate entity to that of Vector's AMS/AMA. Figure 2 presents the market share of AMI ownership at residential ICPs.

What is being observed in the AMI market space is a convergence to only a small number of different meter models being utilised. This outcome is in its own right of interest given the unregulated roll-out, and with respect to this paper gives a clear focus on which models this paper should focus on with respect to their capabilities for the measurement of PQ.

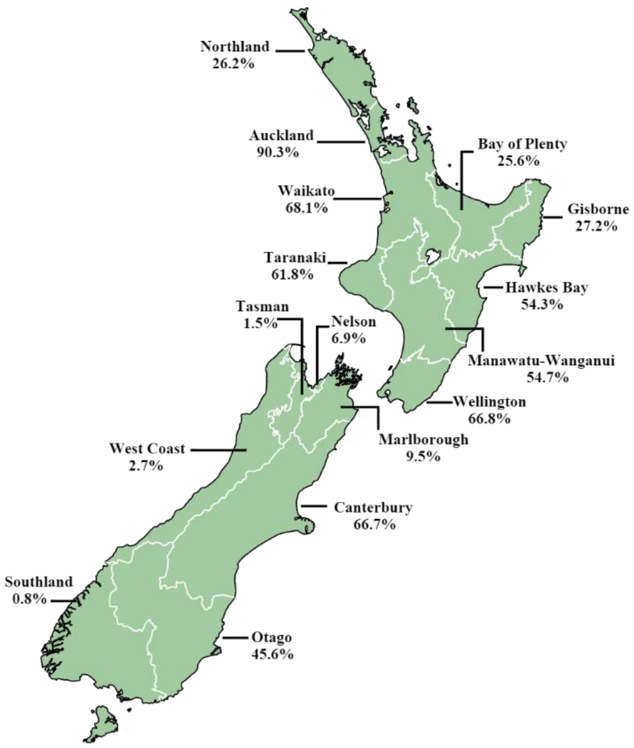

Figure 1: Percentage of residential ICPs with AMI as at 31 December 2014 (Image adapted from [9]).

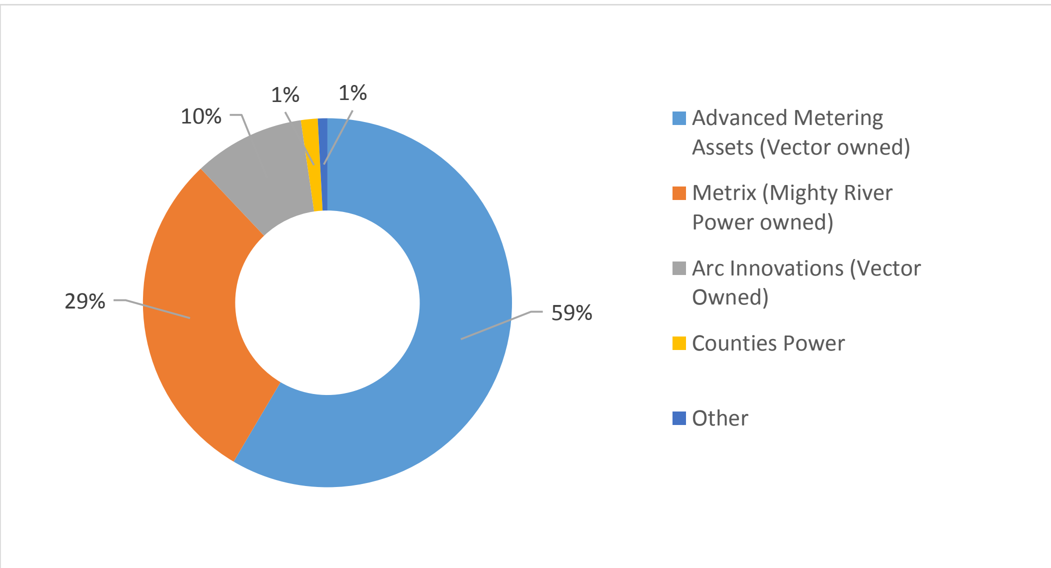

Figure 2: Market Share of AMI Ownership at Residential ICPs as at 31 December 2014 (Data from [8])

An estimate has been made of the numbers of smart meters from different manufacturers deployed in New Zealand. This estimate is presented in Figure 3. It is expected that the proportion of Landis+Gyr meters will rise with forthcoming AMI rollouts.

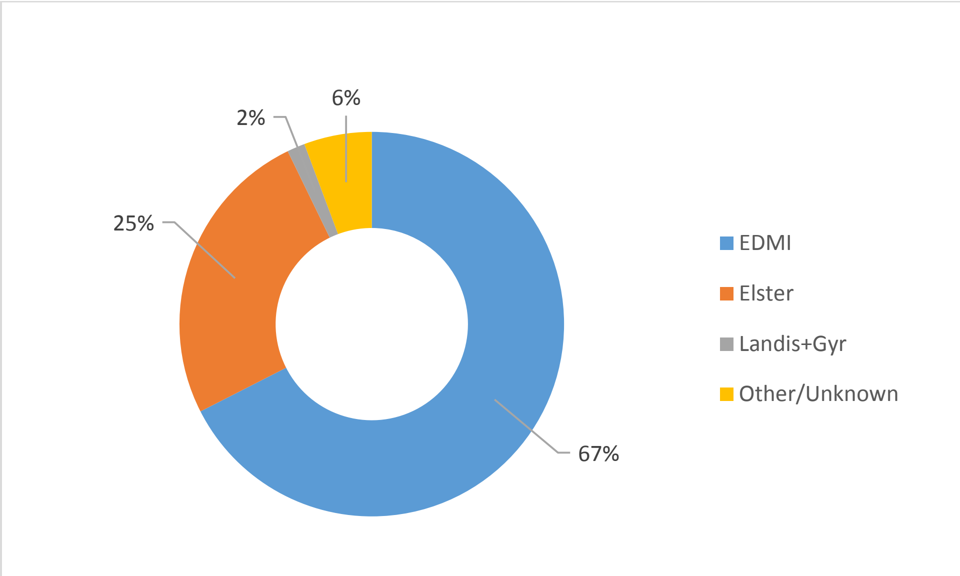

Figure 3: Estimated Breakdown of Smart Meter Brands Deployed in New Zealand as at 31 December 2014

3. Power Quality at Consumer Premises

Power quality at individual consumer premises is not something that is widely known or studied. Typically measurement of power quality variables at consumer premises take place only in response to complaints being made or issues being apparent [9]. As a consumer, however, it is at the consumer premises that power quality is of the greatest importance, and the point at which the EDB's connection contract and service targets apply. Poor PQ has the potential to cause a range of issues affecting both consumer loads and the distribution network, which are covered in more detail in [10].

With the development and growing penetration rates of new technologies such as photovoltaic generation and electric vehicles, voltage profiles on LV feeders are likely to be affected. Distribution networks are tightly regulated to deliver voltages to consumers within an acceptable range to ensure compatibility with consumer loads connected to the network. Non-conformance of the supply voltage has a high societal cost as it impacts the lifetime, efficiency, and performance of consumer loads [11]. The importance of measurement at the LV level is only going to grow as penetration of these technologies grows in order to understand the effects that they are having on both feeder voltage profiles, as well as wider PQ variables. A number of PQ aspects have been identified as being of the greatest interest to an EDB attempting to understand PQ and its implications in their LV network [9] [12]. They are:

- Outage reporting
- Steady-state voltage levels
- Sags/swells
- Flicker
- Harmonics

4. Capabilities of Smart Meters

There are a number of different meter models in use and being deployed across New Zealand. The majority of these meters are manufactured by EDMI, Landis+Gyr, and Elster, though it must be noted that there are other manufacturers' meters also in use. Table 1 presents the most common meters in New Zealand and their capabilities with respect to the measurement and recording of PQ variables.

Table 1: PQ Measurement Capabilities of Common AMI in New Zealand[2]

		EDMI Genius[3]	**EDMI Atlas**	**Landis+Gyr E350**	**Elster gREX**
Basic Load Survey Quantities	**Voltage**	Instant., min., max., average	Instant., min., max., average	Instantaneous	Instantaneous
	Current	Instant., min., max., average	Instant., min., max., average	Instantaneous	Unknown
	Power	Instant., min., max., average	Instant., min., max., average	Instantaneous	Unknown
	Phase Angle	Instant., min., max., average	Instant., min., max., average	Instantaneous	Unknown
	Sampling interval	1 second - 1 month	1-60 minutes	10/15/30/60 minutes	5/15/30/60 minutes
Voltage Sag/Swell	**Resolution**	5 cycles	5 cycles	1 second	32 cycles
	Sag Start	0-255% V_n	0-255% V_n	0-300 V	192-288V
	Swell Start	0-255% V_n	0-255% V_n	0-300V	192-288V
	Hysteresis	Yes	Yes	Unknown	No
Harmonics	**Current THD**	Yes	Yes (Except MK10E)	Pending firmware update	No
	Voltage THD	Yes	Yes (Except MK10E)	Pending firmware update	No
	Individual harmonic measurement	Yes (Up to 50th)	No	Pending firmware update (Up to 25th)	No

If these capabilities are to be used and the PQ variables measured, the meters must also have sufficient storage capability. This is not generally expected to be an issue, with the EDMI

[2] Some capabilities are dependent on deployed firmware version and system configuration
[3] Targeted at commercial and industrial (C&I) metering installations

meters, for example which have sufficient memory for a 365 day PQ log with half hourly recording. If consumption is to be recorded at a shorter interval than the present half-hour periods for revenue purposes, available storage for PQ monitoring may be limited.

In order for the previously discussed benefits to be used, it is not only the capabilities of the meters themselves which must be considered, but also the capabilities of the communications networks and back office systems.

There are two common communication technologies in use with these meters: cellular communication and a meshed radio solution. Meshed radio networks from multiple vendors are in use in New Zealand. There are benefits and drawbacks to the two different technologies. However the greatest difference of note is that last gasp outage reporting is generally implemented with meshed radio solutions as the energy requirements from the storage capacitors in the interruptible power supply are lower than the requirements of a cellular communications modem.

5. Discussion on AMI

5.1 – Data Volumes & Communication

A potential issue raised by the collection of PQ data from AMI is the substantial increase in the volume of data created over simple half hour revenue metering. This data volume affects not only the storage required in the meter, but also communication system, whether cellular or meshed radio networks, as well as the back office systems and data warehousing requirements. The impact of PQ monitoring on these systems is likely to be highly dependent on the data recording methodology employed, of which there are several options.

The first is real-time event reporting where a meter communicates any excursion outside of specified PQ thresholds immediately. This methodology has significant potential impacts on the communication systems, both in terms of overloading, for widespread PQ events, as well as increased costs and network utilization. A potential issue with this methodology arises with sites that are teetering on the edge of a set threshold which would result in the meter transmitting exceptions near continuously.

A second option is reporting power quality indices at a set time interval, perhaps nightly, rather than individual event reporting. Sites with poor indices could, if desired, be configured to then record and report PQ events in greater detail. This option reduces both communication requirements as well as data warehousing requirements [6].

The large volumes of data also present potential problems to the EDBs, which could benefit from the data. For many there is uncertainty around whether the data has any usefulness at all, or at least any greater usefulness than what can already be gained from EDBs' existing systems. Moreover, the question is also raised whether there is any greater benefit from having data from every ICP on a feeder, compared to a representative sample from the transformer, midway point, and end of a feeder.

5.2 – Data Ownership

Issues also lie around the ownership of data obtained from smart meters and the provision of that data to other parties. Some retailers explicitly specify in their agreements with customers that all smart metering data belongs to the retailer, while other do make mention of data ownership. Generally however, the data is owned by the metering service provider and commercial arrangements exist for the provision of that data to other parties. From a philosophical point of view, many would argue ownership of the data should be with the customer, since it is their load being measured. They also should be the ones that have a say in who has access to the data as this has important information that can be missused (i.e. when the premises are empty).

There is no incentive for a metering service provider to discriminate in providing data to EDBs. A metering provider affiliated with a retailer (which is not in competition with any EDB) has no incentive to discriminate when data is requested by any EDB. Likewise, a metering provider affiliated to an EDB (which is not in competition with any other EDBs) also has no reason to discriminate.

If, and when, EDBs pursue the use of AMI data then greater discussion around this topic can be expected and commercial agreements negotiated.

5.3 – Load control

At present mass market loads are largely only actively controlled by EDBs through the established ripple control systems. Many smart meter installations also have load control capabilities. This has the potential to change the way that load control is undertaken as it offers the retailer the opportunity to control load for their own purposes, or even to offer third party load control. Issues then arise if ripple control is still in use as to who has priority control of load, and the effects that this may have on customers, along with the potential for significant confusion as to the exactly quantities and location of loads that are controllable by a particular party.

These capabilities also give rise to the potential for greater use of residential demand response and control of load at a much more granular level than widespread ripple control schemes.

Possibilities have also been raised around the use of smart meter load control by retailers for credit control. If a customer is in debt the retailer could configure their meter so as to switch off their power if a limit set on instantaneous consumption is exceeded. However, it is unlikely this will occur as there may be people in a home dependent on an electricity supply for medical purposes.

6. Alternatives

The specifications of a number of Home Energy Management Systems (HEMS) were studied in an attempt to determine whether any were capable of measuring PQ variables. A list of HEMS was obtained from [13]. The fundamental issue with the use of HEMS is that the majority of systems rely simply on a current clamp around the incoming phase conductor and assume nominal voltage for their power usage calculations. As the majority of PQ variables of interest are voltage related, they are unable to be measured.

There are some HEMS however that do include voltage measurement such as the TED5000 [14] or the eGauge systems [15]. These devices are however at the upper end of the scale in terms of price and installation complexity. They are more typically targeted at either complex home installations (distributed generation) or commercial and industrial energy usage monitoring installations, rather than typical household situations.

Typically these systems are largely oriented around power usage monitoring and little other functionality. The smart meter variants discussed above offer far greater capabilities for the monitoring of PQ than all but the most expensive and well featured HEMS. It thus seems reasonable to conclude the HEMS do not and will not, provide suitable capabilities for wide spread PQ monitoring in LV networks.

Another slightly different, but similar range of devices, are in-home displays (IHD) which connect to smart meters (typically using Zigbee communications) to provide a display of consumption in an easily accessible and viewable location in the home. These are not widespread however, and are unlikely to be in the foreseeable future due to many smart meters being deployed without this capability [3]. These device are also largely being superseded by using smartphones as an access portal to electricity consumption information, and the use of the internet and Wi-Fi technology for communications within the home and smart appliances [16].

7. Conclusion

The idea of using the AMI being deployed nationwide to measure aspects of PQ for EDBs has been explored. While many of the meters being used have the capabilities to measure and log steady-state voltages, voltage sags/swells, and harmonics to a basic level, there a number of other factors that must be considered.

There is a lack of clarity over what data and in what format, timeframe, and level of aggregation would be useful to EDBs. There is also a lack of clarity over exactly how they could utilise that data to improve their network and their business. While the basic capabilities exist with the meters it will not be until the benefits to EDBs can be properly quantified that the development of these capabilities by metering service providers will be fully realised.

This lack of clarity is partly due to the EDBs not having adequate data from smart meters to develop useful applications. Without the data it is difficult to develop the algorithms. Without the algorithms it is difficult to demonstrating the possible benefits that the EDBs receive. Therefore the EDBs are not prepared to spend significant money on obtaining the data that is of unknown benefit. However the authors are aware of recent research projects that have used smart meter data, and are starting to demonstrate the benefit of it to EDBs.

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