THE APPLICATION OF ADVANCED DATA ANALYTICS TO SMART METER DATA

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ABSTRACT

This paper focuses on the development of advanced data analytics algorithms using 5-minute snapshots of current and voltage data available from smart meters, in particular the detection of high resistance connections between the supply substation and the customer's premises. When results of the algorithm are superimposed on the topology of the supply network as captured in the Geographical Information System (GIS), locations of such high resistance connections can be visualized and the impending defects proactively managed.

INTRODUCTION

Distribution Network Service Providers (DNSPs) in the state of Victoria, Australia, have completed the rollout of smart meters in a program mandated by the state government. Known as the Advanced Metering Infrastructure (AMI) program, it covered all customers consuming less than 160MWhr per annum, essentially all residential customers, small commercial and industrial enterprises. About 2.8 million smart meters were installed between 2009 and 2014.

Since the completion of the AMI program, Victorian DNSPs have been investigating the use of the network sensing functions of the smart meters to improve visibility of their Low Voltage (LV) networks, and to implement network diagnostics and asset condition assessment. An initiative undertaken by Jemena Electricity Networks involves the collection of 5-minute snapshots of voltage, current and power factor data from each smart meter and the application of advanced data analytics (ADA) to those data.

MOTIVATION FOR ADA

Electricity Transmission and Distribution utilities worldwide are experiencing significant disruption to their traditional business model of building the infrastructure required to transmit electricity from large, centralised power generation stations to the end use customers. With the advance of distribution energy resources (DER), many customers are now capable of supplying their own energy needs, with the electricity grid relinquished to a backup role when DER are not available. New customer use cases are emerging, such as peep-to-peer energy trading, virtual power plants and demand response, which require the electricity grid to behave in a manner very different to its traditional role. Utility business model would need to evolve if it is to be successful in the new energy paradigm.

In Australia grid-connected roof-top photovoltaic (PV) systems has become a common occurrence. With a total electricity customer base of 10.5 million, there are now over 2 million residential roof-top PV systems, mostly connected to the LV network. Majority of these PV systems are exporting back to the grid at midday, when generation is at its peak and consumption generally at its lowest. The impact of this "reverse" power flow is localised power quality issues (over voltage, flicker, phase unbalance) and asset overloads, while at the system level power system stability becomes an issue when PV (and other intermittent energy sources) displace the more predictable synchronous generation.

To manage the intermittent PV generation, Australian distribution utilities need to improve management of their LV networks. A fundamental requirement is to increase LV network visibility as the saying goes, 'one can't solve a problem that one can't see'. Through ADA, network data collected by smart meters provide a platform to increase LV network visibility.

ARCHITECTURE FOR DATA COLLECTION

The 5-minute voltage and current snapshots are taken and stored in the Network Interface Card (NIC) of the smart meter. The data is collected during the routine 4-hourly reads of the smart meter by the Network Management System (NMS). It is possible to increase the resolution and frequency of the data collection however a careful trade-off is required due to the limited bandwidth of the Radio Frequency (RF) mesh communication network deployed between the smart meters and the Access Points. A schematic of the Jemena's Advanced Metering Infrastructure is shown in Figure 1.

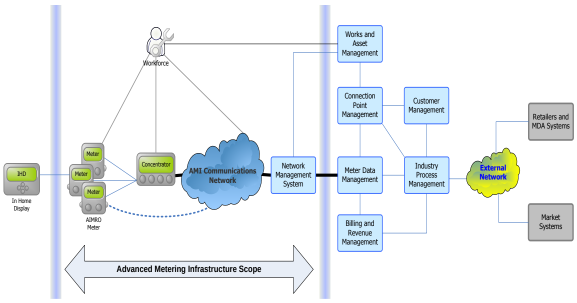

Fig.1. Jemena Advanced Metering Infrastructure

Additional data, such as network topology data from the Geographical Information System (GIS), is also collected.

All the data is pre-processed and passed to the analytics server where it is analysed using algorithms developed in the R programming language.

A high level architectural diagram is shown in Figure 2.

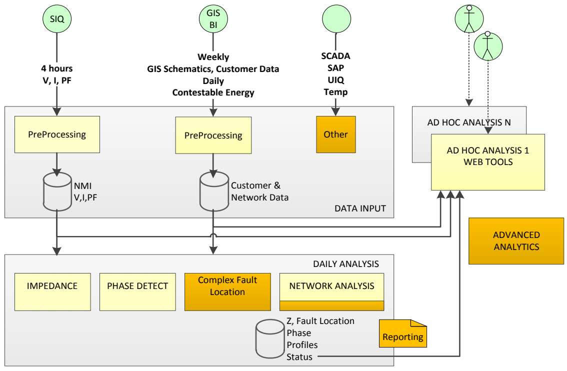

Fig.2. High level architectural diagram of the Jemena data analytics setup

ADA APPLICATIONS

Jemena believes there is a wealth of network and customer information that can be distilled from the analysis of smart meter data. Based on business priority, three ADA applications were selected for development between 2016 to 2018. These applications are customer phase identification, power quality analysis and supply impedance measurement. The application of supply impedance measurement is covered in more details in this paper as it improves the health and safety of Jemena's customers.

Customer Phase Identification

Historically Jemena did not have good record keeping of its LV network. Out of its 335,000 residential customers, approximately half do not have information on which phase (R, W or B) they are connected to. For the other half, there is significant doubt in the accuracy of the phase connection information that is now captured in GIS. The lack of customer phase connection presents several significant issues in the new energy future:

- Sub-optimal asset utilisation as loads/generation could cause overloading in one/two phases while the other phase(s) are under-utilised;
- Unbalance between phase loads can cause excessive current to flow in the neutral conductor, leading to health and safety hazards;
- Generation export of a DER, into the phase it is connected to, will cause localised voltage rise unless the generation is absorbed by adjacent loads in the same phase;
- Hosting capacity of LV network for DER is difficult to assess and Jemena has to constrain the output of new DER based on conservative estimates.

By applying cross correlation technique on the 5-minute voltage snapshots (Figure 3)[1], Jemena has successfully identified the phase connection of majority of its single-phase customers.

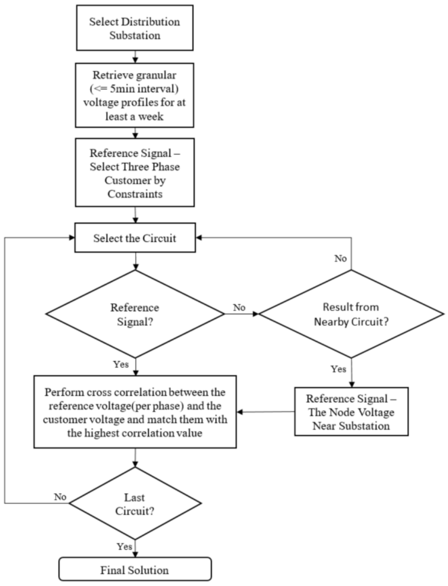

Fig.3. Flow chart of phase identification based on cross correlation

Power Quality Analysis

Once customer phase connection is known, Jemena proceeds to develop an analytics algorithm that estimates the phase voltages and currents at each distribution substation and its LV feeder runs, using 5-minute snapshots of voltages, currents and power factor at each AMI meter location, and network data from its GIS. Example outputs of the power quality analysis are shown in Figures 4 to 6.

Fig.4. Visualization of a LV network with customer phase colouring

Fig.5. Estimated voltages and currents at a 22kV/415V distribution substation

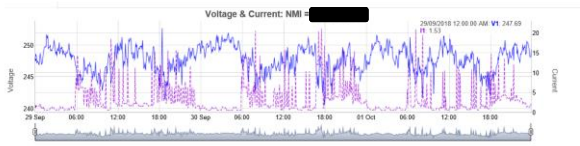

Fig.6. Voltages and currents for a customer connected to Blue phase of the same distribution substation

The visualization provided by the power quality analysis tool is very powerful in that it reveals not only the power quality issues of LV customers (such as steady-state over and under voltages, 3-phase voltage and current unbalance) but it also highlights how the issues are experienced by customers supplied from the same LV distribution circuit/distribution substation at the same time instant. This provides additional insight of how the voltage non-compliance could be rectified. Load unbalance between the three supply phases, for example, could give rise to customers experiencing low voltage on one phase while customers on the other two phases could have normal or even high voltages.

Future version of the tool will include modelling tools so "what-if" scenario can be run before connection of new PV customers and before load re-balancing is carried out.

Supply Impedance Measurements

Principle of supply impedance measurement

By measuring the change in voltage due to a change in customer load current, the impedance from the supply source to the customer connection point (at the smart meter) can be determined. The majority of this supply impedance is made up of the LV network from the distribution substation to the smart meter connection point. The principle of supply impedance measurement is shown in Figure 7.

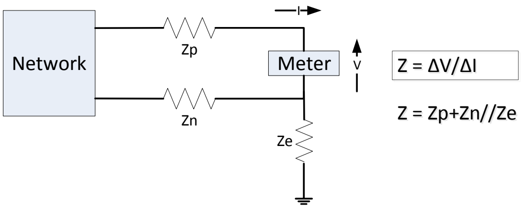

Fig.7. Principle of supply impedance measurement

In practice, the circuit is more complex due to many customer loads connected to the same phase. By applying statistical analysis to the supply impedance data, nominal daily value of supply impedance at each customer connection point can be determined. A larger than normal supply impedance indicates that there is a high resistance connection in the supply circuit. This will affect the customer's quality of supply as a larger voltage drop will be experienced when the load current is increased. More importantly, if the high resistance connection is in the return path of the load current, a potentially hazardous situation arises where a customer can experience an electric shock when he contacts any metallic object inside his house that is bonded to the local earth.

Normal range of supply impedances

Figure 8 is a histogram showing the supply impedance measurements of Jemena's 335,000 LV customers. It can be seen that 60% of the customers have supply impedance ≤ 0.5 Ohm and 90% of the customers have supply impedance ≤ 1 Ohm. From a qualitative perspective, a maximum supply impedance of 0.5 Ohm is considered marginally acceptable as this gives a maximum voltage drop of approximately 20V when a 10kW load is drawn by a customer (e.g. a large air conditioner).

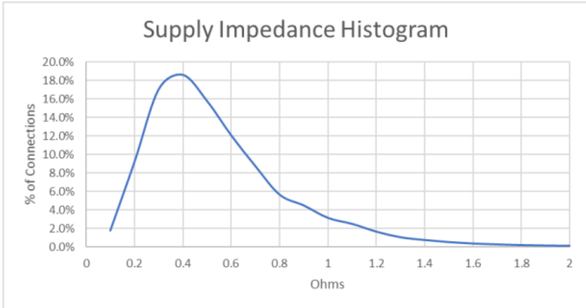

Fig.8. Variation of supply impedances for Jemena's 335,000 AMI meters

From theory to practice – proof-of concept trial

In the early stage of establishing Jemena's data analytics platform, 5-minute snapshots were obtained from a limited number of customers (approximately 5,000). Jemena ran the supply impedance algorithm for these 5,000 customers using one week of data. Three customers were found to have supply impedance over 2 Ohms. Crews were dispatched to perform field verification. Table 1 summarises the results of the investigation:

Table 1. High supply impedance investigation results from proof-of-concept trial

Case	Supply impedance (Ω)	Field finding
1	3.6	Broken neutral screen on LV service cable 
2	2.2	Burnt connection at facia connection point 
3	4.8	No visible damage from Street. Customer side fault identified by performing Neutral Service Test

From theory to practice – full-scale rollout

In the middle of 2018 Jemena was ready to roll out the result of its supply impedance analytics to all its 335,000 LV customers. The initial focus was on rectifying locations where the supply impedance was found to be above 2 Ohms. These high impedance cases justified the use of Jemena's Faults and Emergency process as they were considered to pose significant health and safety risks to customers. The location of the supply impedance measurement meant that the fault could either be on Jemena's or customer's asset so a well-prepared customer communication plan was put in place. The communication plan was also required to cover additional sensitivity of customers with life support or sensitive load.

The field rectification process started in the first week of October by allocating the cases to the Faults and Emergency crews whenever spare capacity was available. By the end of 2018, 90 cases have been attended to, all but one were found to have defects. The high accuracy of the analytics prediction has been very encouraging!

Next steps in supply impedance analytics

While the current Faults and Emergency process is considered appropriate for cases of high supply impedance, a different business process is considered necessary when Jemena extends field investigation and rectification to other cases:

- Jemena would like to progressively extend investigation to cases where the supply impedance is between 1 to 2 Ohms. This will significantly increase the number of cases to be investigated and stretch available operational resources;
- Rectification work is generally more efficient when it is planned. A planned approach is preferred over the Fault and Emergency process when the rectification involves replacing/repairing underground assets or when the analytics result is lower than 2 Ohms;
- Regulatory requirement for customer outage notification is not incorporated in the Faults and Emergency process, and should not be applied in cases where emergency response is not warranted.

It is believed that high resistance connections can develop over time. The advantage of data analytics is the supply impedance result can be trended over time and an appropriate 'trigger' found when field action is considered appropriate.

Benefits of supply impedance analytics

The advanced analytics application provides benefits to both Jemena and its customers.

Jemena will reduce its current Neutral Service Testing, a maintenance program that sees service neutral of each customer tested once every ten years. This results in operational saving.

Jemena will reduce the scope of its proactive service line replacement program as it implements continuous monitoring of supply impedance trends over time.

An improved safety outcome has been delivered to Jemena customers, for defects on both Jemena and customer assets.

CONCLUSIONS

There is an increasing demand of residential customers wanting new forms of energy services from their network connections, from connection of DER to charging of their electric vehicles. Majority of these customer connections are on the LV network, outside the reach of traditional Supervisory Control and Data Acquisition (SCADA) systems, therefore not visible to distribution utility engineers. ADA applied to smart meter data can provide LV network visibility. While this paper focuses on the use of ADA for asset condition monitoring, there are other use cases that are being developed to support new energy services that customers demand. This is an evolving area that holds great promise to support distribution utilities as they move into the new energy future.

Acknowledgments

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