A "BIG DATA" CHALLENGE – TURNING SMART METER VOLTAGE QUALITY DATA INTO ACTIONABLE INFORMATION

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ABSTRACT

This paper provides analysis of over and under voltage events captured by smart meters. Using data analysis techniques, the relationship of voltage events is analyzed with respect to ambient temperature, times of the day, days of the week, duration, magnitude and embedded generation status. Clusters of voltage violation sites are grouped to upstream supply distribution substations and zone substations. The analysis forms the basis of proactive voltage improvement that can be undertaken by the supply utility.

INTRODUCTION

Jemena Electricity Networks (JEN), an electricity distribution company in the state of Victoria, Australia, is currently undertaking a government mandated program to roll out smart meters to 310,000 residential and small commercial consumers. 50% of the smart meters have been installed by December 2012, with the full rollout scheduled to complete by the end of 2014.

These smart meters capture 30-minute energy usage data (import and export) and report to centralized computer systems via a two-way communication infrastructure. The smart meters also monitor steady state voltages. With the installation of smart meters, voltage sensing is progressively available at Low Voltage (LV) supply points of the electricity distribution network. While the availability of supply voltage data is a welcoming development, JEN is now obligated to investigate and correct non-compliance as revealed by the smart meters.

DESIGN OF THE ELECTRICITY DISTRIBUTION SYSTEM

Fig. 1 is a simplified representation of the electricity supply system in the state of Victoria, Australia. The power stations are connected by the transmission network to the terminal stations. At the terminal stations the transmission voltages are stepped down into sub-transmission voltages. The distribution companies take supply from the terminal stations and distribute to end customers through further voltage transformation at zone and distribution substations. It is noteworthy that the distribution companies generally run a 4-wire low voltage distribution network from each distribution substation, which can supply up to 150 customers.

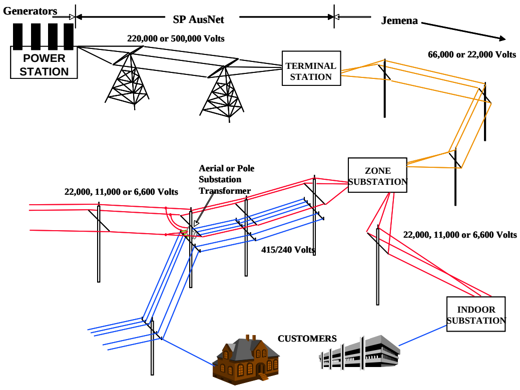

Figure 1 - Typical Electricity Supply System in Victoria, Australia

On-load tap changers and automatic voltage regulation are applied at the power stations, terminal stations and zone substations, and Medium Voltage (MV) in-line voltage regulators for long rural lines. In suburban distribution network, voltage regulation at the zone substations would be designed to allow for voltage drop on the MV distribution line, the distribution transformer and the LV feeder runs, to ensure that the last customer at the end of the LV feeder will be supplied with sufficient voltage during peak load period. There is therefore a tendency to design for a supply voltage at the high end of the prescribed range.

CONSEQUENCES OF VOLTAGE NON COMPLIANCE

Public electricity supply networks are required to deliver voltages within narrow ranges. This ensures that the supply voltages are compatible with the design parameters of consumer electrical equipment. Supply voltage non-compliance has high societal costs as it impacts on the efficiency, performance and life expectancy of electrical equipment.

Except for large commercial or industrial customers, however, direct monitoring of the quality of voltage delivered is not possible due to the relatively high cost of providing measurement at each customer's point of supply. Electricity distribution utilities generally adopt a reactive approach of responding to customer voltage complaints. This approach could be appropriate if it is expected that supply voltages are within declared range for most customers and most of the time. This is because customers generally only complain of high or low voltage when they can observe something abnormal. Hidden costs such as lower equipment efficiency and shortened equipment life are not obvious to most customers.

The recent growth in embedded generation (EG) into electricity distribution networks, facilitated by government greenhouse gas reduction policy, has highlighted the undesirability of high supply voltages. For EG to generate power back into the supply network, the voltage at the point of common coupling (PCC) would need to be raised above the utility supply voltage. There could be local voltage rise along the supply circuit instead of voltage drop [1], [2], [3]. Unless these challenges are overcome, curtailment of EG would have to be in place or expensive network augmentation would be required to accommodate the increasing penetration of EG.

FORM OF VOLTAGE QUALITY DATA

The AMI communication technology utilised by JEN is a mesh radio network between the AMI meters and the meter Access Points. To conserve the limited bandwidth of the mesh radio system, a "report by exception" methodology has been adopted for voltage quality events. Under and over voltage events are generated locally in the smart meter whenever the set thresholds are exceeded. The events are then transmitted to the central Network Management System.

The undervoltage and overvoltage thresholds are set as follow:

- Undervoltage set point is 216V (230V - 6%)
- Overvoltage set point is 253V (230V + 10%)
- Events are only generated when the set point is exceeded for a time period of 180 seconds or more

The events consist of information such as meter identification, event date, start time (for start events), end time (for stop events), average voltage, maximum (minimum) voltage, supply address etc.

Cognos has been chosen as the Business Intelligence tool for data analysis. For the purpose of exploratory data analysis, the events can also be downloaded from the Network Management System as Comma-Separated Values (CSV) files for analysis by software packages such as Microsoft Excel, Microsoft Access or MatLab.

VOLTAGE QUALITY DATA - THE BIG DATA

Gartner, leading information technology research and advisory company, defines "big data" as having characteristics that can be denoted by three "Vs": *Volume*, *Velocity* and *Variety*. Voltage quality data is a form of "big data" as it possesses the following characteristics:

Volume

A snapshot of over and undervoltage events reported by 100,000 smart meters, over a 6-day period in summer 2012, is shown in Fig. 2 below:

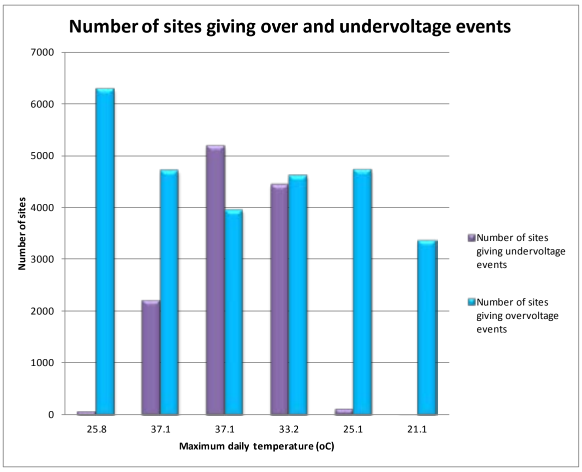

Figure 2 - Number of sites experiencing over and undervoltage events on six consecutive days with different daily maximum temperatures

It can be seen from Fig. 2 that overvoltage condition is a regular occurrence affecting approximately 6,000 customer sites (6%). Undervoltage condition is equally significant affecting approximately 5,000 customer sites (5%) but only on high ambient temperature days, triggered by the use of space cooling equipment. On the other hand, based on customer voltage complaints, confirmed under and over voltage cases total about 120 in calendar year 2011.

The voltage quality data that JEN has to process from smart meters are voluminous in comparison to customer voltage complaints.

Velocity

Velocity refers to the speed of data generation and disappearance.

A total of 6,131 customer sites have experienced undervoltage in the 6-day period. However, not all 6,131 sites experienced undervoltage throughout the six days. In other words undervoltage conditions are transient in nature and do not form an easily recognisable pattern. Refer Table 1 below:

TABLE 1 - ANALYSIS OF THE 6,131 UNDERVOLTAGE SITES

Number of sites experiencing undervoltage					
One day of the 6-day period	Two days of the 6-day period	Three days of the 6-day period	Four days of the 6-day period	Five days of the 6-day period	Six days of the 6-day period
2,195	2,033	1,828	55	7	13

The velocity of undervoltage site generation and disappearance is illustrated by the plot below, which shows the number of "active" undervoltage sites versus time in the 6-day period:

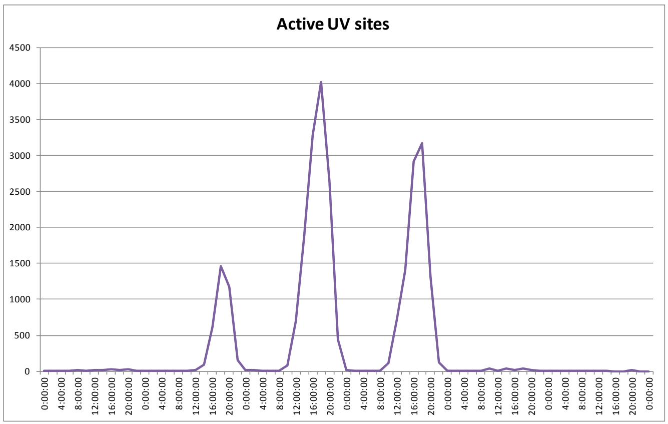

Figure 3 - Number of active undervoltage sites during the 6-day period

Similarly, 12,251 customer sites experienced overvoltage in the 6-day period but few sites gave rise to overvoltage event throughout the period, as shown in Table 2 below:

TABLE 2 - ANALYSIS OF THE 12,251 OVERVOLTAGE SITES

Number of sites experiencing overvoltage					
One day of the 6-day period	Two days of the 6-day period	Three days of the 6-day period	Four days of the 6-day period	Five days of the 6-day period	Six days of the 6-day period
5,192	2,803	2,465	1,242	549	300

The velocity of overvoltage site generation and disappearance is illustrated by the plot below, which shows the number of "active" overvoltage sites versus time in the 6-day period:

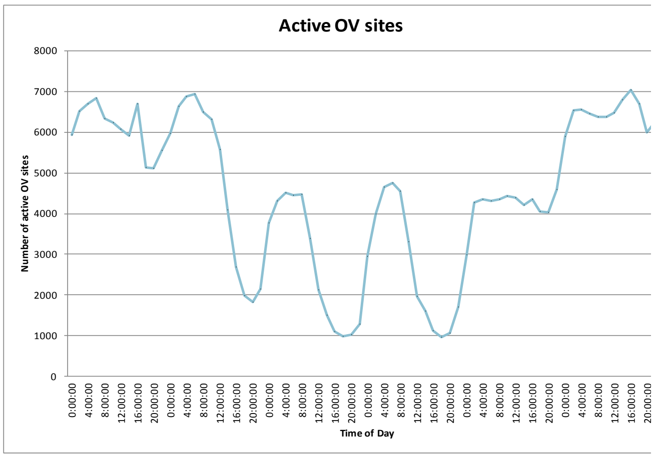

Figure 4 -Number of active overvoltage sites during the 6-day period

Variety

Variety refers to the number of disparate databases containing data that must be processed for enhanced insight and decision making.

To allow corrective action to be taken, the smart meter voltage quality data must be analysed in conjunction with network connectivity data (stored in spatial database such as Geographical Information System GIS), network asset data (in GIS and/or SAP) and real-time voltage data (in Supervisory Control And Data Acquisition system SCADA).

EXPLORATORY DATA ANALYSIS

It can be seen from the discussion above that it is a challenging task to turn the "big data" into actionable information that JEN can use to proactively rectify the voltage non-compliance revealed by smart meters.

While efficient data analytic tools are required to handle the big data, exploratory data analysis conducted on sample data sets is valuable as it allows insight to be gained on the specification for the ultimate data analytic tools, the ancillary data requirement as well as the types of query to be run on the data sets.

The exploratory data analysis presented in this paper is conducted using Microsoft Excel. The sample data sets consist of voltage events collected from 100,000 active smart meters over the 6-day period from 23 to 28 Feb 2012. Other database extracts include network topology snapshots from GIS, residential photovoltaic (PV) installation data from GIS, meter reference data from SAP, and ambient temperature information from the Bureau of Meteorology.

The exploratory data analysis reveals the following useful insight:

- Strong correlation of undervoltage events with ambient temperature - undervoltage events virtually non-existent at ambient temperature below mid 20's, and rising rapidly when ambient temperature reaches the mid 30's. Overvoltage events, on the other hand, do not show strong correlation with ambient temperature;
- Majority of overvoltage events are caused by the existing voltage regulation being set "a tab" too high. Care needs to be exercised, however, to ensure that dropping the voltage regulation setting will not lead to worsening of the undervoltage situation on hot days;
- The appropriateness of conventional Load Drop Compensation voltage regulation schemes may need to be reviewed;
- Definitive pattern of start times can be observed for undervoltage events. Coupled with the

insight gained from ambient temperature relationship, adaptive voltage control schemes based on ambient temperature and time of day could be feasible to improve on the undervoltage situation;

- Residential photovoltaic installations, modest in its current penetration (about 4%), is already observed to have a discernible impact on overvoltage occurrence. The effect will become more significant as the penetration of PV increases further;
- Priority for voltage non compliance investigation and rectification can be set based on the level of voltage deviation and time duration as revealed by the smart meter voltage events;
- Clusters of voltage events around particular distribution substations may indicate inappropriate off-load transformer tap setting;
- Clusters of distribution substations around particular zone substations may indicate inappropriate on-load tap change setting;
- Customers who experience both overvoltage and undervoltage events may indicate an upstream asset overload condition;

Details of the analysis results can be found in [4], [5].

FUTURE WORK

Due to the limitation posed by Microsoft Excel in the size of CSV files that it can handle and the computational speed, only 6-day of voltage events can be analysed at one time.

JEN intends to leverage on the insight gained through the exploratory data analysis and implement in its Business Intelligence tool – Cognos provided by IBM. JEN is also considering other grid analytics tools such as Teradata and Greenplum for applications that demand much faster response times.

For the Victoria University research project, the next phase focuses on modelling residential PV generation and its effect on voltage delivery in electricity distribution network. The ultimate aim of the research project is to develop innovative voltage control scheme that maximises the amount of PV that can be accommodated.

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