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Analysis of voltage quality data from smart meters

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Abstract

Initial analysis of voltage quality information collected from smart meters at premise level is presented. The information reveals instances of over and under voltage at some consumer premises. This revelation means supply authorities now have an obligation to rectify their supply voltages in accordance with codes and regulations. The analysis provides the foundation for future research work to identify effective solutions to the observed over and under voltage problems in the supply network. © 2012 Institut Teknologi Sepulul.

Keywords

voltage, analysis, quality, meters, smart, data

Disciplines

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Analysis of Voltage Quality Data from Smart Meters

P.K.C. Wong, R.A. Barr and A. Kalam

***Abstract*—Initial analysis of voltage quality information collected from smart meters at premise level is presented. The information reveals instances of over and under voltage at some consumer premises. This revelation means supply authorities now have an obligation to rectify their supply voltages in accordance with codes and regulations. The analysis provides the foundation for future research work to identify effective solutions to the observed over and under voltage problems in the supply network.**

Keywords-smart meters, voltage quality, overvoltage, undervoltage, distribution systems.

I. INTRODUCTION

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.

Direct measurement of voltage at each consumer supply point, however, is generally not possible due to the high cost involved. Utilities usually install power quality monitoring equipment in response to customer complaints, or at strategic locations on the supply network to verify that the supply voltage is within the prescribed range.

II. DESIGN OF THE ELECTRICITY DISTRIBUTION NETWORKS IN THE STATE OF VICTORIA, AUSTRALIA

Fig. 1 is a high level 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.

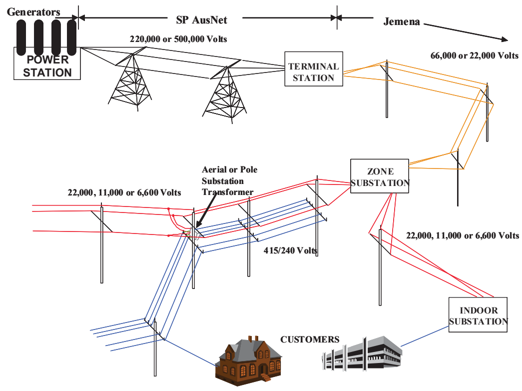

Figure 1 - Typical Electricity Supply System in Victoria, Australia

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 Low Voltage (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.

The Long Term National Power Quality Survey conducted by the University of Wollongong, on behalf of the Australian electricity distribution companies, has consistently found that some 25-30% of the LV sites record steady state voltage level above the regulatory limit some of the time [1]. There is, however, considerable reservation among utility engineers to lower the supply voltage for fear that this may result in under voltage at the end of the LV feeder runs.

III. SMART METER ROLLOUT

Since 2009, the five electricity distribution companies in the state of Victoria, Australia, have been rolling out smart meters in a program mandated by the state government. Known as the Advanced Metering Infrastructure (AMI) program, it is scheduled for completion by the end of 2013. The mandated program covers all customers consuming under 160MWhr per annum, essentially all residential customers, small commercial and industrial enterprises. The smart meters are linked by two-way communication network to a central back office system (Fig. 2). Apart from 30-minute energy consumption, the meters also monitor voltage quality.

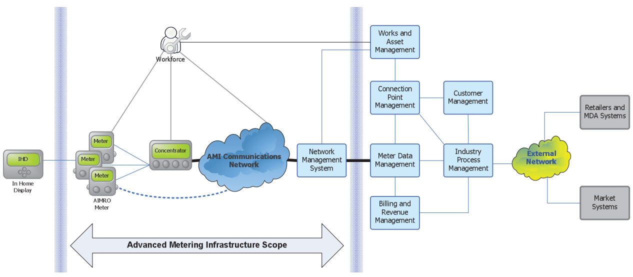

Figure 2 - AMI set-up for Jemena Electricity Networks in Victoria

The mass rollout of smart meters with voltage monitoring capability has therefore provided voltage sensing at every consumer supply point. The information can be used by electricity distribution companies (and government Regulators) to confirm (or otherwise) their compliance with voltage delivery standards, codes and regulations.

The discussion below relates specifically to the AMI program run by Jemena Electricity Networks (JEN). JEN is one of the five electricity distribution companies in the state of Victoria, and supplies approximately 310,000 customers in the North and North West part of Melbourne, Victoria, Australia. Approximately 100,000 smart meters were installed and commissioned by the end of 2011.

IV. Form of Voltage Quality Data

The minimum functional specification [2] of the smart meter program requires it be capable of monitoring the supply voltage and generate overvoltage, undervoltage, sag and swell events when the set thresholds are exceeded. In order to conserve the bandwidth of the meter communication system, the function is implemented locally in the smart meters and transmitted to the central Network Management System as events.

The events consist of information such as meter identification, event date, start time, end time, trigger voltage, average voltage, maximum (minimum) voltage, supply address etc. The events can be downloaded from the Network Management System as CSV files.

A. Meter Thresholds

The undervoltage and overvoltage thresholds are set in accordance with AS 60038 [3] which is called up in the Victorian Electricity Distribution Code [4]:

- Undervoltage set point is 216V (230V - 6%)
- Overvoltage set point is 253V (230V + 10%)

The persistence time is currently set at 180 seconds.

It is important to point out that the smart meters are not power quality meters designed to AS/NZS 61000.4.30 [5] so the events captured should be treated as indicative only and not be used for strict compliance purpose.

B. Volume of Voltage Quality Data

While Jemena suspected that there could be premises with supply voltages that were outside prescribed tolerance some of the time, it still came as a surprise when 260MByte of under and overvoltage events were captured by the 100,000 smart meters in the first three months of 2012.

It was observed that on an average day, the events were nearly all generated by overvoltage. In the few hot days during the period, however, there were comparable numbers of undervoltage and overvoltage events. To reduce the complexity of the analysis, under and overvoltage events are analysed separately before any correlation between the two types of events are studied.

V. Undervoltage Events - Macro Analysis

As there are virtually no undervoltage events during a normal day, analysis of undervoltage events is only carried out for the 6-day period from 23rd to 28th of February 2012 when hot weather has been experienced.

Before analysis is carried out, the undervoltage event data is cleansed to remove outliners caused by (a) Network faults such as supply interruptions and brown-outs (where voltage goes down to abnormally low level due to the loss of one phase of the high voltage supply), and (b) Short duration undervoltage that has marginal effect on equipment thermal performance.

A summary of the undervoltage analysis is presented below:

A. Number of undervoltage events (≥161V and ≤216V for more than 180 seconds)

A total of 15,180 undervoltage events were generated over the 6-day period.

These events were generated from 6,130 smart meters, or approx 6.1% of the total smart meter population. While a site could experience multiple undervoltage events in the same 24-hour period, most of the sites experienced only one undervoltage event in each 24-hour period.

TABLE 1 - NUMBER OF UNDERVOLTAGE EVENTS

Date	**23/2/12 (Thurs.)**	**24/2/12 (Fri.)**	**25/2/12 (Sat.)**	**26/2/12 (Sun.)**	**27/2/12 (Mon.)**	**28/2/12 (Tue.)**
Number of undervoltage events	80	2,664	6,590	5,545	267	34
Number of sites (percentage) giving undervoltage events	68 (0.07%)	2,219 (2.22%)	5,199 (5.2%)	4,446 (4.45%)	121 (0.12%)	24 (0.02%)
Total number of sites giving undervoltage events over the 6-day period						**6,130 (6.13%)**

B. *Correlation of undervoltage events with ambient temperature*

It is observed that the number of undervoltage events exhibits strong correlation with ambient temperature, with undervoltage events virtually non-existent at ambient temperature below mid 20's, and rising rapidly when ambient temperature reaches the mid 30's. This indicates that undervoltage events are triggered by the use of space cooling equipment during high ambient temperature, primarily refrigerative air conditioning. The increase in loading on the distribution equipment and circuits causes increase in voltage drops, with resultant undervoltage experienced by customers especially near the end of low voltage distribution circuits.

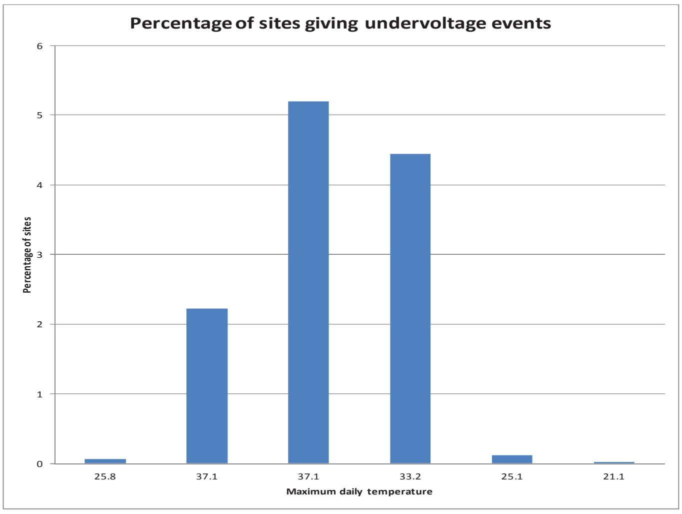

Figure 3 - Percentage of sites giving undervoltage events versus maximum daily ambient temperature

C. *Start times of undervoltage events*

Most undervoltage events commenced between noon to 8pm at night, generally coinciding with heavy electricity usage.

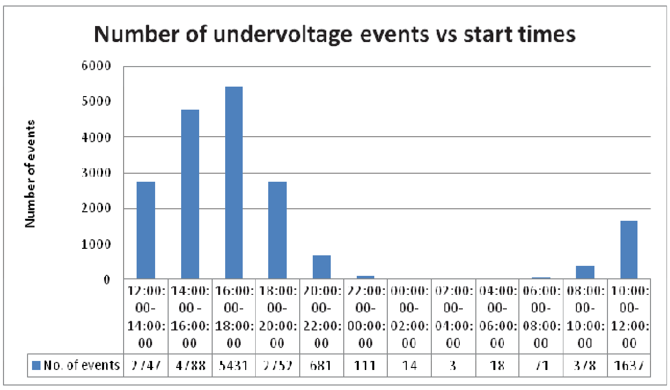

Figure 4 -Number of undervoltage events versus start times

D. *Duration of undervoltage events*

The longest undervoltage event lasted nearly 15 hours. However, most of the undervoltage events lasted between half an hour to 8 hours.

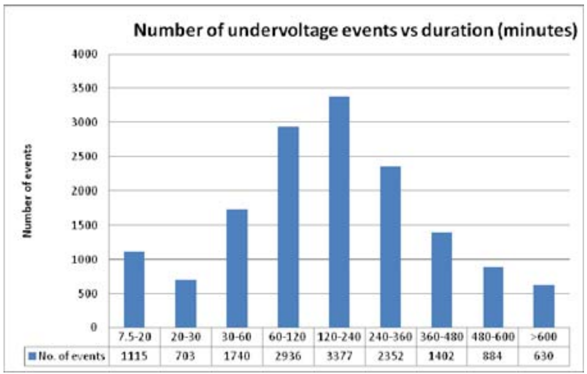

Figure 5 - Number of undervoltage events versus duration (minutes)

E. *Residual voltages*

The event records the lowest voltage during the duration of the undervoltage event. It does not mean the voltage stays at this low level during the whole event. The lowest voltage recorded varied from 161V to 216V. It can be seen from Fig. 6 below that the majority of the undervoltage events are just marginally below the regulatory threshold (230V-6% or 216V).

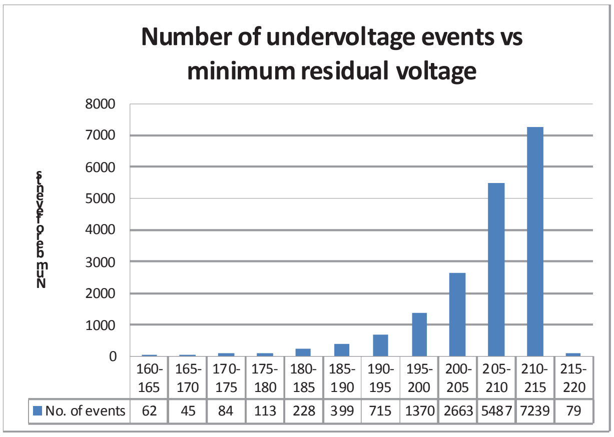

Figure 6 - Number of undervoltage events versus duration (minutes)

VI. OVERVOLTAGE EVENTS - MACRO ANALYSIS

It is observed that there are a lot more overvoltage events generated in a normal day compared with undervoltage events. To explore the relationship between undervoltage and overvoltage events, the same 6-day period was analysed.

Before analysis is carried out, the overvoltage event data is cleansed to remove outliners caused by short duration overvoltage that has marginal effect on equipment thermal performance.

A summary of the overvoltage analysis is presented below:

A. Number of overvoltage events (⩾253V for more than 180 second)

A total of 38,238 overvoltage events were generated over the 6-day period after data cleansing. These events were generated from 12,251 smart meters, or approx 12.3% of the total smart meter population. While a site could experience multiple overvoltage events in the same 24-hour period, most of the sites experienced only one overvoltage event in each 24-hour period.

TABLE 2 - NUMBER OF OVERVOLTAGE EVENTS

Date	**23/2/12 (Thurs.)**	**24/2/12 (Fri.)**	**25/2/12 (Sat.)**	**26/2/12 (Sun.)**	**27/2/12 (Mon.)**	**28/2/12 (Tue.)**
Number of overvoltage events	8,407	6,129	4,942	6,249	6,733	5,778
Number (Percentage) of sites giving overvoltage events	6,294 (6.29%)	4,724 (4.72%)	3,957 (3.96%)	4,620 (4.62%)	4,733 (4.73%)	3,378 (3.38%)
Total number of sites giving overvoltage events over the 6-day period						12,251 (12.3%)

B. Correlation of overvoltage events with ambient temperature

Unlike undervoltage events, it is observed that the number of overvoltage events do not show strong correlation with ambient temperature.

This is expected as overvoltage generally occurs at light load periods when the voltage drop across the distribution circuit is at its minimum. As Melbourne summer tends to have high temperature during the day and cooler temperature at night, air conditioner use during the light load period (i.e. at night) is infrequent unless there are consecutive hot days. One would therefore expect that overvoltage would still be prevalent at light load period even during hot days.

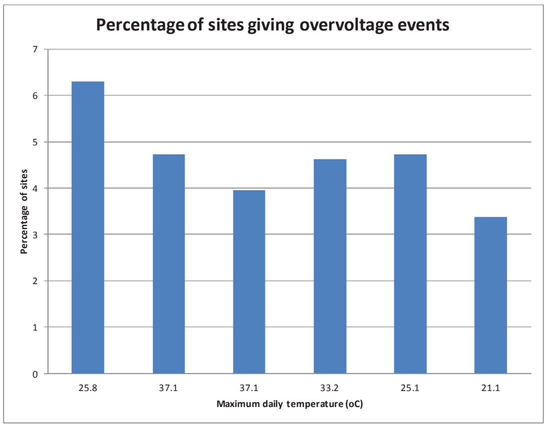

Figure 7 - Percentage of sites giving overvoltage events

C. Start times of overvoltage events

By far the most common start times for overvoltage events are 8-10pm and midnight to 2am. This coincides with low electricity usage.

However, some overvoltage events also occurred at times which are quite unexpected. There is a possibility that these overvoltages could have been generated by solar panels installed at these customer premises. Future research work will be carried out to verify this theory.

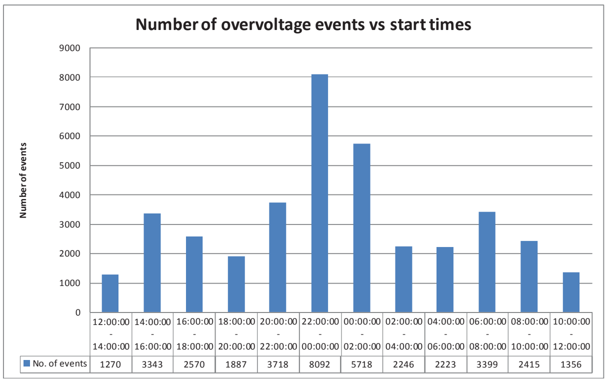

Figure 8 - Number of overvoltage events versus start times

D. Duration of overvoltage events

The longest overvoltage event lasted nearly 45 hours! However, most of the overvoltage events lasted between 2 to 15 hours.

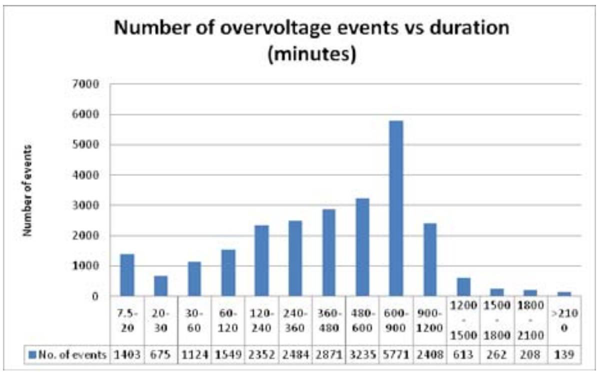

Figure 9 - Number of overvoltage events versus duration (minutes)

E. Highest voltage

The event records the highest voltage during the duration of the overvoltage event. It does not mean the voltage stays at this high level during the whole event. Majority of the overvoltage has the highest voltage between 255V to 260V. It can be seen from Fig. 10 below that the majority of the overvoltage events are just marginally above the regulatory threshold (230V+10% or 253V).

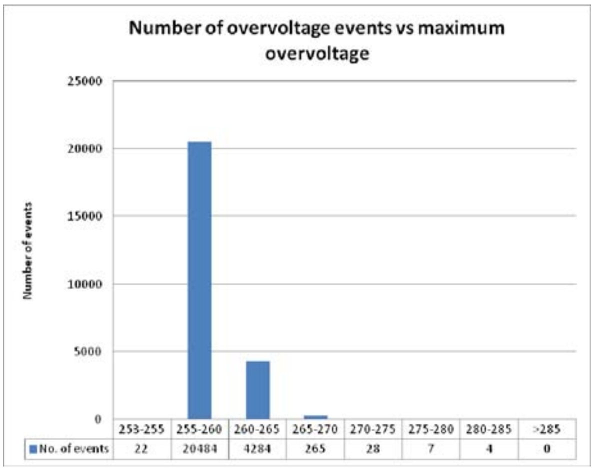

Figure 10 - Number of overvoltage events versus highest voltage

VII. CORRELATION BETWEEN OVERVOLTAGE AND UNDERVOLTAGE EVENTS

During the 6-day period, 12,251 sites and 6,130 sites experienced overvoltage and undervoltage events respectively.

Fig. 11 below shows the total number of sites experiencing over and undervoltage events over the 6-day period, with different maximum daily temperatures.

There were 89 sites that have experienced both under and over voltages. The small number of "common" sites is a good sign as it indicates that relatively straight forward rectification is possible to bring these sites back into compliance. Undervoltage sites, for example, can have their setpoint voltages raised without running into high risk that they will become overvoltage sites, and vice versa.

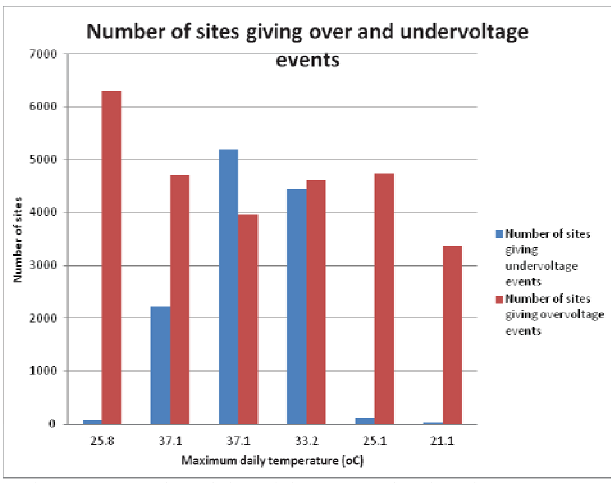

Figure 11 - Number of sites giving over and undervoltage events at different daily maximum temperatures

VIII. CONCLUSIONS

Voltage quality data from smart meters has been analysed at the macro level using data analysis techniques. Results are presented in tables, charts and graphs. High level observations are made based on the authors' experience with electricity distribution networks.

Future research work will focus on identifying the origins of the voltage quality problems. This will enable electricity distribution companies to proactively manage their voltage delivery and improve their customer service.

ACKNOWLEDGMENT

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IX. BIOGRAPHIES

Peter Wong Peter K.C. Wong (Peter) is a chartered electrical engineer, a fellow of the Institution of Engineers Australia, and has over 28 years' experience in the energy industry in Hong Kong and Australia. His areas of technical expertise are protection, control, communications, SCADA, power quality, distribution automation, demand planning and new technology applications. Peter is currently pursuing a Master/Doctoral Study at the Victoria University, Melbourne, using smart meter data to improve quality of voltage delivery in public electricity distribution networks.

Robert Barr Dr. Robert Barr is a consulting engineer and director of his company Electric Power Consulting Pty Ltd. He holds a PhD in electrical engineering from the University of Wollongong. Robert has over 40 years experience in the field of electricity distribution, is a fellow of the Institution of Engineers Australia and a member of the Association of Consulting Engineers Australia. Dr Barr is an Honorary Professorial Fellow at the University of Wollongong and has been named the 2012 Australian National Professional Electrical Engineer of the year.

Akhtar Kalam Professor Akhtar Kalam received the B.Sc. degree from Calcutta University, Calcutta, India, in 1969 and the B.Sc. degree in engineering from Aligarh Muslim University, Aligarh, India, in 1973, the M.S. degree from the University of Oklahoma, Norman, and the Ph.D. degree from the University of Bath, Bath, U.K., in 1975 and 1981, respectively. His Ph.D. work focused on the application of distance protection to series-compensated extra high-voltage lines. He has been actively engaged in the teaching of power systems for more than 20 years in both the School of Electrical Engineering, Victoria University, and overseas. He has conducted research, provided consultancy, and has many publications on power system protection and independent power generation. His major interests are power system analysis, power system protection, and expert system application in power systems, cogeneration, and renewable energy.