TRANSFORMATION OF ENERGY NETWORKS: INITIAL RESULTS FROM INTENSIFIED MV AND LV MONITORING

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INTRODUCTION

EnergyAustralia (EA) is the largest supply and distribution power company in Australia, delivering 30,000GWhs of energy annually to 1.6 million customers within a region that covers greater Sydney and ranges north to Newcastle and the Hunter Valley. The peak demand in 2010 was 5,322MW for the winter peak in June and 5,531MW for the summer peak occurring in the preceding February. The network consists of transmission and subtransmission operating at 132, 66 and 33kV with distribution at 22 and 11kV. The EA distribution network consists of 17,361 kilometers of 11kV. The LV system is fed from approximately 30,000 11kV/400v distribution substations which are kiosk type for the underground cable networks and outdoor pole mounted for the overhead system. EnergyAustralia, realizing that change to existing practices was inevitable, undertook a strategic exercise it named “Electric Thinking” [1] for the transformation of the network. A phased transformation of the distribution network was defined through a number of projects, the initial and most ambitious of which was the Distribution Monitoring & Control project (DM&C) [4]. The intelligent monitoring portion of the project will place third generation smart monitors [2] for HV and LV circuit monitoring in 40% (or 12,000) of the HV/LV substations by 2013. Measurements will be archived in OSISoft PI Historian.

BUSINESS DRIVERS AND BACKGROUND

The business case [3] for the DM&C project identified lack of sufficient network information (loads and faults) on a timely basis as a major detractor in network transformation. Distribution substation loads for asset planning were obtained by twice-annual visits to substations to read the maximum demand indicators (MDI). Fault location resolution was mostly limited to SCADA operation at primary substations. The resulting DM&C project was justified by avoiding the costs of substation visits and by improving fault location knowledge along feeders, with potential for switch control at selected locations. The business case established hard benefits with 65% of the total attributing to SAIDI reduction. The elimination of substation visits together with improved asset management from improved load estimates amounted to 28% of the benefits. The remaining 7% justification was based on smaller items such as LV load balancing, customer quality improvement and asset maintenance. Reduction of losses was not included, because the level of loss reduction could only be an estimate. Now, with the DM&C project, it should be possible to investigate all these parameters and issues.

The measured and locally computed data are sent to the central archive system. Measured parameters (normal current and voltage, as well as calculated real and reactive power) are pushed every 10 minutes to the central Enterprise IT application data bus and PI Historian via an HTTP wrapped XML protocol. Out of tolerance normal values and fault notification are sent spontaneously at the time of the event to ensure rapid response and maximum reduction of outage times. The data volume is considerable and amounts to 1Mbyte/day for a distribution substation with four LV feeders.

This paper will examine certain elements of the data from the initial 1,500 substations where the third generation smart monitors have been commissioned. It will attempt, within the limitations of the data mining applications, to indicate how the DM&C project is starting to deliver results and how such visibility of network performance raises further challenges to improving design, operation and data mining techniques.

ORGANIZATION OF RESULTS

The initial results from the DM&C project will be examined in two ways:

Service Area-wide

Service area-wide examination of approx. 1,500 distribution substations with emphasis on LV feeders and buses. The data will be reviewed for three typical days:

Day 1 - Winter Peak (Wed, 30 June, 2010)
Day 2 - Spring Weekday (Tue, 21 September, 2010)
Day 3 - Spring Weekend (Sun, 26 September, 2010)

Investigation into load diversity across the service area and LV load unbalance and losses due to unbalance will be conducted by examining current flows for all LV feeders extracted with a time tag for occurrence of peak and retrieved at time of system peak.

Voltage performance will be examined by retrieving all out of tolerance LV bus voltages at time of system peak.

Fault indications will be extracted to confirm that this feature of the monitoring device is operating and thus providing business values.

Detailed Analysis

A feeder will be selected with a very high monitoring intensity level (MIL)[1] where load surveys or measurements have been performed previously. Investigations into load coincidence and load values will be conducted.

SERVICE AREA-WIDE RESULTS

The database consisted of all MV/LV substations with installed and commissioned monitoring systems. Naturally, within the population there were unavailable data and outliers where values were remote from the average by at least three standard deviations. The data population comprised 1,636 MV/LV distribution substations with a total of 4,472 LV feeders having all phase’s monitored (13,416 total measurement points). The number of feeders per station ranged from 1-7 with an average of 2.7. LV voltages for each LV bus phase were also captured.

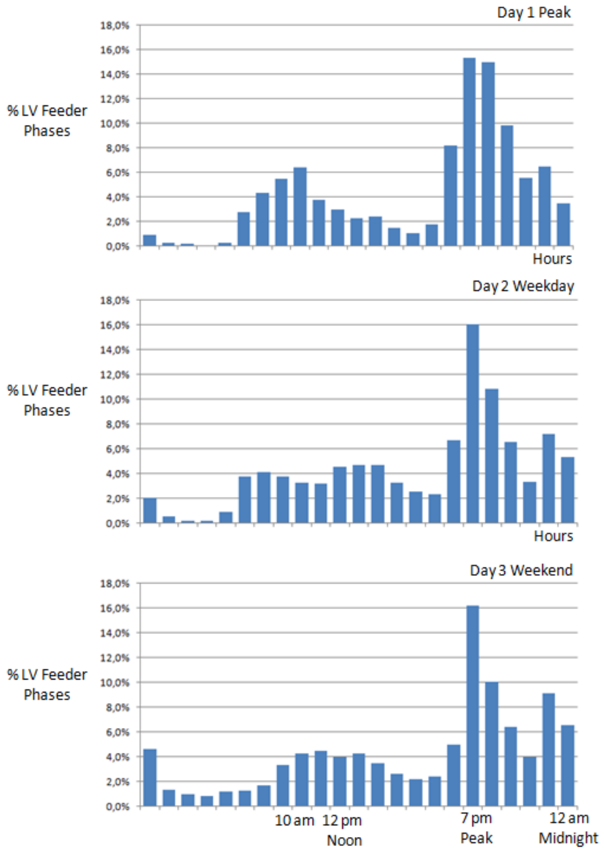

Figure 1 - Distribution of number of LV phases peak current times over a 24- hour period showing the profile for the three typical days selected.

Time of Peak Occurrence of LV Feeder Loads

Examination of the time of peak loads occurring on the population of LV feeder phases in service and with valid data (8,820 feeder phases) gives the distribution over the 24-hour period shown in Figure 1 for the three days viewed. The load for all days peaks around 7 pm and for the peak day a pronounced second but lower peak occurred in the morning between 9 and 10 am. 34% of LV feeders peak at the same time as the evening peak, whereas 19% peak with the morning peak on this day. Observation of LV phases showed cases where one of the three LV feeder phases contributed to the morning peak, whereas the other two phases peaked in the evening. No further information could be extracted without more targeted data mining to prepare a quantitive report on this network characteristic. The distribution of peak LV phase currents for the non-system peak weekday showed a flatter distribution with only the evening peak being significant. The morning peak for the Sunday example showed a one hour delay on the morning peak.

The distribution of the LV feeder phase current magnitudes on Day 1 for the population sample is summarized in Figure 2, where the distribution is normal and the average value is 191 amps.

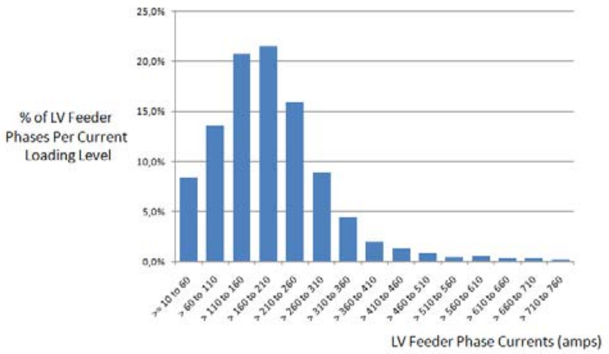

Figure 2 - Distribution of number (%) LV feeder phase individual phase current magnitude for >7,000 phase measurements retrieved on Day 1.

LV Feeder Current Unbalance

The LV feeder phase current measurements allow an analysis of the unbalance existing in the LV network and the increase in losses that causes current unbalance.

The Unbalance Factor is given as:
Unbalance Factor (UF) = $I_{\text{phase max}} / (I_a+I_b+I_c)/3$

The Unbalance Loss Penalty Factor is given as:
Unbalance Loss Penalty Factor (ULPF) = $P_{\text{loss,unbalanced}} / P_{\text{loss,balanced}}$
$= (I_a^2+I_b^2 +I_c^2) / (3*I_{avg}^2)$

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[1] MIL defined in % as the number of locations with distribution monitors compared with the total number of MV/LV substations on a feeder.

The distribution of unbalance for a weekday (Day 2) for each LV feeder in Figure 3 shows that 60% of all feeders have an unbalance below the 27% average value. The results for the other typical days varied little from this value with Day 3 exhibiting slightly more unbalance.

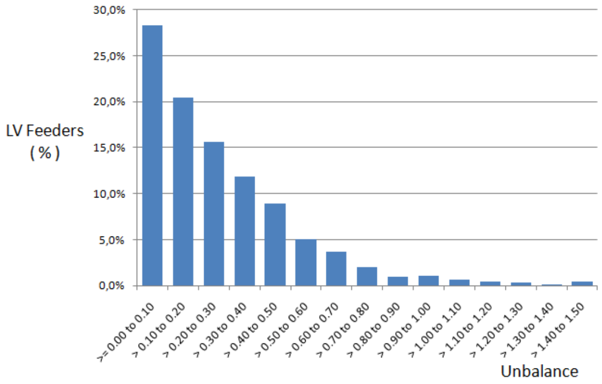

Figure 3 - Distribution of percentage number of feeders with different levels of unbalance for Day 2.

The unbalance loss penalty factor for the same typical day showed that 72% of the sampled feeder contributed to less than the average additional losses of 11.2% due to unbalance as shown in Figure 4.

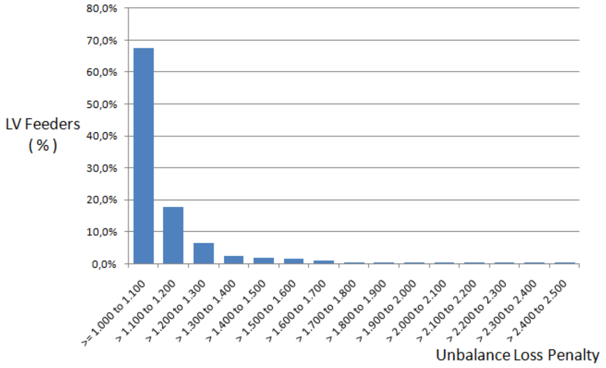

Figure 4 - Distribution of number of feeders in percent with different loss penalties due to unbalance.

The additional losses produced by unbalance can be estimated based on the 30,000GWh of load delivered by EA in 2010, assuming that LV feeder losses approximate 3%. Considering that 91% of all feeders contribute to an Unbalance Loss Penalty between 10-30%, the values of additional losses would amount to 107GWh.

LV Voltage Regulation

The voltage regulation at the consumer's service entrance is specified by the Australian standard as ± 10% about 240 volts. EA adopted a design policy of ± 6%. Analysis of phase voltages at the LV busbar of all 1636 substations for Day 1 (winter peak) revealed the following performance metrics, such as percentage of monitored substations outside limits and the total minutes of violations for the sampled population during the 24 hours.

	EA Design Policy		Australia Standard	
Violations	Upper Limit	Lower Limit	Upper Limit	Lower Limit
Number of Phases	1571	7	96	6
Number of substations	524	3	32	2
% of total substations	32	0.2	2	0.2
Number of minutes	549,000	210	10,687	200

Table 1 - MV/LV substation LV bus voltage violation for EA and Australian Standards.

The upper limit violations are overstated in terms of the consumer's service entrance levels, since LV line drop is not compensated; however, the ability to log such voltage levels across the entire network provides additional visibility for network evolution. The number of substations with voltage violations was counted as those exhibiting out of limit durations >1000 minutes in order to remove any station off supply. The distribution of the violation duration levels was evenly spread over the entire network.

DETAILED ANALYSIS

The second approach to reviewing the data was in a detailed manner, MV Primary Zone substation and feeder by feeder. Load data in this form provides the foundation for improved planning since it allows accurate treatment of load diversity. The feeder selected supplied both residential and light commercial loads. It was an underground cable system supplying 18 MV/LV substations with between 2 and 7 LV outgoing feeders (Figure 5). Data was available from 11 out of the 18 substations giving a MIL of 61% for the feeder.

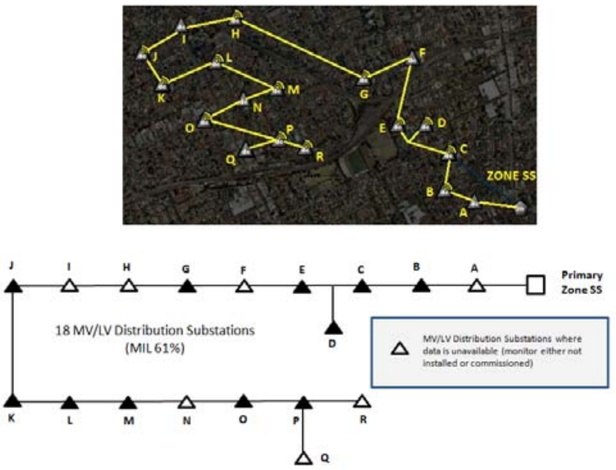

Figure 5 - Sample Feeder Configuration.

The load diversity is shown in Figure 6, indicating that the variation of the MV/LV substation peaks around the feeder peak at the primary zone substation, which occurs at 7:20 pm in the evening, is significant.

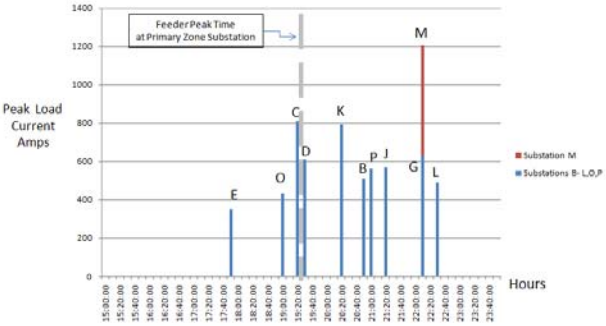

Figure 6 - Distribution of MV/LV substation peak load times and magnitudes, and the time of feeder peak.

The consolidation of the MV/LV substation 24-hour phase load profiles produces the feeder load profile in Figure 7 for the maximum loaded phase, which is taken as the feeder peak loading. This feeder peak is close to the system peak time, thus the majority of diversity, as would be expected, is between the MV/LV substations. This is important information for planning where traditional load models have been calibrated by ratioing the installed capacity or MDI readings and matching with the feeder header current.

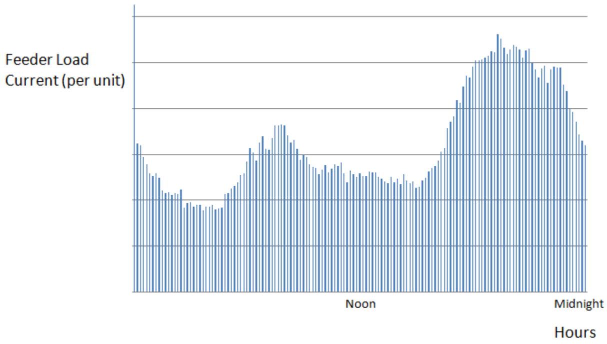

Figure 7 - Feeder load profile for Day 1 created by consolidation of all MV/LV substation LV currents for the peak feeder LV phase.

Optical current sensors installed on selected substation 11kV side are sending information as shown in Figure 8.

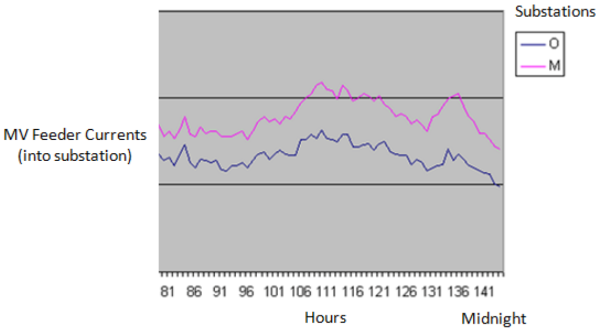

Figure 8 - MV currents on the upstream side at substations O and M around system peak time.

CONCLUSIONS

The DM&C project at EA is definitely producing results and benefits. The improvement in asset loading visibility is substantial, showing the greater load diversity and the peaking of certain MV/LV substations in the morning, rather than at system peak in the evening. The load unbalance at the LV feeder level, although difficult to improve, provides scope for selected connection of new consumers and the information needed for approving domestic and low-end distributed generation sources. Reduction in the loss penalty due to unbalance would be a good metric to set and measure system-wide improvement in this area. The ability to record LV voltage violations can be used directly to evaluate voltage regulation performance and correlate customer complaints. Such measuring capability will become vital as distributed generation is commissioned on the network.

Detailed analysis of the feeders with the load resolution available from direct monitoring accounting for load diversity and will improve planning and asset utilizations by reducing traditional capacity margins necessary in the past, since MDI readings did not have a time stamp. Reductions in CAPEX for future expansion should result. This load data could also improve the accuracy of the real-time network model in the Distribution Management System needed for switching plans.

This initial investigation highlighted the need to implement efficient data retrieval methods to deliver selective data to planning and real-time applications. The retrieval application should employ intelligent and especially relevant data mining technology. The design of realistic and practical system wide metrics to set management goals for improved asset and network management will be vital.

The feasibility and usefulness of such a significant increase in distribution network monitoring was endorsed and shown to be the necessary foundation for successful network transformation into a Smart Grid.

REFERENCES

[1] Adrian Clark, Christopher J Pavloski, Jeff Fry, ”Transformation of Energy Systems: The Control Room of the Future”, *IEEE, Montreal, Canada 22-23 October 2009.*

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[3] James Northcote-Green, Jesper Klingsten Nielsen, Martin Speiermann, Adrian Clark and Shannon Frohlich-Terpstra,” Transformation of Energy Systems- Transparent HV and LV Distribution Networks” *DistribuTECH 2011, San Diego, 1-3 February, 2011.*