DISTRIBUTION NETWORK VOLTAGE DISTURBANCES AND VOLTAGE DIP/SAG COMPATIBILITY

Ian McMICHAEL
Power Quality Solutions - Australia
ianmcm@pqsolutions.com.au

Dr Robert BARR
Electric Power Consulting - Australia
rbarr@epc.com.au

ABSTRACT

The results of a collaborative study into the impact of distribution network voltage disturbances on the operation of manufacturing plants located in rural areas in Australia are discussed.
The concept of voltage dip/sag Immunity Levels 1, 2, 3, 4 and 5 has been introduced as a means for plants to define existing levels of immunity and plan improvements. Requirements for improving voltage dip/sag compatibility that impacts on equipment susceptibility, mitigation equipment performance and related standards are discussed.

INTRODUCTION

This paper presents the results of a collaborative study into the impact of distribution network voltage disturbances on the operation of manufacturing plants located in rural areas in Australia.

The seven manufacturing plants are located in rural areas, all being at least 150km from a state capital. Each plant site takes supply at 22kV, has an operating load of 5MW to 10MW and is the largest customer on each of the Zone substations.

Reticulation in the study areas is at 220kV/66kV/22kV with 66kV/22kV Zone substations located at each rural town supplying the plant, township and neighboring area. The plants are located between 0.5km and 18km from the supplying 66kV/22kV Zone substations.

Each manufacturing plant is highly automated including adjustable speed drives, PLC's, SCADA etc. The equipment is up to 10 years old with the adjustable speed drives being of the PWM type. The utilization voltage within each plant is 415V/240V at 50Hz and the largest drive about 500kW.

The voltage disturbances investigated were restricted to voltage dips/sags as they appeared to be the major cause of plant stoppages.

METHODOLOGY

The data used in the study was obtained from the following sources:
<u>Plant</u>: Records of equipment stoppages attributed to voltage dips/sags and voltage dip/sag data from the 22kV point of supply (POS) to each site.
<u>Network</u>: Zone substation dip/sag data (measured at the 22kV busbar) for events when equipment stoppages correlated with POS meter dip/sag data and network fault details for events when equipment stoppages correlated with Zone substation dip/sag data.

The power quality meter data and corresponding network fault details were entered into the power quality database and analysis software, PQView®.

The POS meters were configured to measure voltage disturbances outside 22kV +/- 10% with durations >0.01sec (half cycle). Most Zone substation PQ meters were configured to measure voltage disturbances outside 22kV +/- 6% with durations >0.01sec (half cycle).

The above methodology had several limitations:

a. All Zone substation PQ meter data was not available for the complete study period
b. Only 2 of the 7 manufacturing plants had POS PQ meters installed at the start of the study
c. The quality of the historical plant stoppage data varied between plants
d. For some plants the plant stoppage data did not cover all production sections.

NETWORK REVIEW

The network arrangements varied between Zone substations with Figure 1 and Figure 2 being typical. Two Zone substations had single radial 66kV supplies and two had 66kV/22kV transformers supplying only the plant feeders. There were no 22kV reclosers installed between the Zone substations and the plants.

Interruption network exposure and voltage dip/sag network exposure distances are shown in Figure 1 and Figure 2.

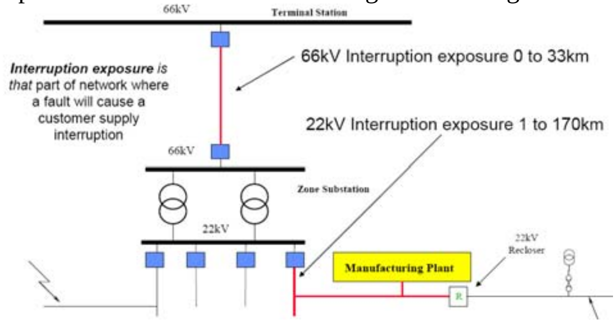

Figure 1 Interruption Exposure

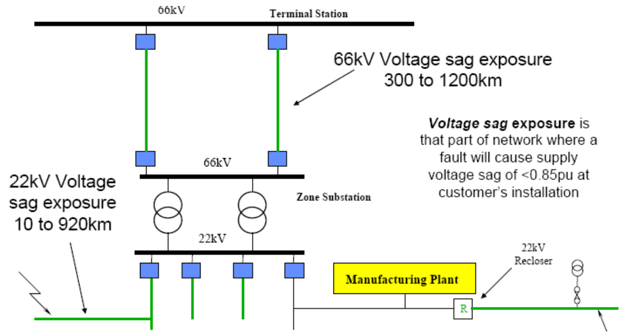

Figure 2 Voltage Sag Exposure

Other key characteristics of the networks are:

- Distance protection of all 66kV subtransmission lines
- Very long 22kV distribution feeders
- Mixture of timber poles and conducting concrete poles across all voltage levels
- No overhead earth wire on 66kV subtransmission lines
- Neutral earthing resistors are not widely used on the 22kV star point of the 66kV/22kV transformers.

The distance protection setting in most systems examined was:

- Zone 1 was generally selected at 80% of the feeder length with an instantaneous time setting. Allowing for a 0.1 second circuit breaker opening time, this results in a circuit breaker opening time and voltage sag duration of approximately 0.1 seconds after the onset of a fault.
- Zone 2 was generally selected to cover the area from 80% to 120% of the feeder length. Typically this protection had a setting of 0.4 seconds. Allowing for a 0.1 second circuit breaker opening time results in a circuit breaker trip time and voltage sag of 0.5 seconds after the onset of a fault.

RMS VOLTAGE DISTURBANCES

The study scope was to analyze available data from 1 July 2003 to 31 January 2005. Plant stoppage data, POS meter data and Zone substation PQ meter data was only available from one site for the full 19 month study period. The data obtained equated to a total of 171 monitor months of PQ meter data or 64% of that possible. Consequently, direct comparisons between sites were not always possible. The most credible data was for the period that there were POS meter dip/sag logs available i.e. at least for the 5½ month period 15 August 2004 to 31 January 2005, giving a total of 77 monitor months of data.

For each plant the voltage disturbances below 90% were analyzed for the full study period and also the period for which POS meter data was available.

For each plant stoppage that could be correlated with a POS meter logged voltage disturbance, the event was tagged as 'Load Interrupted'. For each plant 'Load Interrupted' stoppage, the Distributor investigated the disturbance event to determine if the voltage dip/sag was associated with a network fault. Where a network fault was identified, details were recorded of the faulted feeder, fault cause, weather conditions, details of the protection that operated and if there was an auto-reclose. These details were added into the PQView database.

In the analysis any voltage disturbance events that occur within 1 minute of another event have been temporally and phase aggregated with the 'worst case' data being plotted.

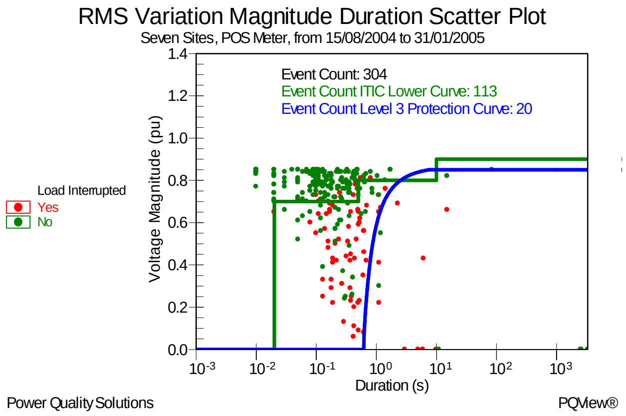

Figure 3 - 7 Sites Magnitude-Duration Plot with Load Interruptions

The Protection Curve in Figure 3 typically represents the expected reflected voltage sag limits for time graded over-current protection used in conventional radial medium voltage networks. [1] [2]

Typical data from one plant supplied by a Zone substation with a 66kV radial feeder are shown in Figure 4.

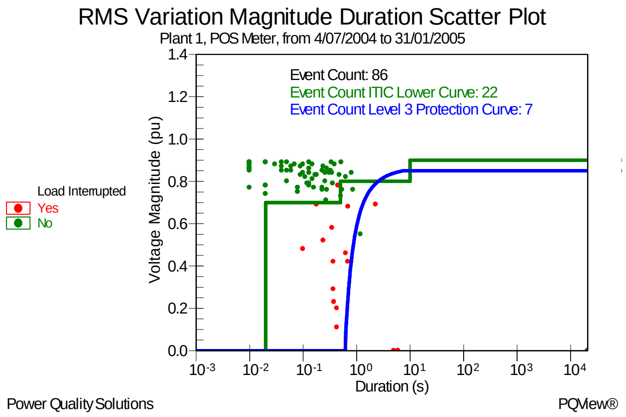

Figure 4 - Plant 1 Magnitude-Duration Plot with Load Interruptions

Typical data from one plant supplied by a dedicated 66kV/22kV transformer substation is shown in Figure 5. This plant is effectively a 66kV subtransmission supplied site.

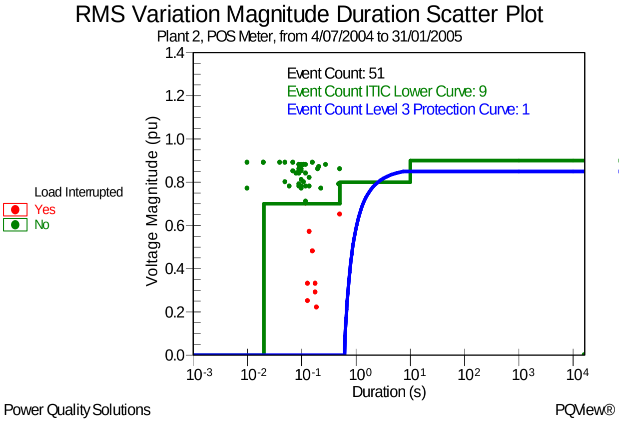

Figure 5 - Plant 2 Magnitude-Duration Plot with Load Interruptions

From the review of the seven plants and the associated networks the following general conclusions have been reached:

- There is a clear mismatch between the network dip/sag performance and plant equipment immunity at all sites.
- The ITIC lower curve generally defines a clear boundary between voltage dips/sags that result in plant equipment trips and those that do not.
- Lightning related network faults were the major cause of voltage dip/sag events.
- Network faults related to birds were the second highest cause of voltage dips/sags.
- Less than 5% of voltage dip/sag events were longer than 10 seconds duration with the majority of these being outages.
- The available options for Power Quality improvement varies at each site depending on the existing network infrastructure.
- Lightning related voltage sag issues occurred at the plant sites despite the areas generally being considered low lightning activity areas as confirmed by the average annual thunder-day map published by the Australian Bureau of Meteorology.

DEFINING PLANT IMMUNITY LEVELS

To assist plants define existing voltage dip/sag immunity levels and set targets for future levels, the following equipment voltage dip/sag immunity levels concept has been developed.

Level 1 Immunity – ITIC Compatible

- See Level 1 ITIC curve in Figure 6.
- Generally represents the voltage dip/sag immunity of the existing plant sites.

Level 2 Immunity – High Speed Protection Compatible

- Ride-through to 0.15 seconds for all dip/sag values.
- Achieves plant ride-through for most transmission and 66kV network faults covered by high speed protection (~ 0.1 second clearing time).
- Level 2 immunity would provide excellent performance for sites supplied from networks with high speed 66kV protection and dedicated 66kV/22kV transformer supplies.
- See Level 2 high speed protection curve with 0.15 second immunity in Figure 6.

Level 3 Immunity– Protection Curve Compatible

- Level 3 immunity requires plant ride-through to at least the 22kV feeder time graded protection curve.
- Level 3 immunity provides plant protection from voltage dips/sags generated from 66kV network faults cleared by Zone 2 distance protection.
- Level 3 immunity provides plant protection from most voltage dips/sags generated from reflected 22kV faults (i.e. faults in the 22kV exposure zone).
- See Level 3 typical MV protection curve in Figure 6.
- Dip/sag events to the right of the Level 3 curve are abnormal and are generally caused by faults on the feeder supplying the plant.

Level 4 Immunity – Trip & Reclose Compatible

- Level 4 immunity requires plant ride-through for about 4 seconds.
- Level 4 immunity provides plant protection from voltage dips/sags generated by a trip and typical auto reclose time setting of 3 seconds.
- Level 4 immunity provides plant protection from voltage dips/sags generated on the 22kV plant feeder.
- See Level 4 Trip & Reclose curve in Figure 6 which shows a 4 second immunity curve.

Level 5 Immunity –Distribution Code Compatible

- Level 5 immunity requires plant ride-through for at least 10 seconds.
- Level 5 immunity provides plant protection from voltage dips/sags and multiple trips and auto recloses on the 22kV plant feeder.
- Level 5 immunity provides plant protection from voltage dips/sags to allow a diesel generator to start and transfer to supplying the plant.
- See Level 5 Distribution Code curve in Figure 6.

Figure 6 shows the proposed immunity level curves added to Figure 3 – "7 Sites Magnitude–Duration Plot for Load Interruptions only".

When deciding if a particular manufacturing plant should be designed to level 1, 2, 3, 4 or 5 immunity (or some other level), consideration needs to be given to the implementation costs and the resulting benefits. The voltage dip/sag network performance at the 22kV point of supply is a critical factor in deciding what future benefits could be achieved from building voltage dip/sag immunity into a particular plant.

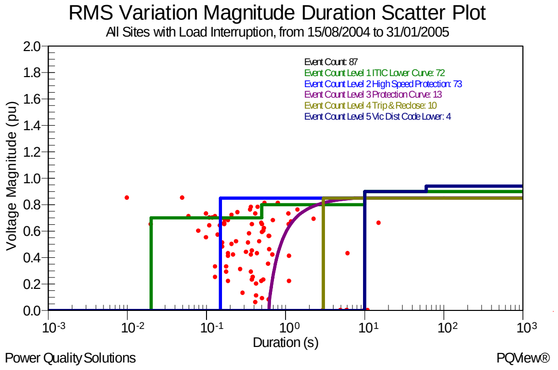

Figure 6 - 7 Sites Magnitude-Duration Plot for Load Interruptions only with Immunity Levels

EQUIPMENT VOLTAGE DIP/SAG IMMUNITY STANDARDS

There are several equipment voltage dip/sag immunity standards in common use. These include IEC 61000-4-11 (<16A), 61000-4-34 (>16A), SEMI F47 and the defacto standard CBEMA/ITIC.

Equipment can be type tested to an immunity standard or an individual item tested and certified.

Figure 7 shows the above common immunity standard curves applied to the data in Figure 3.

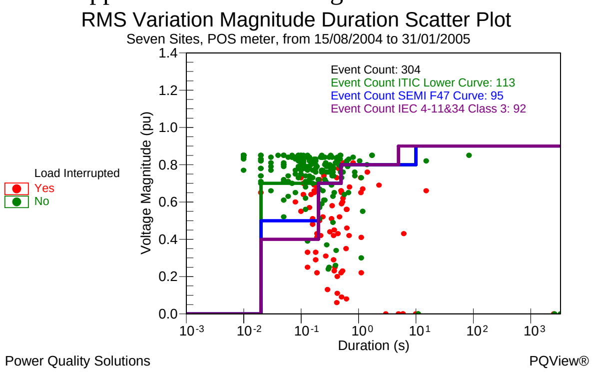

Figure 7 - 7 Sites Magnitude-Duration Plot with Equipment Immunity Standards

Figure 8 shows the common immunity standard curves applied to the data in Figure 5.

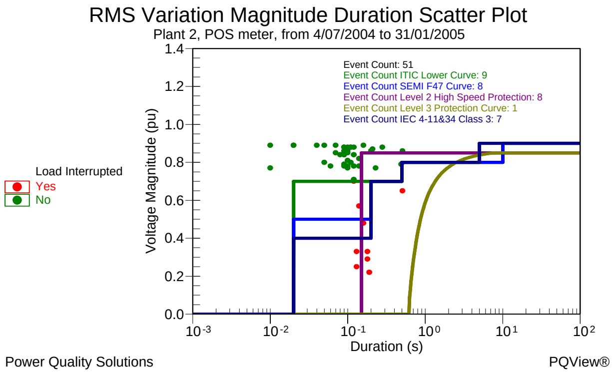

Figure 8 - Site 2 Magnitude-Duration Plot with Equipment Immunity Standards

Figure 7 and Figure 8 show a significant mismatch between equipment complying with existing voltage dip/sag immunity standards and distribution network performance. Even sites effectively supplied at the subtransmission level of 66kV would benefit only marginally from equipment that was compliant with IEC 61000-4-34 Class 3 (Figure 8), the most demanding of the IEC classes.

CONCLUSIONS

The study has shown the clear relationship between network design and voltage dip/sag performance. The study period event data has shown that all manufacturing sites generally have ITIC immunity or Level 1 Immunity. It is believed that this result could be confidently extrapolated to many other modern automated manufacturing plants not covered by the study.

Methods and options for sites to improve the immunity level are network and plant equipment specific. Manufacturing companies need to determine the economic level of voltage dip/sag immunity required at each plant site and then develop a detailed plan to achieve these levels over time. Voltage dip/sag immunity levels, based on network protection performance, have been developed to assist in the analysis. Economically reducing the adverse impacts of voltage dips/sags requires carefully targeted investment in both the networks and the individual manufacturing plants.

Existing equipment voltage dip/sag immunity standards do not appear to adequately consider the significance of network protection design, settings and performance in determining the customer 'voltage dip/sag experience'.

There is still much work to be done by network businesses, end users, equipment designers, standards committees and network regulators in developing a cost effective and equitable approach to improving voltage dip/sag performance. The installation of voltage dip/sag sensitive equipment by all types of consumers is still rapidly growing but does not appear to be complemented with equipment offering appropriate voltage dip/sag immunity. The authors hope that this paper will provide another perspective on this challenging area and assist all parties in developing improved compatibility between networks and customer equipment.

REFERENCES

[1] Dr. R. Barr, 2002, "Voltage Sags – Customer needs versus what Distributors can deliver", *Annual Conference of the Electric Energy Society of Australia, Canberra, 2002,* download from www.epc.com.au

[2] R.A. Barr, V.J. Gosbell, and S. Perera, 2006, "The Voltage Sag Protection Curve ", *12th International Conference on Harmonics and Quality of Power, Portugal, 2006*