PROOF-OF-CONCEPT DATA LOGGER FOR POWER QUALITY MONITORING

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ABSTRACT

This paper describes the results of a proof-of-concept development project to identify and demonstrate a relatively low-cost but flexible or adaptable logger to measure, store and communicate network performance data to meet a variety of needs. The paper discusses the various parameters in which a utility has an interest, the potential for measuring them with sufficient accuracy according to the applications, the combination of several measurements in one device, and approaches to managing the data collected from the device. The key characteristics and specifications of the data logger are identified.

INTRODUCTION

Developments in telecommunications, data storage and integrated circuits for energy measurement applications offer scope for new approaches to the collection of data from electricity distribution networks. At the same time, changes in the regulation and management of electricity utilities have stimulated a need for more performance data related to continuity and quality of supply on low and medium voltage systems, including load currents, voltage variation, dips and swells, unbalance and harmonics.

Low-cost, multi-function data loggers have potential applications in planning, operations, measurement and verification (M&V) of energy efficiency projects, and regulatory compliance monitoring. These various applications affect the physical environment in which instruments are required to operate, reliability targets for the equipment and data, automation of the process of data collection, and the description of data formats to meet the information needs of utilities, customers and regulators.

The paper concludes with comments arising from this proof-of-concept project on the definition and measurement of various power quality parameters.

BACKGROUND

Network planning and optimization is heavily dependent on good load data. In 2004, when this project started, existing data loggers included

- a domestic customer load logger based on an instrument developed locally during the 1980s [1],
- metering-quality recorders for large customers,
- event recorders in distribution switchgear, and
- power quality (PQ) loggers.

While these are useful instruments and provide the needed data, they all suffer from one or more of high instrument cost, practical difficulties in downloading the data, high failure rates leading to loss of data as well as instrument repair or replacement, and relatively high costs for the labour of collecting the data.

The existing activities of load, incident and power quality measurement represented a possible opportunity to develop an instrument suitable for multi-function applications for which there was already a known need. At the same time, several semiconductor manufacturers have developed ICs for Automated Meter Reading (AMR) products. A typical measurement IC offers several potential benefits, such as high accuracy of energy measurement, capability of measuring single and three phase parameters, low computation requirements, less CPU utilization, easy interfacing, integral power quality monitoring of voltage dips (sags), swells and over-current conditions, and low cost.

It was proposed that a new instrument be developed with modern technology and modular design to meet a broader range of data needs than the original LV domestic load logger. Preliminary estimates indicated that the instrument could be less expensive than the existing logger but have capabilities that far exceeded its specification, being suitable for measurement of load data from small and large customers and power quality data. A further benefit could be obtained by improving the data collection procedures to reduce labour expense, and the total savings would exceed the anticipated costs of development.

It needs to be understood that the focus cannot be on a logger or instrument, but an information system. Useful data has to be collected into a database from which it is turned into information for various purposes, such as real time LV network reaction, design guidelines and regulatory reporting. The requirements for the instrument are determined by the information system.

Experience from load data collection

The domestic customer load research programme was based on the measurement of current at single phase loads, but some of the larger households with three-phase supplies could not be measured accurately with the single phase instruments. The measurement of many commercial and industrial loads required three-phase measurement of energy and power factor, especially in installations where M&V programmes were used to verify the effectiveness of energy efficiency modifications.

The data from most existing instruments needed to be retrieved manually. Sometimes this required putting a ladder against a pole, connecting to the device and downloading the information. There were constraints imposed by network safety procedures and, in some cases, a specialist operatorwas needed or the load switched off during data collection.

The load research programme had provided data that could be used to assess aspects of power quality, in particular interruptions and voltage compliance. The South African regulatory specification [2] is that voltages should be between 207 V and 253 V on a 230 V system. Fig 1 illustrates the voltage data collected from 27 positions in a rural electrification site where reinforcement was overdue. At 7 positions, the 5-minute average voltage was outside the specified limits of voltage for more than 10% of the time. A survey of 12 sites showed that the mean of the minimum 5-minute average voltages at all positions was below 190 V (nominal voltage of 230 V) at five of the sites. In particular, the survey showed that the definition of acceptable voltages was ambiguous and incomplete as a measure of the effects on customers.

Analysis of loads and voltages also indicated the potential benefit of having access to maximum and minimum values as well as mean values over a defined period.

Experience from voltage dip data collection

Voltage dips provide useful information for network event analysis, as well as being useful to specify the power quality that customers can expect. The present instruments define a 'dip' from when the first phase drops below threshold to when the last phase rises above it, showing it as a single profile. Experience from voltage dip data collection shows that three single-phase dip records are useful for event analysis, but are not a good indicator of the power quality affecting a three-phase customer. Event analysis or system investigations often require recent data to be available within days, so that remote access to the data is an important operational requirement.

SPECIFICATION

Based on the experience, the requirements for the proposed instrument included measurement capability, communications systems, and software for the instrument management.

Load and voltage measurement

- Accurate and fast measurement, acquisition and storage management with a clock for time-stamping measurements.
- 3 voltage and 12 current channels so that each logger can measure up to 12 single-phase or 4 three-phase loads, or combinations of three- and single-phase loads.
- Continuous measurement of RMS voltage, current, active, non-active and apparent power, sampled at not less than 500 Hz.
- For each measurand: maximum, minimum and mean sampled values over three user-configurable intervals from seconds to hours.
- Ambient temperature measurement and 8 analogue inputs (0-10 Vdc) for monitoring processes associated with the electrical measurements.

Power quality measurement

- Voltage dips and swells over a user-settable threshold, with profile data of all measurement channels as selected by the user, for up to 10 seconds of data per channel per event.
- Voltage unbalance measurement on three-phase systems.
- Ride-through capability to allow the detection and recording of interruptions.

Communications

A variety of communications modules for use in buildings or on electricity networks in urban and rural areas according to the communications networks available, and taking advantage of the best data transfer rates and costs:

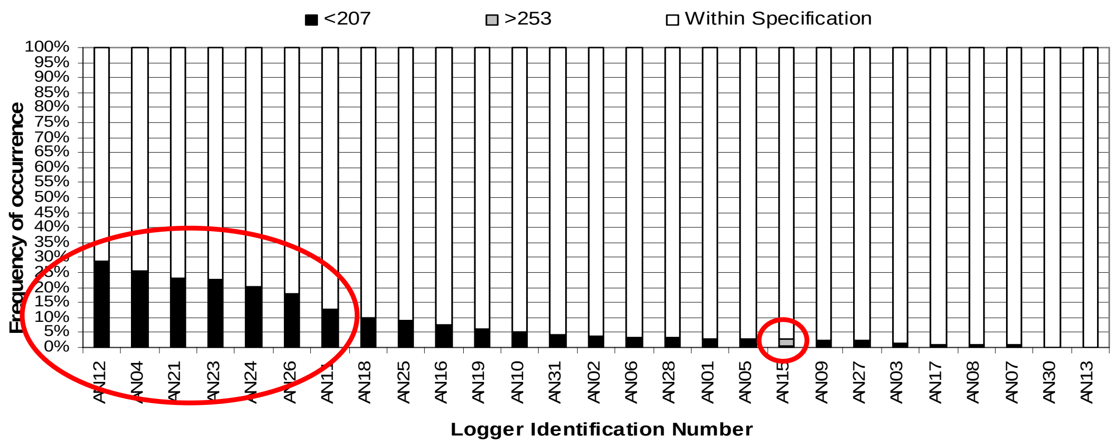

Fig 1: Periods when 5-minute average voltages were outside regulatory specifications at a selected rural site.

- Standard short range communications interfaces: Universal Serial Bus (USB) and RS485 sensor network for connection to remote digital sensors. Optional module for Bluetooth communications.
- Optional remote communications: modules for RS485 communications network (such as for use in factories for M&V metering), GSM modem with GPRS capability, or public telephone network (PTN) modem.

All communications incorporate error-checking for reliable data transfer.

Software capability

- Configuration of measurement channels and control of energy measurement functions.
- Selectable: new measurements overwrite old ones when memory becomes full, or measurements stop recording.
- Data transfer in flat-file format.
- Centralized data retrieval capability, with separate access to voltage dip data.
- Remote and local firmware updating.
- Serial number and password protection for configuration and data access.

PROTOTYPE DEVELOPMENT

The concept instrument was developed in three stages. The first prototype was used to demonstrate that the selected components could be used together to collect and process the data. It was not designed for a particular enclosure, and it was powered from an external source. This prototype identified several improvements to the physical layout and by adopting fewer operating voltages for the main components.

The second prototype was designed to fit into a selected enclosure. It demonstrated the external arrangement of the voltage, current and "industrial" input channels, the internal arrangement of the modules, and the connections between them.

Seven units of the third prototype were used for debugging the software, physical testing and preliminary collection of data in practical installations. This prototype incorporated a revised switchmode power supply and simplified manufacturing processes. Generally, the development plan was over-optimistic in the projection of the time required for developing the hardware design and writing and de-bugging the software. Problems arose from many sources, including incorrect printed circuit board production, errors in the manufacturer's specification of the energy measurement IC, and the complexity of the input configuration possibilities.

Preliminary results from new logger

Preliminary measurements with the prototype concept logger have produced some interesting details. Fig 2 shows the voltage and current measured for a household using 10-second averaging intervals. There were no dips or interruptions. The variation of the voltage between the maximum and minimum values discernable on this scale is largely the result of the resolution of voltage measurement, at about 0.1%. Over a longer averaging period, with more variation of the mean, the maximum and minimum voltages would be further from the mean value.

The current trace in Fig 2 clearly illustrates the switching of some discrete loads making up the profile of the household. For most of the current trace, the difference between maximum and minimum values is not evident. The thermal cycling of a hot water cylinder drawing a current of approximately 13 A (3 kW), a hotplate drawing about 8.5 A (2 kW) and a refrigerator (1 A with a starting current of 6 A) are identifiable. A logger set at short interval averaging could offer an alternative approach to high frequency signal analysis for disaggregating major appliance use without intrusive monitoring.

Even on a robust urban feeder, the loads of one household appear to slightly affect the voltage of the supply. It will be interesting to investigate similarly the variation of voltage in weaker rural feeders.

The recording of maximum, minimum and average values allows for more comprehensive information retrieval, but suitable methods are needed to manage and present meaningfully the results from large quantities of data.

POWER QUALITY ISSUES

Two issues arise already from the collected measurements.

Voltage variation

The variation of voltage at the sites represented by Fig 1 does not demonstrate non-compliance, which is defined, as in many countries, in terms of the 95% weekly 10-minute value, and two successive 10-minute periods [2]. The specific combination of the averaging interval and discarded data means that large deviations for short periods may not be outside the specifications, even if they detrimentally affect customers' appliances and equipment.

An alternative approach to compliance might be to define an acceptable envelope for the duration and magnitude of the voltage excursion, as illustrated in Fig 3. The compliance limits and the values of Vmin and Vmax will be determined by economic considerations: network investment against customer costs and the risk of damage to appliances and equipment. Upper and lower boundaries of voltage excursion need not be the same shape.

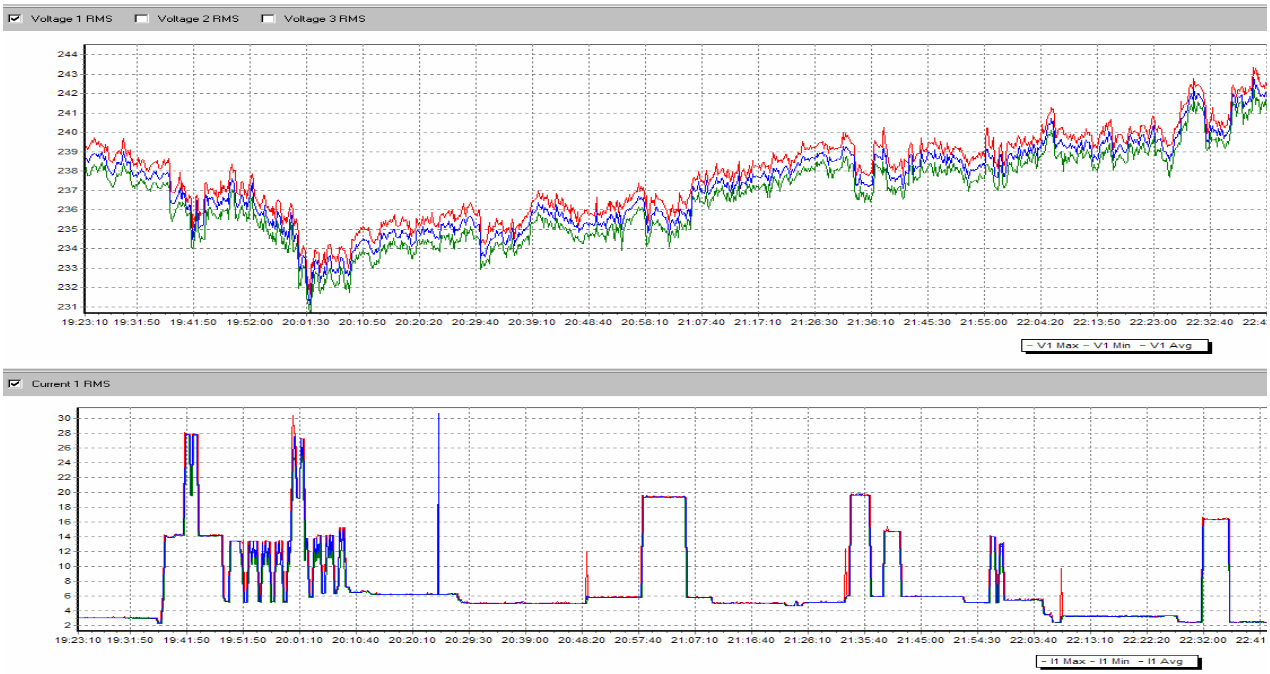

Fig 2: Voltage and current of a single phase household supply; 10-second measurements over 3 hours

Not discarding any measurements during the monitoring period removes uncertainty about the optimum averaging interval. Shorter intervals will produce higher excursions from the limits. The logger has the flexibility to test this approach easily with practical data.

A similar approach might be needed for other power quality parameters, including voltage unbalance.

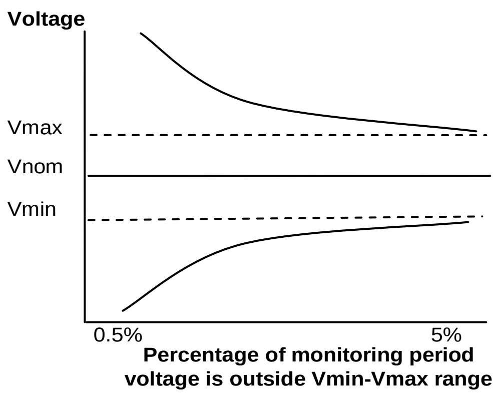

Fig 3: Proposed definition of allowable voltage variation

Quantity of data

The instrument has the capability to generate very large quantities of data, from the parameters measured and the number of channels, and it is possible to bring that data to a central point by remote communications. However, the processes of managing and analysing so much data to generate and present useful information for power system management and regulation or for M&V assessments needs to be developed in most utilities and operators.

CONCLUSION

The preliminary results from the proof-of-concept logger successfully demonstrate its possibilities in load research, power quality monitoring and regulation, and M&V of energy efficiency projects. A versatile and inexpensive measurement and communications instrument allows alternative approaches to power quality specifications and system operations to be considered. Further work is needed on data management approaches and to complete the instrument.

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