A resolution was taken that a power quality management system and programme must be implemented for its entire network, as well as those clients identified by experience as requiring special attention e.g. key customers above 1 MVA.

Ekurhuleni distribution networks are supplied from 45 Eskom intake points and serve a mixed customer base of approximately 305 000 customers. The total maximum demand from Eskom during the winter months of 2007 exceeded 2300 MVA. Approximately 99,5% of electricity is purchased from Eskom and 0,5% from City Power, Johannesburg.

Power quality

Power quality covers a wide range of phenomena. This paper will concentrate specifically on annual power quality performance reporting, with the emphasis on quality of voltage supply. It is hoped that it will highlight the importance of the well known saying “to measure is to know and if you do not measure how can you manage?” The City of Ekurhuleni has made good progress in implementing a power quality management system, and the necessary operational and maintenance systems to comply with the NERSA directive and reporting requirements.

Why is power quality important in the Southern Africa context?

Everyone, sooner or later, will have an issue with power quality, even home owners with their microprocessor-controlled appliances. There are many benefits from monitoring power quality, e.g. early warning of overloaded circuits, over-and under voltage detection, warning of equipment failure on tap changers, establishment of the causes of problems, data collection in abnormal operational status of networks, etc.

General

The NERSA power quality directive acknowledges that when starting a power quality monitoring program, it is not appropriate from a cost, technical, and logistical point of view to specify a monitoring requirement that achieves full statistical accuracy in reporting distribution licensee power quality performance. The random placement required by such a statistical sample may also not provide optimal value in terms of managing the levels of quality on the network.

Previous difficulties in managing and implementing the PQMS (before implementing an outsourced PQMS), include:

- Change of personnel
- Lack of education and experience
- Lack of data security
- Lack of clear direction from industry and the Regulator
- Changes in communication infrastructure (GSM network changes, technology changes)
- Changes in operating systems (Windows 95, 2000, XP, Vista)
- Organisational changes (regions, responsibilities)
- Instrument changes
- New software functionality and enhancements
- Insufficient instruments and ad-hoc nature of PQ reporting

The specification of the PQMS and selection of sites to be monitored were planned to address all of the abovementioned issues. The following is a brief summary of the tender document specifications:

The power quality monitoring system (PQMS) will be the platform in which power quality measurements are stored, managed and reported on according to the NRS048 specification. This complete task will be outsourced to the successful bidder for a
period of 3 years. The successful bidder will take responsibility for:

- Receiving raw meter data
- Data warehousing of meter data (history)
- Sufficient data for 95% reporting purposes
- Generating NRS048 reports
- Providing general functionality as described in this document to Ekurhuleni staff and the Ekurhuleni key customers
- Ensuring and maintaining communication links with the power quality instruments
- Data backup and disaster recovery
- Transforming data into an agreed data format and population of the Ekurhuleni Oracle database with this data
- Providing operational reports to key staff members on a regular basis

A separate specification was issued for power quality instruments as well as for the mechanism to store metered information at a central server, which houses the power quality monitoring system (PQMS). The specification described the general requirements of the PQMS, and the successful bidder could propose a proprietary application if it provided similar functionality. It was also required of the successful bidder to transform the raw meter data into a format to be agreed upon between Ekurhuleni and the bidder, and replicate this data on an Oracle database situated on an Ekurhuleni data server. The power quality system will store information as received from the power quality meter instruments.

What Ekurhuleni got from the PQMS

A network of permanently installed VectoGraph and ProvoGraph power quality recording instruments collects PQ data throughout Ekurhuleni network. This data is automatically forwarded to a central PQ database. Imported data is enriched through calculation of assessment statistics (95% CPF, min, max, etc...) captured from different instruments are automatically grouped together to form network incidents. Reports can now be generated per network incident, and users can attach different support information (pictures, documents, etc...) to each network incident.

A new alarm unit is currently under construction which will send an SMS backed up with an E-Mail containing measured details about each network incident to registered users within minutes of its occurrence. Users can then access detailed information about the network incident and comment on it. The proposed alarm unit and the PQ web portal will maximise the time value of power quality information and will make information easily accessible to both the electricity supplier and key customers.

PQ reports available on "Logon"

Manage by exception

These reports are used to quickly pinpoint problems related to, for instance, voltage regulation, unbalance and harmonic deviations, and should be viewed on a daily basis to maximise their value. Reports include:

- Daily assessment summary: Summary of all 7 day sliding NRS048 assessed values as well as dips for a specific day, over all nodes.
- Daily incidents: List of all incidents that occurred on a specific date, drilled down to each NRS048 classified event related to the incident.

Statistical assessments

These reports the 7 day sliding assessments over a period of time, for a specific node. Period selection is monthly or custom. Reports include:

- Voltage magnitude assessment (voltage regulation)
- Voltage unbalance assessment
- Voltage THD (total harmonic distortion) assessment
- Voltage harmonics (individual harmonic assessments)
- Voltage dip report (NRS048 classified events)

System information

This report provides information on overall system performance. Reports include:

- Data availability summary: node view - this report shows total data availability from the view of nodes.
- Data availability summary: instrument view - this report shows total data availability from the view of instruments

Yearly reports

These reports summarise information over a period of 12 months. Reports include Tables 9 to 12 of the yearly NRS048 report as required by NERSA.

Incident browser

Incidents are formed by grouping classified events (dips, surges etc) that occurred within a specific time window. Probabilistically they share the same cause. Reports include:

- Show most recent incident: this will bring up the most recent incident that occurred on the network.
- Browser: used to investigate incidents over a selected period of time. A list of incidents is given for the period selected. Each incident can then be viewed, and the related classified events can be drilled down to for each incident.

Lessons learned in planning the power quality meter database

It is very important that the system provides for a mechanism by which meters can logically be accessed according to their position in the Ekurhuleni network. Such a system must allow for a search mechanism from the region down to the meter. The following documents also had an impact on, and assisted with the implementation of the power quality monitoring system:

- City of Ekurhuleni: power quality management system
- Key customer policy

Together with the PQ instruments, the PQdb system now provides a comprehensive electricity PQMS, that forms the platform on which measurements are stored, managed and reported on, according to the annual power quality performance reporting specification and NRS048 specifications. The primary roles of the system are:

- Importing raw data
- Validating data
- Extracting stats
- Browsing of data
- Generating reports
- Archiving reports
- Matching incidents to events
- Generating alarms
- Authentication of users
- Logging of audit trial
- Providing data backup and disaster recovery.

PQMS configuration

The PQMS consists of various instruments, protocols, networks and components that are all related to the overall functioning of the system as indicated in Fig. 1.

PQ meters

All data collected by remotely installed PQ meters are transmitted in near real-time to a server located at CT Lab, South Africa. From here data is imported and validated.

Data importer

Raw data collected by CT Lab instruments are imported into the PQ database using the data importer software. The data importer is capable of importing other raw data in Excel format.

Data validator

The data validator software allows users to set up acceptance or rejection criteria to test the raw metered data. Rejected data will be presented to the user for intervention.

Stats extractor

The stats extractor software will be used to calculate daily statistics using raw, validated and derived data.

Oracle database server

This is the database where all the recorded data from the PQ instruments is saved.

User authentication

All users log in with a username and password and rights are managed through the ORACLE authorisation management process. All user actions will be recorded to create an audit trail.
Fig. 3: NRS Voltage dip characteristics.

Fig. 4: Bottom line shows values that were derived from the first 69 PQ instruments from the average number of dips seen by all 69 sites (6.6 kV to 44 kV) over a one year period.

Fig. 5: Voltage dip statistics.

**Alarm generator**

The user can set up different data acceptance criteria through the alarm generator software. If the criteria are not met, the alarm generator will generate an alarm to be sent via e-mail or SMS to different users.

**Data browser**

The data browser will graphically display and classify all captured data according to NR5048:2003 classification. The data browser will display both raw and validated data. All displayed data can be exported in Excel format.

**Report generator**

The specified reports are available for viewing on the system interfaces, as well as for downloading in a CSV or other open document format.

**Report archive**

All reports generated are stored in PDF format in an archive that will be accessible through a web interface to authorized users.

**Event to incident matching**

Events throughout the network that occur within a specified timeframe can be grouped together and associated with a physical incident requirement.

**System modules**

The modules making up the system are shown in Fig. 2.

**Power quality terms and definitions**

**Flagging**

A new and very important point is the so-called flagging concept. The principle behind it is to not count PQ events more than once (in different parameters). Flagging is only triggered by dips, and interruptions.

**Voltage dip**

This is a sudden reduction in the r.m.s. voltage, for a period of between 20 ms and 3 s, of any or all of the phase voltages of a single-phase or a polyphase supply. In terms of the NERSA power quality directive, voltage dip statistics (number of measured events) for X1, X2, S, T, Z1 and Z2 dips (defined in NRS 048-2:2004) must be reported on an annual basis. See Fig. 3

Characterising City of Ekurhuleni network dip performance.

Real value-added benefits can be obtained from the PQMS by quantifying and graphically depicting dip statistics to managers and not only for the purpose of NERSA reporting.

Fig. 4 shows EMM data collected during 2007 against Table 10, of NRS 048-2:2008, latest edition 3, derived from data collected up to mid 2002.
Fig. 5 indicates the dip statistics (range per dip category RED 2 VS. Ekurhuleni). The stock graph depicts the dips at transmission delivery points. Data was obtained from the final annual power quality performance reporting specification: July 2003. The glowing line graph depicted dip figures that were derived from the first 69 PQ instruments installed and shows the average number of dips seen by all 69 sites (6.6 kV to 44 kV) over a one year period.

Voltage dip performance is strongly influenced by annual weather patterns, and for this reason year-on-year comparison of dip performance is probably not a good indication of actual performance trends. Ekurhuleni is also still in the process of rolling out the number of instruments.

Fig. 6 shows a typical trend that a utility would want to prevent. Should the three-year average of a dip category suddenly increase considerably comparing with previous years it may require an investigation to determine the causes.

Voltage regulation

The South African NRS 048-2 specification defines voltage regulation as: “the ability of the steady-state rms voltage to remain between the upper and lower limits”.

NRS 048-2: Clause 4.2.2.2 compatibility levels

Unless otherwise agreed upon in a supply contract, the compatibility levels for the magnitude of supply voltage shall be as specified in Table 1.

<table>
<thead>
<tr>
<th>Voltage level</th>
<th>Compatibility level</th>
</tr>
</thead>
<tbody>
<tr>
<td>V%</td>
<td>±10</td>
</tr>
<tr>
<td>&lt;500</td>
<td>±5</td>
</tr>
</tbody>
</table>

Table 1: Deviations from standard or declared voltages.

Fig. 7 shows voltage magnitude compliance with NRS 048-2, and its is expressed as a percentage of the declared rms voltage. Daily seven-day sliding assessment values are compared to specific compatibility and limit criteria. Upon evaluating this rms voltage level it is immediately clear that the voltage level has risen above the upper compatibility level of 105% and requires attention.

Voltage unbalance

On three-phase systems, the voltage and currents on each phase should, in theory, match the voltage and currents on the other phases. Voltage unbalance is regarded as a power quality problem of significant concern at the electricity distribution level. Although the voltages are quite well balanced at the generator and transmission levels the voltages at distribution level can become unbalanced due to unequal system impedances and the unequal distribution of single-phase loads.
Fig. 8 shows both 10-minute window three phase rms voltage readings per phase as well as the percentage voltage unbalance measured. Fig. 9 depicts the voltage unbalance assessment trend, using daily 7-day sliding assessments. Voltage unbalance quantifies the contribution of negative voltages as a percentage of positive sequence voltage defined in NRS 048-1 and IEC61000-4-30:2003 section 5.7. The green line indicates how the voltage unbalance, highest 95% weekly, has dropped to below the required compatibility level, after certain network adjustments were made to the Eskom network in this specific case.

In terms of NRS048-4, a utility is responsible for limiting the unbalance load drawn by its customers. A utility shall ensure that its network does not contribute significantly to unbalance conditions. Fig. 10 depicts the rapid reduction in transformer life should the voltage exceed the normal operating voltage. Note this may only be applicable under certain loaded conditions and not when the transformer stands idling.

Fig. 11 shows a diagram of a typical section of the network. The red arrow, blue dot, may indicate the placement of a power quality measuring instrument. It is then clear that a number of power quality parameters may not be monitored at transformer number two and three, e.g. voltage regulation, voltage unbalance, interruptions etc will not be monitored. Ekurhuleni has taken a principle decision to monitor at most primary transformers which are connected to separate busbars. Thus PQ instruments were later on added, as indicated at the yellow dots, to also monitor transformers two and three. Note this was not done as a compliance requirement but should rather be seen as good management practice.

Cost to implement a typical statistical power quality monitoring and technical performance data reporting system.

Table 2 summarises the costs involved in implementing the system.

Conclusion

Although the City of Ekurhuleni has made much progress in establishing a power quality monitoring system, it has certainly not reached the fully matured state envisaged for the future. The implementation and results obtained have identified the essential need for assessing power quality and monitoring thereof. Power quality monitoring information provides insight into the operation and characteristics of the network, supplies and loads. The visibility and knowledge provided are essential operational and business management information. In terms of monitoring quality of supply, the objective should be not to set easier goals, but to set even more audacious and ambitious goals.

The national regulators of most countries have put in place various legislative and regulation documents to ensure electrical energy is generated, transmitted, and distributed efficiently.
Table 2: Cost summary.

and distributed at acceptable minimum standards. If all role-players in the electrical industry do not participate, the countries PQ objectives are ineffective.

Finally, to conclude the PQMS implemented at City of Ekurhuleni has proved that statistical reporting on the following is now “easy”:

- Total data availability for all permanently monitored sites can be better than 95%.
- Individual distribution supply points can be continuously monitored due to outsourced communication systems and management practices.
- Voltage quality statistics to be reported on by licensees, e.g. Voltage harmonics, Voltage Unbalance, Voltage magnitude compliance per site over the reporting period can exceed the appropriate requirement in NRS.
- Voltage dip statistics (number of measured events) for X1, X2, S, T, Z1 and Z2 dips can now be reported on an annual basis. Two sets of statistics to be reported on against each of these dip types, i.e. the total number of events (caused internal), and transmission events (caused external) are now possible.

The City of Ekurhuleni is now in a position to submit sampling statistics from 95% of all sites to NERSA on quality of voltage supply, which makes the three-hundreds of a cent per kWh sold to customers justifiable in relation to the huge benefits obtained.

This paper has been prepared by Stephen Delport does not necessarily represent the views of his current employer Ekurhuleni Metropolitan Municipality.

References

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